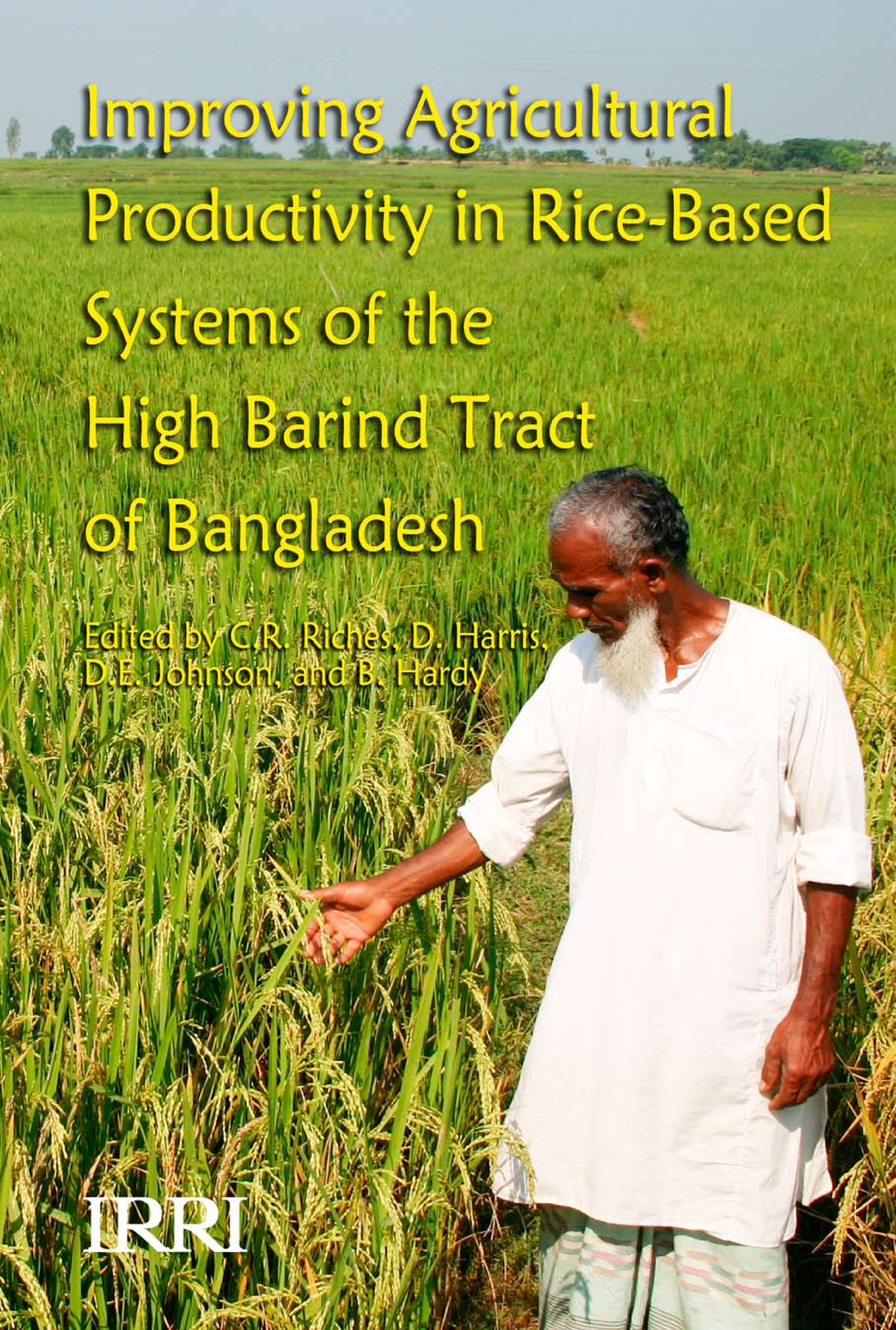
Improving Agricultural Productivity in Rice-Based Systems of the High Barind Tract of Bangladesh



Edited by C.R. Riches, D. Harris, D.E. Johnson, and B. Hardy

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2008
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Suggested Citation:
Edited by C.R. Riches, D. Harris, D.E. Johnson, and B. Hardy. 2008. Improving Agricultural Productivity in Rice-Based Systems of the High Barind Tract of Bangladesh. Los Baños (Philippines): International Rice Research Institute. 215 p.

Cover design: Juan Lazaro IV
Page makeup and composition: George R. Reyes
Figures and illustrations: George R. Reyes

ISBN 978-971-22-0229-2

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Foreword

The High Barind Tract of northwest Bangladesh is an area of low and erratic rainfall with limited irrigation potential. Farmers there largely rely on rainfed cropping but face problems of late transplanting of *aman*-season rice when the monsoon is delayed or low yields when drought sets in during the booting stage of the rice crop in October. It is also important in this area to harvest rice early to provide food during the *monga* season, a hungry period before the harvest of the main monsoon aman rice crop, and to ensure that winter *rabi* crops can be planted on time to take advantage of residual soil moisture. Farmers are operating in a time of rapid change, with increasing input costs and emerging labor shortages. It has therefore been a priority to identify agricultural practices for the Barind that allow increased production in a marginal rainfall environment while at the same time improving the efficiency with which inputs, particularly labor, are used. To ensure that farmers have a productive aman rice and rabi system, research efforts have for some years focused on developing early-maturing drought-tolerant aman rice cultivars and high-yielding disease-resistant rabi crops such as chickpea. However, farmers also need good practical advice on the best practices for timely establishment of vigorous and weed-free crops to make best use of the short rainy season.

Over the past six years, with support from the United Kingdom Department for International Development, farmers, extension workers, and researchers from the Bangladesh Rice Research Institute, Bangladesh Agricultural Research Institute, International Rice Research Institute, and universities from the UK have worked in partnership to develop cost-effective ways of increasing the productivity of both rice and rabi crops in the High Barind Tract. The improved practices that have been validated by farmers are knowledge-intensive. New sources of information such as posters, leaflets, and other training materials have been produced. The challenge now is to make this information widely available to farmers in the Barind so that the reliability and productivity of agriculture in this marginal cropping area and food security and income from agriculture can be increased.

IRRI, together with the Crop Protection Programme and Plant Sciences Research Programme of DFID, organized a workshop on “Improving agricultural productivity in rice-based systems of the High Barind Tract,” held 4-5 March 2006 in Dhaka, Bangladesh. The workshop brought together more than 70 extension workers, scientists, and policymakers to discuss the application of validated technologies to the High Barind Tract and similar drought-prone environments in Bangladesh and to identify opportunities and requirements for enhancing the scaling-up of these technologies in extension programs. The Barind environment continues northwest across the border into India so researchers from India contributed to the workshop to ensure the sharing of experiences of technology development for this highly variable rainfed environment.

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Acknowledgments

IRRI is most grateful to the Crop Protection Programme and the Plant Sciences Research Programme of the United Kingdom Department for International Development for funding the workshop and financially contributing to the publication of this book. The views expressed are not necessarily those of DFID. Many people contributed to the success of the workshop upon which it is based. The local organizing committee from the IRRI-Dhaka Office was led by Dr. Hamid Miah.

Setting the scene

The High Barind Tract: a challenging drought-prone agricultural environment

C.R. Riches

The Barind Tract is a distinctive physiographic unit comprising a series of uplifted blocks of terraced land covering 8,720 km^2 in northwestern Bangladesh between the floodplains of the Padma (known as the Ganges in India) and the Jamuna rivers (the main channel of the lower Brahmaputra). Spread over parts of the greater districts of Rajshahi, Dinajpur, Rangpur, and Bogra of Bangladesh, and Maldah District of West Bengal in India, the Barind includes 773,000 ha in Bangladesh, of which 532,000 ha are cultivable. Rainfall is comparatively low in this region, with the long-term average being about 1,250 mm in the west and 2,000 mm in the northeast, occurring mainly from late April to October. With a variable rainfall and temperature ranging from 25 to 35 °C (regularly exceeding 40 °C) in the monsoon season, the area is considered semiarid and drought-prone. The *aman* rice[1] (monsoon)-growing season ranges from 180 days in the west to 220 days in the northeast but the frequency of dry periods, particularly in July and August, is the highest in the country. The Barind is at a comparatively higher elevation than the adjoining floodplain and there are two terrace levels—one at 40 m above sea level and the other between 19.8 and 22.9 m. Therefore, when the floodplains go under water during the monsoon, the Barind Tract remains relatively free from flooding and is drained by a few small streams. About 47% of the Barind region is classified as highland, about 41% as medium highland, and the rest is lowlands. Although 55% of the Barind was forest in 1850, subsequent rapid population growth resulted in 70% of the land being converted to arable land by 1970. The area is now characterized by terraced slopes with bunded fields without water control other than drainage by gravity to lower-lying fields and streams.

The High Barind Tract, lying in Rajshahi, Chapai Nawabganj, and Naogaon districts, is one of three distinct areas of the Barind, occupying 160,000 ha, roughly 21% of the region. This is the most marginal area of the Barind Tract for rainfed cropping, accounting for 12% of the drought-prone lowland rice land in Bangladesh. As shown

[1]Rice in the aman growing season is usually transplanted. Traditionally, farmers used photoperiod-sensitive varieties to fix optimum flowering and harvesting dates. Modern varieties are insensitive to photoperiod and seedlings for long-duration varieties such as Swarna (> 150 days) must be planted from mid-July to mid-August for optimum yield (Zaman 1986).

Table 1. Variability in the start and end dates for combined monsoon (aus and aman) and rabi growing seasons at Rajshahi, High Barind Tract, 1947-84.

Timing	Earliest date	25% probability	Mean date	75% probability	Latest date
Begin	18 April	12 May	25 May	8 June	23 July
End	6 October	3 December	28 December	9 January	20 February

Source: Brammer (2000).

by Table 1, variability in total rainfall, timing of onset, and cessation of the rain as well as occurrence of in-season drought periods mean that farmers must use a flexible, opportunistic approach to cropping decisions and experience considerable annual variation in production. Rice in the *aus* season,[2] either broadcast-seeded or transplanted on early premonsoon showers, is important for food security in the *monga* period (hungry season) of September-October prior to harvest of the main aman crop. However, the aus crop may experience drought in April to early June while in wet years seedlings can be damaged by premature flooding.

Land in the High Barind Tract exhibits gray terrace soil, is silt loam to silty clay in texture, and is poorly drained, with a 6–8-cm thick plow pan and low organic matter content (0.8–1.2%). Most land lies fallow during the aus season and under the traditional farming system farmers grow a single crop of transplanted rice in the aman season established after the first week of June when the onset of the monsoon is expected in three years out of four. A premature end of the monsoon in early October brings terminal drought at grain filling, particularly for late-transplanted aman crops. Indeed, the probability of 10- and 15-day dry spells during grain filling is 73% and 53%, respectively, so that a 2-week period without rain during the grain-filling period of currently grown rice cultivars is expected once in two years. Soil moisture remaining at aman harvest in late October to late November varies from year to year and is generally sufficient only for an early, quick-maturing crop to be grown satisfactorily in the postrice rabi season. There is sufficient moisture for a wheat crop to be grown without irrigation in the rabi season only once in four years when showers extend to mid-February. As a result of the low probability of significant rainfall after mid-October, some 80% of the area currently lies fallow in the rabi season. Approximately 20,000 ha are sown to a range of drought-tolerant rabi crops planted on residual soil moisture after the rice harvest, including chickpea, linseed, and mustard, or wheat where irrigation from farm ponds is available.

The use of groundwater for irrigation of boro rice in the rabi season has been a major policy option contributing to a near threefold increase in rice production in Bangladesh since 1960. Since 1985, the Barind Multipurpose Development Project has installed a network of more than 5,000 deep tube wells, bringing 162,000 ha under

[2]Rice in the aus growing season is photoperiod-insensitive, short-duration (90–110 days), and usually sensitive to cold (temperature below 20 °C will cause stunted growth and sterility). It is generally grown rainfed as a broadcast or transplanted crop and planted optimally between mid-March and mid-April (Zaman 1986).

irrigation across the entire Barind of Bangladesh. The potential for irrigation development is limited, however, and restricts cultivation intensity to below 175% in the High Barind, considerably less than in other regions of the country where irrigation allows two or three rice crops each year. Attempts to increase the productivity of the High Barind therefore continue to focus on rainfed lands and in recent times have aimed to simultaneously improve the reliability and yield of aman rice while increasing total system productivity by increasing the area planted to rabi crops.

Crop improvement research in the Barind has a long history, with many organizations making contributions over the years. Work led by the Bangladesh Rice Research Institute (BRRI) regional center in Rajshahi, supported by the Rainfed Lowland Rice Research Consortium, coordinated by the International Rice Research Institute (IRRI), has focused on characterizing the physical environment, rice cultivars, and soil nutrient requirements (Wade et al 1999); drought risk (Fukai et al 1999); and improving rice productivity through the introduction of dry direct seeding of the rice crop. Research on suitable rabi crops has been undertaken by the Bangladesh Agricultural Research Institute (BARI). From 1999 to early 2006, a series of research projects funded by the UK Department for International Development (DFID) worked to develop a profitable, practical rice/rabi system for the High Barind. Research focusing on the productivity of aman rice, and in particular crop establishment and weed management, funded by the DFID Crop Protection Programme, involved collaboration among the Natural Resources Institute in the UK, University of Liverpool-UK, IRRI, BRRI, and the Bangladesh Department of Agricultural Extension (DAE). Parallel research, largely targeting an improvement in rabi crop productivity, involved partnership among CAZS Natural Resources (formerly the Center for Arid Zone Studies) at the University of Wales, Bangor, UK; BARI; International Crop Research Institute for the Semi-Arid Tropics (ICRISAT); the NGO People's Resource-Oriented Voluntary Association (PROVA) based in Rajshahi; and DAE. This rabi crop research has been funded by the DFID Plant Sciences Research Programme. Characterization work indicated how farmers are operating in a period of rapid change, with increasing input costs and emerging labor shortages. An important focus was therefore to identify agricultural practices for the Barind that allow increased production in a marginal rainfall environment while at the same time improving the efficiency with which inputs, particularly labor, are used.

A workshop, organized by IRRI, was held in March 2006 in Dhaka to summarize the findings of research in the High Barind Tract over the previous 5 years and to outline several technologies that had been validated by farmers under their own management. This work led to the new challenge of seeking opportunities for widespread promotion of these technologies through dissemination of knowledge to DAE, NGO extension workers, and then on to farmers.

The workshop was therefore planned with two objectives in mind:

- To assess the application of validated technologies to the High Barind Tract and similar drought-prone environments in Bangladesh.
- To identify opportunities and requirements for enhancing scaling-up of validated technologies within extension programs.

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Notes

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Workshop synthesis

Farm-level opportunities for increasing productivity and income in the High Barind Tract: a synthesis

A. Orr, C. Riches, M. Mortimer, D. Harris, and M.A. Mazid

This paper synthesizes recent research by two projects to develop new technology for the High Barind Tract in Bangladesh. Farmers in this complex drought-prone ecosystem usually grow a single crop of transplanted *aman* rice. The research strategy was to expand the area that could be planted to *rabi* crops using residual soil moisture by introducing new technology that advanced the harvest of rice and improved yields of chickpea. Direct-seeded rice (DSR) with long-duration variety Swarna and introduced varieties of short-duration rice (SDR) gave earlier harvesting without reducing rice yields. Higher-quality seed, seed priming, and improved crop management also improved the profitability of chickpea. Because the farming system is complex, SDR and DSR should not be seen as prescriptive recommendations but as choices that allow timely rice establishment with variable monsoon rainfall. Dissemination of these technologies requires local partnerships to build a reliable supply chain to deliver knowledge and inputs to farmers.

A systems approach is a prerequisite for effective research in unfavorable rice ecosystems, where new technology must be carefully designed to fit a combination of climatic, physical, and socioeconomic constraints. In drought-prone environments, farmers have developed systems that prioritize stability over productivity. The bottom line is to ensure survival in bad years rather than to maximize income in good years. The research challenge is to design technology that can somehow squeeze higher productivity and income from these systems without compromising household food security.

The workshop brought together two projects funded by the Department for International Development (DFID) working on different components of the same system. One project, funded by the Crop Protection Programme, worked on direct-seeded rice (DSR) and weed management. A second project, funded by the Plant Sciences Programme, worked on *rabi* cropping with chickpea and on short-duration rice (SDR). Although they shared results and collaborated in on-farm demonstrations, the two projects operated independently. A joint workshop was held at the end of these projects to see what new technology was available for the system as a whole and, with representatives from the extension service that had been a partner in much of the original research, to explore how this technology could be promoted and disseminated to farmers.

The theme of the workshop was "Improving agricultural productivity and income in the Barind Tract." The aim of this paper is to combine different perspectives—agronomy, plant breeding, and economics—on this theme. The paper does not try to achieve a consensus. There is still disagreement about the performance and potential of various technology options, as well as about the role of farmers in rice breeding. Rather, the objective has been to present a synthesis, or an interpretative overview, of what we have learned over the past five years of field research, and what must happen now to give farmers the opportunity to fine-tune this technology for use in their own fields.

The analysis is structured around four key themes that emerged during the workshop. We start with the system itself, before moving to discuss the various technical options, and how farmers might use these options to cope with rainfall variability. We end by discussing promotion. The conclusions outline some key lessons.

System complexity

Complexity is a defining characteristic of the High Barind Tract (HBT), an area of 0.7 million ha where two-thirds of the cultivated area grows only a single crop of transplanted rice (TPR). This complexity arises because of a unique set of interactions between the rice ecosystem and the agrarian structure. These interactions create a farming system that is designed for survival rather than for maximizing income and where land tenure acts as a "built-in depressor" that discourages risk-taking and innovation. As a consequence, in their attempts to maximize income, farmers are confronted with a series of problems (Table 1) arising from the key components in this system. These problems follow.

Unpredictable rainfall

Drought can either delay or damage TPR. The optimum time for transplanting is mid-July, but, once every two years, erratic rainfall delays transplanting until after mid-July, and twice every 10 years transplanting is delayed until after mid-August. Moreover, a two-week period without rain during the grain-filling stage occurs once every two years (Saleh et al 2000).

Toposequence

The HBT has a distinctive topography with pronounced differences in land height. Higher land holds water for less time and dries out more quickly, making it more risky for rice and less suitable for rabi crops that rely on residual soil moisture. Medium land is more favorable for both rice and rabi. Rice planted on low-lying land may be submerged by rainwater and rabi sowing may be delayed if the soil remains too wet after the rice harvest.

Table 1. First- and second-order problems and technical options.

Problem	Technical opportunity
First-order problems	
Low rice yield	Timely manual weeding, herbicides
Late transplanting due to erratic onset of monsoon	DSR allows sowing with limited rainfall, SDR allows late transplanting
Rice yield loss from dry periods at flowering	DSR, SDR mature earlier
Limited soil moisture available for sowing rabi crops	DSR, SDR allow earlier harvesting of rice and sowing of rabi crops into moist soil
Rabi cropping unprofitable	Chickpea a low-input crop
Second-order problems	
DSR encourages weed growth	Preemergence herbicide
Manual DSR is labor-intensive	Lithao, drum seeder
Pod borer damage to chickpea	IPM
Continuous chickpea cropping causes root diseases	Alternative rainfed rabi crops, e.g., linseed, mustard, wheat, barley
Herbicide-resistant weed species	Hand weeding

Low soil fertility

Soil patterns are complex, often varying within the same field (Brammer 1997). The gray terrace soils of the High Barind have low organic matter (0.8–1.2%). The combination of silty-loam and clay-loam soils with low moisture-holding capacity and a strong plow pan that prevents root penetration by dryland crops limits the potential for rabi cropping without irrigation.

Rice variety

The transplanted *aman* (T. aman) crop is dominated by variety Swarna that combines several desirable traits. It performs well under drought conditions, its long field duration (150–155 days) gives a high yield, it allows seedlings to be transplanted late if necessary, and its fine grain is tasty and earns a market premium. Its disadvantages are susceptibility to sheath blight and, when transplanted late, its long field duration reduces the chance of there being sufficient soil moisture after harvest with which to sow a rabi crop.

Land tenure

Because rice is grown in the monsoon season, most land is rented on a sharecropping basis, wherein the risk is shared equally between the landlord and tenant, rather than on a fixed-rent basis wherein the risk is borne entirely by the tenant. The HBT has a large number of absentee landlords who leave crop management entirely to the tenant and have no interest in cultivation other than their share of the final yield.

Subsistence pressure

Land pressure, poor soils, and sharecropping both create and reinforce subsistence pressure on small farms and place a premium on achieving household food security. Small farmers with limited land have a higher incentive than others to increase productivity and income but only if this does not increase the risk to their food supply and their security as tenants.

Interactions

The interactions among these components illustrate how difficult it is to design new technology that can deliver an increase in productivity and income while also meeting farmers' need for household food security in a drought-prone environment.

- Short-duration rice (SDR) that can be harvested earlier gives farmers greater opportunity to maximize income from rabi crops, but, if yields are lower than from long-duration varieties such as Swarna, farmers may be unwilling to trade lower food security for higher income.
- Direct-seeded rice (DSR) may reduce labor for crop establishment but, if tenants are afraid that landlords will equate "less labor" with "lower rice yields," they may be unwilling to adopt labor-saving technology.
- DSR is generally unsuitable for low-lying land because water accumulates quickly after heavy early-monsoon storms either prevent seeding or wash germinating seedlings across fields.
- Even when sufficient soil moisture is available, farmers may be unwilling to sow profitable rabi crops such as chickpea on infertile soils because they expect low yields.

What seems at first sight, therefore, to be a straightforward problem of increasing the window between the rice harvest and rabi sowing is in practice a formidable technical challenge. Increasing cropping intensity in the HBT requires adapting technology not only to a difficult environment but also to farmers' socioeconomic conditions. Adaptive research has done a good job developing the "hardware" or a set of fairly robust technical solutions to the problems of methods of direct seeding, weed management, and chickpea cultivation. But the institutional "software" that will give farmers the capacity to adopt this new technology may be absent, as in the case of sharecropping, or need strengthening, as with seed supply, or still need to be developed, as with equipment for seeding DSR.

Technology options

New technology for the HBT is the outcome of a long learning process that dates back to farming systems research in the 1980s (Ahmed 1992) and subsequent research by the Rainfed Lowland Rice Research Consortium (RLRRC) in the 1990s (Mazid et al 1999, 2002). Combined with BARI's breeding and adaptive research program for chickpea, this resulted in a recommended "technology package" of short-duration T. aman (BRRI Dhan 32 or 33) followed by chickpea (Nabin or BARI chola-3) (Haque et al 2001). Building on this research, scientists have successfully identified technology options for the problems of low rice yields and low cropping intensity, and for the second-order problems associated with these options.

None of these technical options is problem-free. Each has limitations in terms of land type, soils, and rainfall conditions. But, provided these conditions are met, they offer farmers a fairly robust set of technologies (Table 1) to raise income from agriculture.

Short-duration rice varieties (TPR)

Rice varieties suited to direct seeding that combine early maturity with high yield would be of substantial benefit to farmers (Mazid et al 2002). Experience in field trials showed that some short-duration rice (SDR) varieties have lacked traits that farmers want and that these compared poorly to Swarna. Experience with SDR using varieties from Nepal show that under farmers' management variety Judi 582, which matured in only 90 days, had a yield similar that of Swarna (Joshi et al, this volume). Under high-management conditions, however, Judi 582 gave a lower yield than Swarna and short-duration varieties developed by BRRI (Salam et al, this volume). Some cultivars were also vulnerable to losses from pests and diseases, and susceptible to sterility caused by rainfall during flowering, while other cultivars show greater promise. It appears likely that further testing of the available short duration rice cultivars will result in widely adapted cultivars being identified for promotion.

Swarna (DSR)

After farmers rejected short-duration BRRI varieties because of their lower yields, we switched to comparing DSR and TPR using Swarna. The results showed that farmers could get identical yields to TPR on high or medium land yet harvest rice earlier. Dry-seeded and wet-seeded Swarna were harvested 8–9 days earlier than transplanted Swarna (Mazid et al, this volume). Hence, early-maturing cultivars were not a prerequisite for advancing harvest date, although the time "saved" by SDR could be greater than 8–9 days.

Chickpea

Modern varieties of chickpea with good adaptation and high yield potential (>2 t ha^{-1}) exist for the HBT (e.g., Barichola 2, 3, and 5). Chickpea cultivar Barichola 5, which has early maturity (120–125 days) and some resistance to *Fusarium* wilt, has been particularly successful in expanding the area planted to chickpea in the HBT (Uddin et al 2005). Farmers have experienced difficulty in finding good-quality seed of improved varieties, however (Saha 2002). To overcome this problem, village-level seed production plots were established and farmers were trained in seed storage and preservation.

Herbicides

Earlier efforts to introduce DSR were frustrated by the high cost of manual weeding to control weeds that, when farmers grow TPR, are suppressed by standing water. The rapid adoption of herbicides has now reduced the need for manual weeding and made DSR a realistic option. A preemergence herbicide is sprayed onto saturated soil within 4 days of seeding. Because the herbicide is effective only in the right soil conditions, farmers must be able to drain the field if the water level is too high. This effectively rules out DSR on low-lying land (Mortimer et al, this volume).

Seeding DSR

Broadcasting seed made DSR difficult to weed, whereas manual line-sowing requires too much labor to be practical in farmers' fields. Hence, the absence of suitable equipment for seeding was an obstacle to popularizing DSR. The introduction of a *lithao* allowed farmers to dry-seed rice three rows at a time, which were then covered by a harrow. The introduction of the drum seeder in 2004 allowed farmers to wet-seed 12 rows at a time. Although these machines have to be pulled by hand, they require far less labor than transplanting.

Improved chickpea yields

A combination of techniques is now available to boost yields of chickpea. Seed priming (soaking seeds overnight, briefly drying them, and then sowing) enhances germination and seedling vigor. Paired-plot trials over four rabi seasons between 1998-99 and 2001-02 showed an average additional yield from seed priming of 22% to 48% (Johansen and Musa 2004, Musa et al 2001, Harris et al, this volume). Other techniques include nutrient enhancement by adding trace elements such as molybdenum (Mo) and various control strategies for pod borer (*Helicoverpa armigera*), the major insect pest of chickpea in the HBT. In addition, because continuous cropping with chickpea results in the buildup of *Fusarium* spp., farmers need to rotate chickpea with other rabi crops (Johansen et al, this volume).

Profitability

All these technology options have been evaluated by economists and the results show that they raise both income and productivity (Table 2). With DSR, a labor-saving technology, the benefits come not from higher rice yields but from the lower cost of labor required for crop establishment and weeding (Jabbar et al, this volume). With short-duration rice varieties and chickpea, which are land-augmenting technologies, the benefits come from more intensive use of land. Chickpea is the most profitable rabi crop grown in the HBT, provided that weather conditions are favorable, and lower input costs also make it more profitable than irrigated rabi crops such as boro rice or wheat (Musa and Johansen 2004, Saha 2002).

Table 2. Economic evaluation of new technology (Tk ha^{-1}).

Technology	Total variable costs	Gross return	Gross margin	Benefit-cost ratio
TPR (without herbicide)[a]	24,941	49,499	24,558	1.98
TPR (with herbicide) [a]	23,323	52,762	29,439	2.26
DSR (DS, with lithao)[a]	20,918	50,981	30,063	2.43
DSR (WS, with drum seeder)[a]	19,743	52,166	32,423	3.74
Chickpea[b]				
Southern HBT	6,508	27,735	21,227	4.26
Central HBT	6,508	28,015	21,507	4.30

[a]2004-05 aman season. [b]2002-03 rabi season (Barichola 5).
Sources: Rice: Jabbar et al (this volume), Table 6; chickpea: Musa and Johansen (2004): p 24-25.

Processes

As well as new products, the workshop highlighted new processes that had helped researchers to identify and evaluate technology. Farmer participation was a common feature of both projects. The complexity of the rice environment meant that only farmers were really able to judge the effectiveness of new technology. Researchers had to learn from farmers and adjust the technology to fit the system.

Farmer evaluations

Detailed farmer evaluations of DSR trials exposed constraints to adoption, including the need for equipment to allow line-sowing over large areas, the additional expense to and delay for dry seeding caused by heavy rainfall, and the justifiable reluctance of sharecroppers to risk adoption of DSR and short-duration varieties that might reduce their take-home yield.

Farmer groups

The formation of farmer groups encouraged farmers to share experiences and to learn together the best conditions under which to use DSR. By initially selecting a few fields on which the group could observe the advantages and disadvantages of DSR and wet seeding with a drum seeder, the wider community was drawn into evaluation in a more meaningful way than initially when researchers worked with individual farmers on small plots. Encouraging farmers to evaluate the technologies on whole fields also provided demonstration plots of a meaningful size for the community to assess implications for labor use and crop productivity.

Participatory variety selection (PVS)

The mother and baby trials system used to evaluate and promote chickpea cultivars (Johansen et al, this volume) and SDR embodies this group approach, yet is rigorous enough to provide data suitable for official varietal release procedures (Joshi et al, this volume). PVS is an effective way to identify farmers' requirements for new varieties and is also a valuable tool for the dissemination of preferred varieties (Harris et al, this volume).

On-farm demonstrations

Going from on-farm trials (OFTs) to on-farm evaluations (OFEs) (in which farmers compare an improved package with local practices) and then to large-scale, farmer-managed demonstrations (OFDs) was effective in popularizing chickpea cultivation on the rice fallows of the HBT (Harris et al, this volume). A large collaborative program between PROVA and DAE, whereby PROVA trained block supervisors, who, in turn, trained farmers, showed the advantages of such a phased approach: the science is developed under appropriate conditions, practical difficulties are identified (and possibly solved) by farmers, and farmers (and extension workers) are empowered to operate and further develop the technology.

Socioeconomic constraints

It is frequently claimed that farmers in the HBT lack incentives to adopt new technology because of sharecropping and absentee landlords (Brammer 1997, Hamid and Hunt 1987). However, farmers have not been slow to adopt technology that was appropriate for their needs. Swarna was virtually unknown a decade ago. More recently, herbicides have been adopted rapidly in transplanted rice and SDR varieties are also spreading (Riches et al, this volume). The following three potential constraints were discussed at the workshop.

Sharecropping

Sharecropping has not proved to be a disincentive to the adoption of new rice technology in Bangladesh. Similarly, sharecroppers have been willing to use herbicides because these reduce the cost of weed management and enhance their reputation as good tenants. Sharecropping is a more flexible institution than previously thought. However, sharecroppers may be less willing to adopt DSR or short-duration varieties if they are perceived as risky or resulting in lower yields than TPR, which may lead to eviction by landlords. This may change in the future as farmers gain experience with these technologies.

Harvest labor contracts

At present, farmers harvest all rice varieties simultaneously, irrespective of their maturity, in order to reduce the transaction costs of the *zin* contract system, whereby cutting and removing straw are separate operations and farmers must supply transport to remove dried straw from the field (Orr et al, this volume). The key question here is: How much early-maturing rice is needed to persuade farmers that staggered harvesting is worthwhile? This issue is important because chickpea yields best when planted early. Even with 20% of the rice area planted to improved earlier maturing varieties,

Table 3. Farmers' choice of technology according to monsoon rainfall.

Strategy	TPR (Swarna)	SDR	DSR-WS	DSR-DS
Planned	Normal practice	Normal monsoon	Normal monsoon	Normal premonsoon
Adaptive	Too much water for DSR	Late monsoon	Heavy premonsoon	Late monsoon

farmers harvest these and Swarna simultaneously. One suggestion at the workshop was to contract with landless labor groups that would harvest early-maturing plots within a specified period.

Poverty

Resource-poor farmers had higher land, poorer soils, and more sharecropped fields than others. This reinforced the need for household food security and they were less likely to grow improved varieties in the aman season, which suggests they would be particularly reluctant to abandon Swarna. Despite this unfavorable resource base, however, poorer farmers had a higher level of cropping intensity in the rabi season, reflecting the need to squeeze whatever they could from limited land. This suggests that they would benefit from interventions to improve rabi cropping through low-input crops such as chickpea.

Giving farmers choices

The complexity of cropping patterns in the HBT limits the scope for prescriptive recommendations that give farmers simple rules for the use of new technology. Instead, farmers need a series of options from which they can choose and that will vary between seasons, between specific fields, and between farmers according to their resources.

Consider the additional options that short-duration varieties and DSR now give farmers for coping with erratic monsoons (Table 3):

- Farmers may use TPR as a planned strategy (their normal practice) but also as an adaptive strategy when heavy monsoon rains prevent DSR, which requires moist or saturated soils.
- Farmers may use SDR as a planned strategy instead of longer-duration Swarna in TPR but also as an adaptive strategy when the monsoon is late. SDR can be transplanted when the monsoon arrives and still be harvested in time to allow a rabi crop.
- Farmers may use dry-seeded DSR as a planned strategy when the monsoon rain is normal but also as an adaptive strategy instead of TPR or SDR when the monsoon is late and delayed transplanting will prevent timely sowing of rabi crops.

- Farmers may use wet-seeded DSR as a planned strategy when the monsoon rain is normal but as an adaptive strategy when heavy premonsoon rain prevents dry-seeded DSR, which requires only a moist soil and not a saturated soil.

In practice, the full range of technology options is limited by toposequence, by soil type, and by timely access to seed of a range of varieties. DSR is not suitable for low-lying land or for sandy soils that do not hold water and have high weed growth. Similarly, chickpea is not usually grown on soils that dry out quickly.

The advantages of particular strategies depend on rainfall probabilities. TPR in the HBT is delayed every other year by 2 weeks and every 10 years by 1 month (Saleh et al 2000). Hence, dry-seeded DSR is an attractive planned strategy in "normal" years. However, "excessive" premonsoon rain occurs once every three years (Brammer 1997). This would rule out dry seeding and instead farmers would have to wet-seed or transplant. Similarly, a 2-week period without rain during the grain-filling stage occurs once every two years (Saleh et al 2000). SDR or DSR is therefore an attractive strategy in normal years to avoid late-season drought.

Helping farmers make the right choices means providing them with the information they need to decide for themselves. Farmers need to be made aware of different options and how these could work in different contexts. Thus, these new technologies are knowledge-intensive and this has important implications for the type of information that farmers need and the role of the extension service. This issue is discussed in the next section.

Promotion

What has to happen for these technologies to be widely disseminated and then adopted? The workshop identified several factors, on both the supply and demand sides, that might either promote or prevent adoption of these new technologies (Table 4).

DSR equipment

Without lithaos and drum seeders, farmers will not be interested in DSR. At the moment, only farmers who have participated in field trials have access to this equipment. The key question, therefore, is how quickly the market will respond to meet demand. The equipment is relatively simple to make. Lithaos require only angle-iron and welding and can be made by a local blacksmith. Drum seeders require plastic molds and are manufactured in factories in Dhaka but not yet in Rajshahi. Costs are low. The retail price for a lithao in 2005 was US$15 and $75 for a drum seeder. The cost of the investment can be reduced when the equipment is shared by farmer groups or by renting it out to others.

Mechanical seed drills

Promotion of DSR could be facilitated by mechanical seeding. Seed drills drawn by power tillers have recently been introduced for wheat. The same could be used for

Table 4. Drivers of technology adoption for the Barind.

Supply side	Demand side
Commercialization of DSR equipment	Rising labor costs
Mechanical seed drills	Poverty elimination
Availability of SDR and chickpea seed	Market for chickpea
Commercial supply of trace elements (Mo), *Rhizobium*, HNPV	Mass exposure through demonstrations and farmers' groups
Decision-support system for farmers	
Training of DAE staff	
Local partnerships	
Breeding to replace Swarna	

dry-seeded DSR until the soil becomes too wet. The window of opportunity for DSR using mechanical seeding would therefore vary from season to season, depending on the onset of the main monsoon rains. Seed drills are most likely to be purchased by contractors who already undertake much of the land preparation for TPR in the HBT. Contractors who become skilled in seeding are then likely to drive wider adoption.

Seed availability

Demand for seeds of new farmer-preferred varieties of chickpea and rice needs to be met by supply if adoption is to be widespread. The supply of rice seed is less problematic because seed production is possible throughout the year in Bangladesh, whereas chickpea seed can be produced only during the rabi season and so must be stored for around 7–8 months. Nevertheless, large amounts of chickpea seeds have been produced by individual farmers and seed production groups, coordinated by PROVA (Musa et al, this volume). In the absence of a large market for chickpea seeds, it is likely that seed production by farmer groups will continue to be significant in the future. In contrast, the huge potential market for seed of new rice varieties is more likely to attract the commercial sector.

Trace elements, *Rhizobium*, and HNPV

A deficiency of molybdenum (Mo) prevents nitrogen (N) fixation by chickpea even though appropriate *Rhizobium* may be present and satisfactory nodulation has been achieved. Widespread Mo deficiency may explain the low response to *Rhizobium* inoculation and symptoms of N deficiency observed in chickpea across the HBT. Adding trace elements such as Mo directly to the crop is difficult for farmers because of the minute quantities involved. However, it is feasible for farmers to add Mo and *Rhizobium* in the priming solution. The bottleneck now is commercialization of the supply of Mo and *Rhizobium,* which were previously supplied to farmers through the project. Similarly, the production of *Helicoverpa* nuclear polyhedrosis virus (HNPV), an effective IPM strategy against pod borer (*Helicoverpa armigera*), is practical only under reasonably aseptic laboratory conditions, and ways of commercializing this process and distributing HNPV to farmers still have to be worked out. Other control strategies against pod borer such as placing bird perches to encourage bird predation of larvae, intercropping or mixed cropping to discourage oviposition by *Helicoverpa* moths and encourage natural enemies of pod borer, and physically removing the pod borer from the plants can be carried out by farmers themselves.

Decision-support

The complexity of the farming system means that new technology is knowledge-intensive. Farmers need information that will help them choose between various options. Researchers therefore need to develop decision-support systems that will allow extension workers to communicate this information effectively. Simplified decision-tools should be developed that outline when and where different options can be used successfully. Examples include leaflets about DSR in question-and-answer format, or posters with information about herbicides for display by dealers, who are an important source of information for farmers. These resources are available to extension workers on the Web through the Bangladesh Rice Knowledge Bank. Information leaflets in Bangla on production practices for chickpea are already widely available.

Training of DAE staff

Both projects that have been working in the HBT have made considerable investments in training the DAE community (*thana* and district-level staff) in DSR and improved rabi-cropping practices. DAE field officers have also been encouraged to work with farmer groups associated with the projects. We believe that this emphasis on group formation that allows DAE and farmers to learn and demonstrate technologies together needs to continue.

Local partnerships

Dissemination will require building a reliable supply chain. This cannot be left to the market because the benefits to private firms would not justify the cost of delivering these knowledge-intensive technologies to large numbers of small farmers. Dissemination will therefore require local partnerships between the extension service, NGOs with access to small-farmer groups, and private-sector suppliers of seed, herbicides, and equipment, as well as technical backstopping from researchers. This partnership is likely to be driven by a "champion" of these technologies, such as an NGO with a mandate to work directly with small farmers.

Breeding to replace Swarna

Swarna is the key to the rice-farming system in the Barind. The breeding objective for rainfed lowland rice is to produce an improved variety with the same yield as Swarna but which is resistant to sheath blight and can be harvested 1 or 2 weeks earlier. This would immediately unlock the potential for rabi cropping, since rice would not only be harvested earlier but could continue to be harvested simultaneously. Because Swarna has such a strong combination of desirable traits, however, finding a replacement has not been easy. Some Nepalese varieties with traits that are acceptable to farmers have been selected in on-farm trials and adopted by participating farmers (Joshi et al, this volume), but they have not yet been officially approved for release in Bangladesh. Farmers in the HBT have started to replace Swarna with Sada (white) Swarna, a new variety that is reported to be less susceptible to sheath blight and to mature earlier. The provenance of this variety is not known but it may be Rajendra Mashuri, bred in Rajendrapur, Bihar, as an alternative to Swarna (MTU 7029). The field duration of this variety is 140 days or 15 days earlier than Swarna.

Rising labor costs

The growth of the nonfarm economy in Bangladesh has reduced the supply of agricultural labor and increased the cost of this labor to farmers. At the same time, rice prices have fallen in real terms. Mahabub Hossain, in his opening address to the workshop, highlighted the need for labor-saving technology that allowed farmers to cut costs and maintain profitability. Obviously, DSR will reduce employment for transplanting and weeding. In the HBT, this will reduce employment primarily for tribal (Adivasi) households, particularly for tribal women who participate in these operations, and for seasonal male migrants from other regions of Bangladesh. However, agricultural labor now accounts for only 10% of total income among landless households in Bangladesh. Hence, the social costs of DSR are not excessive. And, if DSR is followed by a rabi crop on land that might otherwise have remained fallow, the net loss in employment is reduced considerably.

Poverty elimination

In Bangladesh, the month before the aman harvest is often one of hunger and deprivation for poor rural households. Rice prices are high but employment is scarce. Shorter-duration varieties that can be harvested earlier offer resource-poor farmers a possible way to shorten or even eliminate this hungry period, known in northern Bangladesh as *monga*. Several NGOs are working with groups of marginal farmers in several districts to evaluate SDR varieties and DSR to discover whether they can help reduce monga in northern Bangladesh.

Markets for rabi crops

High prices make chickpea an attractive rabi crop for farmers. Demand is high due to a national decline in chickpea production, mainly because of disease and failure to compete with irrigated crops in traditional growing areas, and chickpea remains a staple food. Other dryland rabi crops such as linseed and mustard are less profitable but can also provide a useful income. Chickpea does not compete with wheat, which is usually grown on land that farmers can irrigate from ponds.

Mass exposure

Many farmers in the Barind remain unaware of the potential these technologies offer to raise productivity and income. There is therefore a need to create demand by demonstrating the technologies in villages throughout the region. The DAE and PROVA, an NGO, have successfully collaborated on a program of demonstrations for chickpea in all thanas in the HBT.

Conclusions

The complexity of the farming system means that it has taken several decades to develop new technology for the HBT. That investment now seems to be paying off and several technologies are now available that have demonstrated good potential to raise farm productivity and income.

The strategy behind these interventions has been to expand the area planted to rabi crops by promoting new technology to improve yields of chickpea, and by bringing forward the time of the rice harvest. Earlier maturity can be achieved by transplanting short-duration rice or by direct-seeding long-duration cultivars such as Swarna. Either way, farmers gain extra time to take advantage of residual soil moisture, which increases the potential for successful chickpea cultivation, although this depends on the ability to harvest rice early. These interventions have been tested over several seasons, are profitable, and now deserve wider dissemination to farmers so that they can assess their potential for themselves.

Dissemination of these technologies cannot be left entirely to the market because they are public goods that will primarily benefit resource-poor small farmers rather than private firms. Instead, dissemination will require partnerships between the state-run extension service, farmer groups perhaps working with NGOs, and private-sector suppliers of the seed, herbicides, and equipment that are needed if they are to be adopted. Dissemination will also require technical backstopping from researchers, in both providing the right kind of information for extension agents and working closely with farmers to fine-tune these technologies as they are adapted to fit local conditions.

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Notes

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Workshop discussion

Participants discussed several issues that emerged from the presentations made at the workshop. As a result of the discussion, the following recommendations for future action emerged for some key research questions and technology promotion issues.

Research questions

Can dry seeding be mechanized?

- Several participants supported the need to mechanize dry seeding as a way of popularizing direct seeding in the Barind. They argued that the *lithao* (a hand tool used to open planting furrows) is not traditional in Bangladesh, adding that it is slow and labor-intensive to use. Mechanization will allow timely direct seeding.
- It was suggested that custom hire of a power-tiller-operated seeder is the way forward as 70% of the land in the High Barind Tract is already prepared by hired power tiller; a suitable drill attachment is already available in Bangladesh.
- It was pointed out that in eastern India direct-seeded rice (DSR) has been promoted by use of a wheat zero-tillage drill or a tractor-mounted seed drill. Mechanization by custom hire of tractors and drills has been very successful in parts of India.
- However, a note of caution was introduced. DSR needs very good timing of operations regarding rainfall to achieve good stands of rice. When rainfall is erratic in the premonsoon period, farmers need the ability to respond quickly to sow when soil moisture is suitable. Relying on custom hire of machine seeders may compromise timely planting.
- The alternative view that custom hire can be timely was also advanced. Management issues can be overcome by working through groups. One power tiller can cover 1 ha per day.
- It was pointed out that the Indian experience has involved tractor-drawn drills. When farmers cannot arrange use of a drill on time, they broadcast seed. It was suggested that it will always be best to give farmers all options—let there

be choice. Some work has already been done by BRRI on broadcasting seed over furrows opened by lithao and this could be looked at further.

- Some further testing of seeders is needed in the Barind. In previous tests, it had been difficult to achieve a uniform plant stand due to poorly leveled land. A lithao, on the other hand, is easier to use, particularly in small fields.

Recommendation: Adaptive work is needed to examine technical issues involved in mechanized DSR and the impact of custom hire on timely planting. However, all options should be offered to farmers.

How can we develop a chickpea variety that is suitable for the Barind?

- The Pulse Research Centre uses germplasm and breeding lines from ICRISAT and staff indicated there is capacity to develop a new variety if this is needed. They reported that some pod borer–resistant lines have been identified and these need to be tested in the Barind. However, the 585 farmers trained by PROVA generally achieved low yields so it was suggested that more training of farmers, and better identification of constraints, is needed as a route to yield improvement.
- Participants considered that chickpea breeding needs a multidimensional approach—pod borer, *Fusarium,* and BGM resistance are among the important traits.
- It was pointed out that chickpea has been cultivated in northern India for centuries. Four races of *Fusarium* can be controlled by resistance breeding. A good approach is to identify characters that farmers need and to collaborate with ICRISAT to identify lines for PVS and then promote community breeding. Community-based organizations can then be involved to make sure that a new line is locally adapted.
- Barichola 5 and 7 have tolerance of some diseases so, if more breeding is needed, it was suggested that support from international institutes could be sought for marker-assisted work to improve these.
- However, the need for breeding at this stage was questioned. Barichola 5 and 7 have a yield potential of 2 t ha^{-1} but farmers do not achieve this. Can we use agronomy to close the yield gap? The traits needed to improve Barichola 5 are known. The process can then be to use PVS to involve communities in a few targeted crosses and then involve farmers in selection.

Recommendation: A considerable yield gap exists between the potential of currently available chickpea cultivars and yields under farmer management. Further promotion of current varieties with improved agronomy, including soil nutrient management, is needed while examining the potential for additional breeding efforts for key traits.

How can we identify a short-duration rice cultivar for the Barind?

- BRRI has identified a number of lines maturing in 115 to 130 days in the Barind environment, with yields similar to those of Swarna. Backcrosses are in progress to introduce "Swarna grain quality."
- Some participants were worried that exotic materials from Nepal (e.g., Judi 582) are not as good as BRRI materials and are susceptible to neck blast. This has not previously been seen in the Barind.
- The rice innovation system in Bangladesh within BRRI and the universities is comprehensive with clear regulation. The Plant Science Programme project has demonstrated the value of early involvement of farmers in variety evaluation by PVS.
- Rice cultivars have a limited life span in production so there is a continuous need to develop new materials to give maximum profit to farmers. Yield is not the only trait farmers consider.
- It was pointed out that there is differential performance of some rice lines under different environments, including various levels of salinity and fertility. It is therefore important to take local conditions into account when assessing cultivar performance. It was suggested that a comparison of the performance of Nepalese lines tested on-farm by PROVA needs to be made with BRRI lines under low soil fertility. Care needs to be taken that cultivars that can be useful for farmers are not discarded during screening just because they do not perform well under high-fertility conditions.
- It was pointed out that BRRI has a national remit to introduce and test exotic materials. So long as the pedigrees are known, there is no difficulty for BRRI to evaluate and work with the lines introduced by PROVA. Currently, an application has been submitted for registration of Judi 582 by PROVA. If necessary, it was suggested this could be released just for the Barind as niche registrations are legal.

Recommendation: It was agreed that all institutions need to follow the rules concerning rice variety introductions and release. Farmers' perceptions have a vital role to play in the variety development process. Some of the exotic Nepalese lines are reported to be performing well under farmer management in the Barind. BRRI should undertake trials to test this material further.

How can we control weedy rice and other emerging weed problems?

- This question relates to changes in the weed flora and the occurrence of "weed species shifts" that occur with changes in agronomic practice. Experience elsewhere in Asia has shown that an increase in abundance of weedy rice is associated with the introduction of dry direct seeding. This process may take 5–10 cropping seasons. Weedy rice is a form (ecotype) of rice that typically drops seed before harvest. These plants volunteer from the soil at the time of crop establishment and are highly competitive with the crop. Control is complicated and expensive, requiring an integrated approach with emphasis on tillage and hand roguing. No selective herbicides are available. Seed health/purity and generating awareness are important parts of knowledge dissemination. Long-awned, early-maturing types of rice that shatter at maturity have been found in transplanted rice in the Barind. These may be selected for by the practice of direct seeding, as has happened in Malaysia and Vietnam, and so could become a threat to the sustainability of DSR. Weedy rice often has a long seed dormancy so is not controlled by puddling prior to wet seeding.

- Grass weeds will also build up with direct seeding. Farmers need to be aware of this and to ensure that hand weeding follows the use of herbicides.
- Work by the CPP weed project had involved collaboration with industry to move information on safe and efficient use of herbicides, including the issue of potential resistance, by the supply chain to local pesticide dealers and on to farmers. A workshop at BRRI involving the main companies supplying herbicides in Bangladesh had demonstrated considerable interest from the private sector to be involved in stewardship of its products and to engage in farmer training.
- It was reported that where dry DSR is common in India, wild rice infestations have developed. These have been managed by using a stale seedbed in the premonsoon. A purple-foliage rice variety may also be sown so that wild rice can be easily identified and removed from the field. A high-yielding variety is planted in the following season.
- So far, DSR has not been adopted on a sufficient scale in Bangladesh to offer a business opportunity to herbicide suppliers. However, industry participants expect solutions to be available in the future. It was suggested that tank mixes of herbicides need to be tested as an approach to preventing weed shifts.

Recommendation: Further investigations of weed problems associated with DSR are hampered by the limited weed science capacity in Bangladesh. Collaboration with external institutions, to provide training on these issues to Bangladeshi research and extension organizations, should be developed.

Promotion issues

Socioeconomic context: The workshop had emphasized the need to understand the farmers' situation in greater depth so that technologies could be targeted effectively. There has been only limited adoption of improved technology in the Barind Tract in the past. The major resource of the area is the people and this includes the tribal culture that introduces a cultural dimension to the acceptance of technology. Access to land and availability of labor for agriculture are evolving, with share-cropping giving way to fixed tenancy. The implication is that farmers may be more receptive to technologies that result in productivity increases. Despite these changes, share-cropping continues to some extent and, in this marginal rainfall area with inherent risk for crop production, this may act as a disincentive for investment.

What is an effective way of extending technology—DSR and the rice/rabi system for the Barind?

- Access to machines or seed and adequate knowledge are essential. Greater availability of the drum seeder or the *lithao* is needed in the farming community to accelerate farmer adoption of DSR.
- Zero-tillage drills for wheat were extended in India by establishing nucleus villages upon which knowledge transfer and availability of equipment were initially concentrated. A group approach including supply of inputs and information was very effective. The key was good training initially at the farmers' group level and training of extension agents. Once technologies had been established in nucleus villages, they were extended to satellite villages using the KVK university extension system operating with the government extension service. Custom-hire services were also important in extending the technologies in India.
- Following the lead from DAE, the meeting agreed that progress could be made by more farmer group formation and by using groups as the basis for mainstreaming a national program on DSR. This implies an institutional issue and the need for very close interaction and collaboration between NARES and DAE.

Recommendation: Central to any promotion program on DSR/rabi is the need to provide farmers with choices through demonstrations that facilitate widespread testing and adaptation of technology at the household level.

How can we best achieve stakeholder collaboration?

- Various models had been tried in the past, but even when successful they had not necessarily been continued after the termination of project funding. Examples are the National and District Technical Committees of DAE and the Focal Area Forum approach tested by the Poverty Elimination Through Rice Research Assistance (PETRRA) project.
- Regular meetings can be held between stakeholder groups but leadership and direction are a key issue and there needs to be identification of which institutions can provide these.
- Good-quality training material will be essential in closing the knowledge gap. It is suggested that a set of fact sheets on materials and messages should be prepared for the Bangladesh Rice Knowledge Bank (RKB) to form a short training module for extension workers.

Recommendation: Research/extension linkages should be strengthened to ensure direct farmer involvement in the design and delivery of knowledge on the DSR/rabi crop system. The focal area forum and district technical committees approach should be considered. The information resulting from the DFID projects needs to be uploaded to the Rice Knowledge Bank (coordinated by BRRI) to be made available through a link to a Barind section.

How can we improve farmer access to seeds?

- The NGO RDRS worked under PETRRA with 260 federations each with 400 to 500 households. Each selected 5–10 committee members and individuals to produce seed for the federation members. RDRS provided training and support. Seeds were collected for storage and marketing by the federation after harvest.
- The NGO CARE in Rajshahi works through the community to select resource farmers who are trained in collaboration with DAE on how to produce seed and handle other inputs for the community. PROVA has used a similar approach to help farmers to produce chickpea seeds. Given the greater vulnerability of chickpea to deterioration and losses during storage, particular emphasis has been placed on training farmers in safe storage techniques.
- DAE provides seed of modern rice cultivars to selected farmers on the understanding that some of the harvest is passed on to others.
- BRRI Rajshahi gives seed in 3-kg bags to trainees who attend sessions at the research station.
- A number of case studies on seed systems developed in Bangladesh by PETRRA are described in the book *Innovations in Rural Extension*.[1]

Recommendation: BRRI provides breeders' seed of released rice cultivars to various institutions in the private sector and to NGOs via a memorandum of understanding. There is a shortage of breeders' seed so BRRI should expand seed multiplication on BRRI stations. A number of models for seed systems have been developed and tested for both rice and chickpea. A commonality is the need for farmer involvement in the process.

[1]Van Mele P, Salahuddin A, Magor NP. 2005. Innovations in rural extension: case studies from Bangladesh. Wallingford (UK): CABI Publishing.

Opportunities for improving rice production in the High Barind Tract

Developments in direct seeding of rainfed rice in the High Barind Tract

M.A. Mazid, B. Khamarker, A.M. Mortimer, and C.R. Riches

A key development challenge in the drought-prone rainfed agriculture of the Barind Tract of northwest Bangladesh is to simultaneously improve the reliability and yield of monsoon rice while improving total system productivity by increasing the area planted to drought-tolerant postrice crops. Research trials and field-scale evaluations by farmers have demonstrated that dry direct seeding or wet seeding of pregerminated seed reduces labor for crop establishment and results in rice yields similar to or higher than those of conventional transplanting and advances harvest by a week to 10 days. An earlier harvest has the potential to reduce the risk of terminal drought in rice when the monsoon ends abruptly and increases the opportunity for establishing a postrice crop of chickpea on residual moisture. Herbicide use is essential with direct seeding and this further reduces rice production costs. This modified rice/legume system, using direct seeding, is knowledge-intensive. Widespread sustained adoption will depend on farmers undertaking timely tillage, adequate land leveling, and timely application of herbicides.

The major cropping pattern of the High Barind Tract of northwest Bangladesh consists of a single crop of transplanted rice grown during the monsoon *aman* season from June to October, when 80% of the 1,200 to 1,400 mm annual rainfall occurs, followed by fallow during the dry season. This area includes 100,000 ha of predominantly rainfed land, accounting for some 12% of the drought-prone rainfed lowland rice in Bangladesh (Mazid et al 2001). Limited irrigation potential restricts cultivation intensity to below 175%, considerably less than in other regions of the country where irrigation allows two or three rice crops each year (Nur-E-Alahi 1999). Some 80% of the area currently lies fallow in the postrice *rabi* season. Approximately 20,000 ha are sown to a range of drought-tolerant rabi crops planted on residual soil moisture after rice harvest, including chickpea, linseed, and mustard, or wheat where irrigation from farm ponds is available.

The agricultural development challenge in the Barind is to simultaneously improve the reliability and yield of aman rice while increasing total system productivity by increasing the area planted to rabi (Mazid et al 2003). Mazid et al (2001) demonstrated that the reliability and productivity of the aman rice–rabi chickpea system can be improved through the introduction of direct seeding of the rice crop (DSR) to replace the existing system of transplanting rice (TPR) on well-drained land. Late onset of the monsoon or low rainfall can delay rice transplanting as a minimum of 600 mm of cumulative rainfall is needed to complete land preparation, including puddling and transplanting. Direct seeding, on the other hand, can be completed after land preparation following only 150 mm of cumulative rainfall (Saleh and Bhuiyan 1995). The earlier planted DSR crop matures 1–2 weeks before TPR, thus reducing the risk of terminal drought, and allows earlier planting of a following nonrice crop (Saleh et al 2000). Swarna, the most widely grown cultivar in the area, matures after 140 to 145 days and, when transplanted, may not be harvested until early to mid-November. In many years, soil dries rapidly at this time, reducing the likelihood of successfully establishing chickpea. Weeds, however, are a major constraint to the adoption of DSR as weed suppression, an inherent advantage of puddling and transplanting rice into standing water, is lost (Mazid et al 2002). Labor shortage constrains the timeliness of first weeding for many households and, with current practices, 34% of the farmers lose more than 0.5 t ha^{-1} of attainable yield due to weed competition (Mazid et al 2001). The weed pressure associated with DSR may be overcome, however, by the timely application of a preemergence herbicide after seeding and follow-up hand weeding (Mazid et al 2001, 2003).

In this chapter, we report on a series of research trials and farmer evaluations of direct seeding leading to the development of a reliable and productive rainfed cropping system for the High Barind Tract.

Methods

A long-term systems trial

The yields of two rice cultivars when either direct seeded or transplanted were evaluated in the Barind in a long-term trial established in 2001. Cultivar BRRI dhan 39 (maturity of 120–125 days) was compared with the widely grown Swarna (maturity of 150–155 days). The experiment used a split-split-plot design with three main plots as crop establishment and associated weed management, four subplots as nutrient management, and two sub-subplots as cultivars. Establishment treatments were (1) *transplanted rice (TPR)*—soil puddled prior to transplanting and plots hand-weeded twice at 30 and 45 days after transplanting (DAT); (2) *direct-seeded rice (DSR)*—soil plowed prior to dry seeding (2001 and 2004) or plowed and puddled before sowing pregerminated seed (2002 and 2003) in rows by hand, with hand weeding at 21, 33, and 45 days after sowing (DAS); (3) *direct-seeded rice with chemical weed control (DSRH)*—as with DSR but with oxadiazon (375 g a.i. ha^{-1}) applied 2–4 days after seeding, with one hand weeding at 33 DAS. Nutrient regimes (kg ha^{-1}) were (1) single superphosphate, 40 P + 40 K; (2) compound 60 N + 40 P + 40 K; (3) farmyard manure (FYM) + inorganic fertilizer totaling 60 N + 50 P + 50 K; and (4) diammonium phosphate (DAP) (18% N) + controlled-release urea (CR-N 45% N) totaling 43 N + 40 P + 40 K.

Chickpea (cv. BARI chola 2) was broadcast onto residual soil moisture after harvest of direct-seeded rice and covered with soil by cross plowing with an ox-drawn country plow. Rice yield was assessed from one 5-m^2 area of each plot. Total weed biomass was recorded in two unweeded quadrats per plot at harvest.

On-farm verification of the DSR-rabi system

Trials were undertaken in 16 farmers' fields during the 2003 monsoon season to verify the productivity of a DSR rice-chickpea system. Chickpea (cv. BARI chola 2) was sown after harvest of Swarna or three shorter duration BRRI dhan cultivars (maturity 140–145 days) established by either transplanting or direct seeding. Prior to dry direct seeding in June, the land was plowed (at least 3 times) with an animal-drawn country plow and leveled with a ladder. Seed was sown in lines by hand into furrows opened by a hand-pulled *lithao*. Seedbeds were established at the same time and seedlings were transplanted approximately 30 days later following conventional plowing and puddling operations. In direct-seeded rice, a single application of oxadiazon (375 g a.i. ha^{-1}) was made to control weeds, whereas in transplanted rice pretilachlor (450 g a.i. ha^{-1}) was applied.

Field-scale evaluations

Evaluations of three practical methods of direct seeding were undertaken on a field scale in three districts of the High Barind Tract during aman 2004. Dry seed of Swarna and BRRI dhan 31 (duration of 140–145 days) was sown into shallow furrows made by a manually drawn lithao in several fields managed by a group of farmers who had previously seen the technique used in research trials. The lithao opens three rows at a time into which seed is sown by hand. Fields were leveled with an ox-drawn ladder to cover the seed after sowing. Weed control was by oxadiazon applied after seeding with a single follow-up hand weeding when necessary. Village extension officers, supported by an NGO, collaborated with researchers to evaluate broadcast sowing of dry seed onto moist soil or drum seeding of pregerminated seed onto puddled soil, each on 13 farms. Plot size was 666 m^2. Weed control was also by a preemergence application of oxadiazon and hand weeding. Direct-seeded plots were compared with transplanted rice established from seedlings raised in seedbeds sown the same day as fields were direct seeded. Weed control in transplanted rice involved preemergence application of pretilachlor (450 g a.i. ha^{-1}) after transplanting, followed by hand weeding.

In 2005, fieldwork was concentrated with farmer groups in six villages, in Rajshahi District, where farmers planted a field by one of the two following methods of direct seeding:

- Sowing dry seed into moist soil by hand into rows opened by a locally fabricated furrow opener (lithao). A total of 43 sites were planted by dry seeding between 6 and 29 June. Subsequently, monsoon rain flooded fields, preventing further use of this technique.
- A hand-pulled drum seeder (model imported from Vietnam) was used to sow pregerminated seed on wet soil at 11 sites. This method was used between 29 June and 10 July.

Table 1. Planting dates, direct-seeding method, and monthly rainfall, 2001-04.

	Rainfall (mm)			
	2001	2002	2003	2004
DSR planting date	26-VI dry seed	3-VII wet seed	20-VI wet seed	14-VI dry seed
TPR planting date	27-VII	2-VII	27-XI	16-VII
May	235	95	73	100
June	367	312	248	454
July	268	228	97	176
August	182	341	111	177
September	176	252	130	145
October	198	95	163	185

Previous work had demonstrated that direct seeding can be undertaken on what farmers classify as either "highland" or "medium land" fields of this terraced landscape. Both land types were represented in each of the villages where groups planted direct-seeded plots. Herbicide (oxadiazon) was applied 2–4 days after seeding and one hand weeding was undertaken by 30 DAS. A comparison plot of the same rice cultivar was established by the farmers' usual method of transplanting at 45 sites. Transplanted plots were usually weeded twice. The majority of farmers chose to grow either Lal Swarna or Sadar Swarna, cultivars that are widely grown in the Barind. The farmer groups operated within a "farmer field school" framework, coming together regularly to visit plots and discuss progress.

Results

System trial

Rainfall in May and early June was sufficient in 2001 and 2004 for sowing dry-seeded rice into moist soil during June (Table 1). In 2002 and 2003, an abrupt onset of the monsoon resulted in flooded fields so pregerminated seed was sown on saturated soil in DSR plots after water levels fell. Drought during July and August 2003 delayed transplanting until late September, 92 days after DSR. Yields of DSR and DSRH exceeded those of TPR (Fig. 1) for both cultivars, except for 2002 (cv. BR 39) and 2001 (cv. Swarna), when the cropping system did not significantly influence yield. Yields of transplanted rice in 2003 were severely depressed by drought from early July to mid-August that led to late transplanting, whereas under direct seeding yields were higher and Swarna outyielded BR 39 by 1 t ha^{-1}. Over four years, mean yields were highest from direct-seeded rice ($P<0.001$), with TPR producing 1.81 t ha^{-1} compared with 2.63 t ha^{-1} for DSR and 2.94 t ha^{-1} for DSRH (S.E.D. 0.13). The higher yields under direct seeding were accompanied by earlier maturity and harvesting dates (3–10 days), especially with BRRI dhan 39. On average, longer-duration cultivar Swarna outperformed BRRI dhan 39 ($P<0.001$).

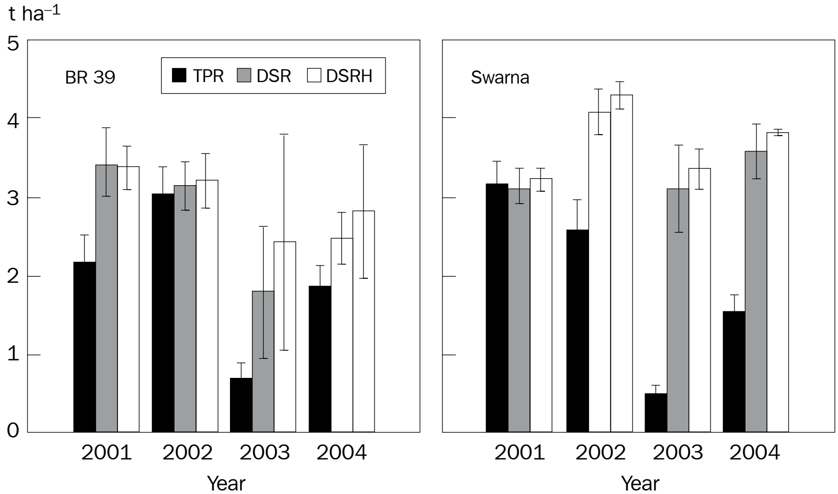

Fig. 1. Effect of crop establishment and weed control method on grain yield (t ha^{-1}) over time of two rice cultivars. Yields are for DAP + K + CR-N nutrient treatment.

As expected, fertilizer source significantly (P< 0.001) influenced tiller density, panicle density, and final grain yield. The highest grain yields resulted from the use of NPK or diamonium phosphate + controlled-release N in DSR (Table 2A). Over the four seasons, grain yields were variable (Table 2B), however, especially in TPR, with lowest yield variability being seen in long-duration Swarna with controlled-release fertilizer. BRRI dhan 39 on average exhibited more unproductive (non-panicle-bearing) tillers than Swarna (25% and 21%, respectively) and more were present under TPR than under DSR (28% and 18%, respectively). Unproductive tiller densities were not significantly affected by fertilizer source (P = 0.127) and were determined by seasonal responses of cultivars to methods of establishment and management (P < 0.001). Rice yields following preemergence application of herbicide with a follow-up hand weeding (DSRH) were similar to those achieved by hand weeding alone (DSR).

Yields of chickpea grown after DSR declined from 2001 (Table 3). Cultivar BARI chola 2 was used throughout but proved susceptible to soil-borne *Fusarium* wilt disease. Over the period of the trial, yields were higher (P = 0.030) for crops planted after the earlier maturing rice cultivar BRRI dhan 39 than for those planted following Swarna.

Weed control in direct-seeded rice

Detailed counts made during the first three seasons of the long-term trial showed that significantly more weeds occur at harvest in areas that are left unweeded in direct-seeded plots (228 m^{-2}) than in transplanted plots (75 m^{-2}; P = 0.023). Two practices were shown in an earlier trial to overcome the increased weed population that would otherwise be a problem after the emergence of direct-seeded rice (Table 4). Weed

Table 2. (A) Mean effect of fertilizer on rice yield (t ha^{-1}) over cultivar in relation to establishment method and weed control, 2002 to 2004. (B) Cultivar variability (coefficient of variation) in yield in relation to fertilizer and method of establishment.

(A) Grain yield

Establishment method	Fertilizer			
	PK	NPK	NPK + FYM	DAP + CR-N
TPR	1.56	1.91	1.82	1.95
DSR	1.92	3.08	2.46	3.09
DSRH	2.35	3.29	2.81	3.32
Standard error of difference of mean		0.1615		

(B) Variability (coefficient of variation)

Establishment method	Cultivar	Fertilizer			
		PK	NPK	NPK + FYM	DAP + CR-N
TPR	BR39	51.6	44.7	51.1	48.1
	Swarna	54.0	55.8	51.4	56.2
DSR + DSRH	BR39	40.6	25.5	31.8	32.8
	Swarna	30.2	20.6	19.3	15.2

Table 3. Effect of rice cultivar on grain yield (t ha^{-1} ± S.E.) of chickpea sown after harvest of direct-seeded rice.

Season	Previous rice variety	
	BR 39	Swarna
2001-02	1.01 ± 0.06	0.91 ± 0.05
2002-03	0.76 ± 0.05	0.49 ± 0.04
2003-04	0.38 ± 0.04	0.16 ± 0.02
2004-05	0.31 ± 0.06	0.35 ± 0.06

biomass can be reduced by undertaking an additional and earlier plowing than is usual when preparing land for transplanting. Application of the herbicide oxadiazon 4 days after seeding reduced weed biomass at 30 days to levels similar to those following hand weeding at 2 weeks.

The main weed species present at the site of the long-term trial were *Fimbristylis miliacea*, *Cyperus iria, C. halpan,* and *Cynodon dactylon.* The greater weed biomass developed in rice established by direct-seeding was successfully controlled by herbicide

Table 4. Effect of frequency of preplant plowing and weed control practice on weed biomass at 30 days after planting and grain yield at 14% moisture of direct-seeded rice.

Treatment	Weed biomass[a] (g m^{-2})	Mean yield (kg ha^{-1})
Presowing tillage	–	–
Additional plowing	51	3,905
Normal plowing	–	–
In-crop weed control	62*	3,610*
Hand weeding at 21, 35, and 49 DAS	56	3,823
Oxadiazon + hand weeding at 35 DAS	46	3,941
Hand weeding at 30 and 65 DAS	68 ns	3,825 ns

[a]Significance levels for treatments by column: ns = not significant, * $P \leq 0.05$.
Source: Mazid et al (2001).

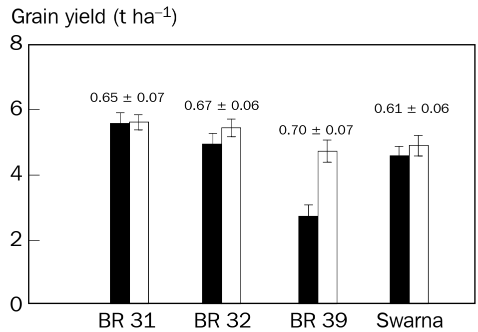

Fig. 2. Productivity (t ha^{-1}) of rice and chickpea grown in transplanted rice (open columns) and direct-seeded rice (solid columns) systems. Data are means of 16 on-farm sites in 2003 (aman and rabi seasons). Weed control in rice by preemergence herbicide. Data above each pair of columns are chickpea yields (t ha^{-1} ± S.E.).

application. In transplanted plots and direct-seeded plots not treated with oxadiazon, the rank order of weed biomass at 45 DAT was sedge > grass > broadleaf weeds. The use of oxadiazon changed the ranking: grass > sedge > broadleaf weeds.

On-farm verification of the DSR-rabi system

Rice yields were considerably higher on-farm in 2003 (Fig. 2) as the drought in July and August was less severe than at the site of the systems trial. On-farm, the yields of cultivars Swarna, BRRI dhan 31, and BRRI dhan 32 were independent of crop establishment method, whereas yields of transplanted BRRI dhan 39 were over 1.8 t higher than when dry direct-seeded. Chickpea yields were not significantly affected by the preceding rice cultivar. Rain during November ensured adequate moisture for

Table 5. On-farm trials of a drum seeder in Barind, 2004. Data are for 7 on-farm sites in aman 2004 (rice grain yield in t ha^{-1} ± standard error). Weed control in transplanted rice by hand weeding at ± 15 and 30 DAT; in drum seeding by oxadiazon at planting plus hand weeding at ± 30 DAS.

Cultivar	Transplanting	Drum seeding
Swarna	4.66	5.90
BR 11	4.82	5.86
S.E. (18 d.f.)	0.24	
Establishment method	$P< 0.001$	

Table 6. Median planting and harvest dates and mean grain yields of all cultivars used with three planting methods, field-scale evaluations in 2004. Dates are days after 1 June for planting and 1 November for harvesting, numbers in parentheses indicate date ranges. Grain yields are t ha^{-1} ± standard error.

Method	Median date		Rice grain yield (t ha^{-1})
	Planting	Harvesting	
Transplanting	53 (33–65)	20 (3–37)	5.20 ± 0.20
Broadcast	28 (23–41)	15 (3–27)	5.34 ± 0.30
Drum seeder	33 (24–40)	11 (4–30)	5.61 ± 0.37

chickpea germination and establishment, unlike in many years when the crop was established on residual moisture.

Crops of either Swarna or BRRI dhan 11 established by a drum seeder significantly outyielded transplanted rice in on-farm trials in 2003 (Table 5). Drum seeding was undertaken during the last week of June, with transplanting 21 to 33 days later.

Field-scale evaluations

Dry direct-seeded crops of Swarna, sown into furrows made by a lithao, produced higher yields than adjacent transplanted crops under farmer management in 2004 (Table 6). Yield of dry-seeded BRRI dhan 31 was similar to that of transplanted Swarna. Dry seeding was undertaken in the third week of June into weed-free moist seedbeds prepared by four previous passes with an ox-drawn country plow and three passes with a ladder to level the land. This is a similar intensity of tillage required to prepare land for transplanting. The crop survived more than 300 mm of rain in a 24-hour period 5 days after seeding as farmers were able to drain excess water from their fields.

Although direct-seeded rice was planted on a field scale by farmers at 59 sites across three Barind districts, crops were established well and brought to yield at only 26 sites—13 by broadcasting and 13 by drum seeding. Reasons for failure elsewhere ranged from flooding leading to loss of seeds, particularly when heavy rain fell within

10 days of broadcasting, to low plant populations associated with weedy, poorly leveled seedbeds at many sites where the drum seeder was used. This was the first experience of broadcasting aman or using the drum seeder for extension workers and farmers. Tillage at many sites was undertaken only a few days prior to planting, leaving insufficient time for weed suppression in a stale seedbed; laddering was also inadequate. The sites brought to yield indicate the potential for wider adoption of direct seeding, provided farmers have sufficient knowledge of how to manage these alternative planting practices. Rice grain yields, averaged across all cultivars chosen by farmers, were similar for transplanting, broadcast planting of dry seed, or drum seeding of sprouted seed (Table 6).

Median planting dates for broadcasting and drum seeding were 25 and 20 days earlier, respectively, than transplanting. This resulted in median harvest dates of 15 November for broadcast plots, 11 November for drum seeding, and 20 November for transplanting with harvest continuing in transplanted fields for a week longer than in direct-seeded plots (Table 6). Harvest dates of long-duration cultivar Swarna, planted at only four sites, ranged from 7 to 30 November for direct seeding and from 19 November to 6 December for transplanting. These dates indicate when farmers actually harvested rather than when grain was sufficiently mature so there may have been instances when the harvest was delayed. The data do, however, demonstrate how direct seeding can bring forward the rice harvest to allow farmers the opportunity for timely planting of rabi. All participants were encouraged to plant chickpea and a median sowing date of 25 November was achieved. The median sowing date on plots that had previously been direct seeded with rice was 21 November (ranging from 6 November to 7 December), some 7 days before the planting of transplanted rice plots (11 November to 18 December).

Dry direct seeding, wet seeding with the drum seeder, or transplanting all produced significantly similar mean yields ($P = 0.52$) across field-scale evaluations conducted by six farmer groups planting in 54 fields in Godagari *upazilla* in 2005 (Fig. 3). The mean difference between transplanted and direct-seeded (dry and wet seeding pooled) rice yields was 0.04 ± 0.117 t ha^{-1}. There was also no significant effect of field location on the toposequence ($P = 0.623$), with highland fields producing 5.35 ± 0.136 t ha^{-1} and medium-land fields 5.41 ± 0.076 t ha^{-1}. During 2005, farmers chose to plant one of two Swarna cultivars. Analysis of harvest dates (Table 7) provides further evidence that direct-seeded crops have a shorter field duration ($P = 0.002$) and, most importantly for farmers wishing to establish rabi crops on residual moisture, they can be harvested earlier.

The labor input needed to establish dry-seeded rice using a lithao averaged 79 person-hours per ha compared with farmer estimates of 240 hours per ha for uprooting and transplanting seedlings. There is an additional benefit that no rice nursery is needed. At least three people are needed in a field when using the lithao, two to pull and one to steer, but farmers did not find that it was too arduous to use. Even larger labor savings are associated with drum seeding as the implement can be pulled by one person. On-farm observations indicated a mean of 3.8 hours for establishing 1 ha of rice. Herbicide use reduced weed control time in dry-seeded crops to a mean of 84

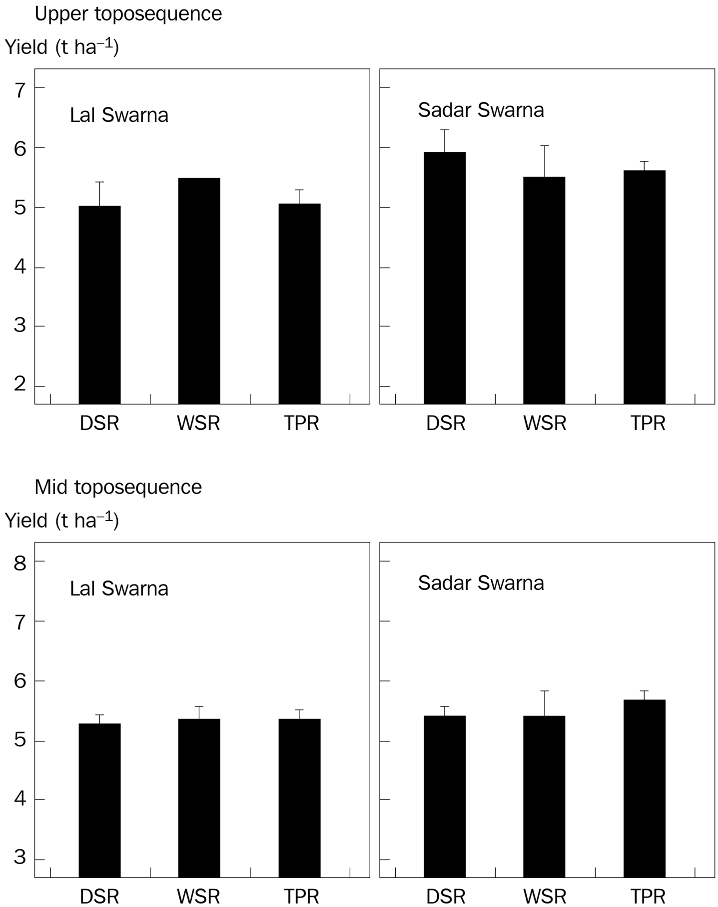

Fig. 3. Mean yields of two rice cultivars established by three methods in the aman season of 2005 in Rajshahi District. Yields were recorded from field-scale evaluation of methods by farmer groups. DSR = dry direct-seeded rice; WSR = pregerminated seed planted by drum seeder; TPR = transplanted rice (seedbeds established on day of direct seeding).

hours per ha compared with 590 hours in conventionally managed transplanted rice for which at least two hand weedings are needed.

Discussion and conclusions

A single rice crop each year combined with land pressure and a high proportion of share-cropping and other tenancy arrangements in the Barind places a premium on optimizing rice yield for household food security, particularly for those cultivating smaller areas (Mazid et al 2001, 2003). Mean farm size is 0.76 ha and 40% of rice

Table 7. Mean harvest dates and field duration for direct-seeded and transplanted crops in aman 2005. Data taken from field-scale evaluations undertaken by farmer groups. The number of field days is calculated from the initiation of the seedbed in all cases, that is, it includes days in the nursery in TPR.

Cultivar	Establishment method	Mean harvest date	Mean (± S.E.) number of field days
Lal Swarna	Transplanting	14 Nov 2005	147 ± 2
Sadar Swarna		8 Nov 2005	148 ± 1
Lal Swarna	Wet seeding	12 Nov 2005	127 ± 1.5
Sadar Swarna		9 Nov 2005	126 ± 0.9
Lal Swarna	Dry seeding	6 Nov 2005	136 ± 1
Sadar Swarna		30 Oct 2005	138 ± 1

producers are share-croppers. Our surveys have also indicated that the majority of farmers hire additional labor for transplanting and weeding. As the laborers are local people, competition results and larger holdings are likely to be short of labor at peak times and this causes late weeding (Mazid et al 2001). The series of trials reported here indicates that rice yields are maintained or even increased above the amounts achieved by transplanting when the crop is either dry or wet seeded. The widely grown cultivar Swarna, which has good grain quality and a good market price, performed well when direct seeded. Dry direct seeding using a lithao was found by farmers to be a practical labor- and cost-saving approach to rice establishment. The estimated cost of a locally fabricated lithao is taka 450 (approx. US$4.50) and group members participating in these trials suggested that one could be shared by 5 to 7 farmers, making this an inexpensive technology to use. Although high-yielding rice crops were also established by broadcasting dry seed, heavy rain within a few days of planting prevented establishment of adequate stands by this method at several sites. Seeding into furrows behind a lithao provides a less risky approach to direct seeding. A series of trial plots planted by farmers in 2005 showed that further labor savings can be made when dry seeding by broadcasting seed after making furrows with a lithao. The seed was subsequently covered by leveling land by a lithao so that the rice emerged in rows.

Yields of drum-seeded rice in trials and field-scale evaluation have also been equivalent to or higher than those from transplanted crops under farmer management. Currently, a limited number of imported units are available in Bangladesh for evaluation so the likely cost of locally fabricated drum seeders is not known although this will clearly influence the potential for adoption. In view of labor constraints on Barind farms, the application of preemergence herbicide is essential to avoid increased amounts of weeds in crops established by direct seeding. Herbicide use reduces labor and costs for weed control. Follow-up hand weeding on herbicide-treated fields is important to remove difficult-to-control herbicide-tolerant species, including annual and perennial grasses (e.g., *Ischaemum rugosum*, *Cynodon dactylon,* and *Paspalum distichum*). If hand weeding is not sufficient to prevent increased abundance of individual species, it may be necessary to consider rotating transplanted rice every few years with direct-seeded crops to allow better weed control with puddling and transplanting.

Direct seeding has advanced the rice harvest by about 7 to 10 days in field-scale evaluations for both Swarna and shorter-duration cultivars. An earlier harvest may prove significant in seasons when the monsoon ends abruptly in October for avoidance of terminal drought in rice and to allow farmers to establish chickpea or other postrice rabi crops while seedbeds are still moist. Although farmers evaluating direct seeding in 2004 did not always achieve rapid turnaround times between rice and rabi, they did plant chickpea after direct seeding on average 7 days earlier than after transplanting, reflecting the earlier harvest of direct-seeded crops. A system incorporating direct seeding and herbicides therefore has the potential to maintain or increase rice yield, reduce production costs, and overcome labor constraints and allow timely rabi crop planting to increase overall productivity of Barind agriculture.

Experience in 2004 and 2005 underlines how farmers need access to different crop establishment options given the variable rainfall pattern in the Barind. Direct seeding has potential on well-drained fields but its use and that of herbicides is knowledge-intensive. Extension/farmer training supported by clear decision support frameworks will enhance the promotion of crop establishment and weed control options in the future. These need to integrate knowledge on rice performance with each option according to land type, rainfall pattern, cultivar maturity, weed spectrum, and farmer resources. When there is a gradual onset of the monsoon allowing land preparation during late May to mid-June, rice can be dry seeded using a lithao. Once land becomes inundated, it can be puddled and leveled. Provided fields can be drained, rice can be established effectively with a drum seeder. However, for successful crop establishment by either direct-seeding practice, good tillage and land leveling to achieve weed-free seedbeds and timely herbicide application are essential.

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Acknowledgments: This work was partially funded by the UK Department for International Development (Crop Protection Programme Project R8234). However, the views expressed are not necessarily those of DFID. The Consortium for Unfavorable Rice Environments, coordinated by the International Rice Research Institute, has also provided support.

Direct-seeded rice in the High Barind Tract: economics and farmer evaluation

M.A. Jabbar, A. Orr, and B. Karmakar

Farmers' experience with direct-seeded rice (DSR) was explored through both formal economic and informal farmer evaluations of on-farm trials (OFTs). Although yields were almost identical, net returns from DSR were higher because of lower costs, chiefly for seedbed preparation and crop establishment. DSR reduced labor requirements by 30 days ha^{-1} for transplanted rice (TPR) with herbicide and by 50 days ha^{-1} for TPR without herbicide. Farmers saw the prime advantages of DSR as allowing earlier planting of *rabi* crops and savings in labor costs. The main perceived disadvantages were more weeds if herbicides were not used effectively, more damage from pests, and lower yields. Sharecroppers were reluctant to adopt DSR because they feared eviction if yields were lower than with TPR. The economic rationale for DSR in the High Barind Tract is strong but adoption among OFT farmers has been limited by erratic premonsoon rainfall, pest damage to early-maturing rice, and land tenure.

One-quarter of the net cultivated area in Bangladesh falls under the drought-prone rice ecosystem. Farmers in this ecosystem have not shared equally in the benefits from new rice technology. Although modern varieties (MVs) cover about 70% of the total area planted to rice in Bangladesh, adoption in the drought-prone rice environment averages only 32% (BRRI 2005). Adoption of new rice technology in the *aman* season is constrained by the risk of yield loss from drought, the lack of a modern variety suitable for the prevalent land and soil types, and socioeconomic factors (Islam and Jabbar 1998, Shah-E-Alam and Jabbar 1999). Stakeholder analysis by farmers, researchers, and extension workers ranked the lack of an appropriate MV for the aman season as the principal problem in rice production in the High Barind Tract (Mazid et al 2000).

Within the drought-prone ecosystem, the Barind Tract covers almost 1.82 million hectares, of which 20% is occupied by the High Barind. Although this area receives on average 1,200–1,400 mm of rainfall each year, about two-thirds remains fallow during the *aus* and *rabi* seasons. Cropping intensity in Rajshahi District averages 158%, compared with the national average of 174% (BBS 1996). The agrarian structure is conventionally regarded as dominated by absentee landlords and sharecroppers. According to one 1989-90 survey in three *thanas*, 78% of the land rented by tenants belonged to absentee owners (Islam et al 1996). According to the Agricultural Census, however, the area operated by large farms in Rajshahi District (20%) is similar to that for Bangladesh as a whole (17%) and the share of holdings operated by owner-tenants and pure-tenants (38%) is also similar (35%) (BBS 1996). Poverty mapping shows that the Barind Tract is not characterized by extreme poverty (Khan et al 2004). Of the 64 districts in Bangladesh, Rajshahi ranks 30th according to the Human Development Index, and 38th according to the Human Poverty Index (Khatun 2001). Thus, the development challenge in the Barind Tract is not primarily one of agrarian structure or poverty but of how to exploit unused potential to stabilize and raise income from agriculture in a region where farmers have not adopted new rice technology and have limited access to irrigation in the dry season.

Socioeconomic research on direct-seeded rice (DSR) between 2001 and 2005 included economic evaluation and farmer evaluation of on-farm trials (OFTs). Testing and evaluation of new technology in this complex rice environment have required a farmer participatory approach. Farmer participation may take different forms (Biggs 1989). OFTs for DSR used a "consultative" style in which most decisions were made by researchers. This reflected the nature of DSR technology, which required new knowledge such as how and when to apply herbicides, as well as new tools that were not otherwise available to farmers such as a *lithao* for dry seeding and a drum seeder for wet seeding. However, farmers chose whether to wet- or dry-seed OFT plots and they also participated in evaluating results.

The general objective of this chapter is to present experience with DSR in these OFTs from a farmer perspective. The specific objectives are to

- Describe farmers' current weed management practices,
- Compare the profitability of DSR and transplanted rice, and
- Identify farmer perceptions of the new technology.

Previous research results have been reported in a series of Working Papers (Jabbar 2003, Orr and Jabbar 2002, Orr et al 2004) and in the BRRI Internal Review (Jabbar 2002, 2005). Copies of Working Papers are available on the compact disc that contains the final project report, which is available on request from the authors.

Data and methods

Weed management practices

Information was collected through a structured questionnaire survey in Nachole, Godagari, and Nawabganj Sadar *thanas*. Households were listed and stratified according to three farm size groups, using Bangladesh Bureau of Statistics (BBS) categories for large, medium, and small, with sampling proportionate to each size group. Information on farm management was collected for a subsample of plots stratified according to land type. The survey was conducted in January 2001 after the harvest of the aman crop in November/December 2000, and results refer to the 2000-01 agricultural year (Orr and Jabbar 2002).

Table 1. Sample selection for costs and returns survey, High Barind Tract, T. aman season, 2005.

Thana	Village(s)	Farm size[a]	Number	Percent	Sample (no.)
Godagari	Rajabari	Small and marginal	69	59	17
		Medium	43	37	11
		Large	5	4	1
		Total	117	100	29
Tanore	Telipara, Monumara	Small and marginal	66	60	16
		Medium	33	30	8
		Large	11	10	3
		Total	110	100	27
Nachole	Laxmipur, Monipara	Small and marginal	67	54	17
		Medium	54	43	14
		Large	4	3	1
		Total	125	100	32
Godagari	Edulpur	Small and marginal	61	62	15
		Medium	30	31	8
		Large	7	7	2
		Total	98	100	25
All	All	Small and marginal	263	58	66
		Medium	160	36	40
		Large	27	6	7
		Total	450	100	113

[a]Small and marginal, 0.01–1.00 ha; medium, 1.01–3.0 ha; large, 3.01 ha and above.

Economic evaluation of OFTs

Information was collected through a structured questionnaire survey in Godagari, Tanore, and Nachole thanas. Households were listed and stratified according to three farm size groups, using Bangladesh Bureau of Statistics (BBS) categories for large, medium, and small, with sampling proportionate to each size group. Of 352 households listed, 88 (25%) were selected for survey (Table 1). Of these, 48 farms were purposively selected since they had participated in OFTs, while the remaining 40 were randomly chosen. In addition, one village in Godagari thana (Edulpur) was selected from outside the project area and 25% of the rice farmers from that village were sampled for cross-checking. This gave a total of 113 farmers selected for survey. Data was collected using a structured questionnaire during the T. aman season in 2005.

Table 2 shows the socioeconomic profile of the sample farms. Average farm size for OFT farmers (1.40 ha) was higher than for non-OFT farmers (0.92 ha). Average aman yields were also slightly higher among this group. Bigger farms, higher yields, and a higher proportion of owner-operators meant that OFT farmers were more likely to be self-sufficient in rice. Fewer OFT farmers had received education beyond the primary level, however.

Table 2. Socioeconomic profile of sample farmers, T. aman, 2005.

Variable	OFT	Non-OFT	All farmers
Farm size (ha)	1.40	0.92	1.18
Tenure status (%)			
Owner-operator	49	38	44
Owner-tenant	44	60	51
Pure-tenant	7	3	5
Education (%)			
None	28	30	29
Primary	56	46	51
Secondary	16	24	20
Rice self-sufficiency (%):			
Self-sufficient (%)	91	70	81
Not self-sufficient (%)	9	30	19
Rice yield (t ha^{-1})	5.25	5.10	5.18

Source: Farmer evaluation, 2005.

Farmer evaluations of OFTs

Evaluations were conducted in 2003 and 2005. The 2003 evaluation was made with 19 farmers in six thanas in three districts (Rajshahi, Naogaon, and Chapai Nawabganj) who had participated in OFTs in the 2003 aman season (Orr et al 2004). The 2005 evaluation was made with 20 farmers from the same three districts who had participated in OFTs in various years since the 2002 aman season. Information was collected using a structured questionnaire. Farmer perceptions in 2003 were obtained using open-ended questions, whereas in 2005 perceptions were captured mostly through closed questions that reflected our greater knowledge of what farmers thought about DSR. In addition, farmers were asked to rank the three most important advantages/disadvantages of DSR.

OFT farmers from the 2005 evaluation are profiled in Table 3. Eight farmers (40%) had no education, ten had primary education, and two had been educated to the secondary level. Average farm size was 2.5 ha and most households were self-sufficient in rice. Only five farmers (25%) were owner-cultivators, while eight were owner-tenants and seven were pure-tenants. Socioeconomic indicators placed OFT farmers in the medium (*majari*) category (Mazid et al 2000).

Results

Weed management

Land preparation was better on large farms, which had significantly more plowings and harrowings (Table 4). But the timeliness of both first and second weedings was significantly later on large farms. The difference in mean date of the first weeding

Table 3. Socioeconomic profile of sample OFT farmers, farmer evaluation (2005).

Variable	Year of first participation					All farmers
	2001	2002	2003	2004	2005	
OFT	1	3	3	9	4	20
Dry-seeded[a]	1	3	1	7	3	24
Wet-seeded[a]	0	1	0	2	1	10
Education						
None	0	2	2	3	1	8
Primary	1	0	1	6	2	10
Secondary	0	1	0	0	1	2
Households self-sufficient in rice (no.)						
Yes	0	1	2	9	4	16
No	1	2	1	0	0	4
Household food security (months per year)	10	10	12	12	12	12
Area cultivated in aman season (ha)	0.47	1.03	2.04	3.97	1.6	2.54
Tenure						
Owner-operator	0	0	1	4	0	5
Owner-tenant	1	0	1	4	2	8
Pure-tenant	0	3	1	1	2	71

[a]Some farmers used both methods.
Source: Farmer evaluation, 2005.

was 1 full week (6.7 days). This reflected the availability of labor. Large farms had a significantly smaller stock of family labor available for weeding and half their plots were weeded using purely hired labor. A higher proportion of large farms also reported a shortage of hired labor for weeding.

The time of first weeding in Rajshahi (28 DAT) was much later than in Comilla (15 DAT) (Orr and Jabbar 2002). The normal practice in Rajshahi was to weed only once. Discussions with farmers revealed that late first weeding reflected a trade-off between the cost of weeding and the revenue forgone from lower rice yields (Orr et al 2004). Farmers who weeded later got lower yields but because weeds were taller (making them easier to pull and removing the roots, thus reducing regrowth), they weeded only once. Farmers who weeded earlier got higher yields, but had to weed twice. Hence, later first weeding in Rajshahi reflected the relatively high cost of manual weeding.

Weeding in Rajshahi was often done by women as well as men. Wages for the first weeding were similar to those for transplanting and averaged roughly 70 Tk day^{-1} for men and 50 Tk day^{-1} for women. Wage differentials reflected differences in the

Table 4. Variations in weed management by farm size, Rajshahi District, T. aman season, 2000.

Variable	Farm size				
	Tercile 1 (n = 40)	Tercile 2 (n = 40)	Tercile 3 (n = 39)	All farms (n = 119)	Sig. level *P* >
Area planted to T. aman (ha)	0.45	0.94	2.11	1.28	0.000
Mean no. of plowings per plot[a]	4.26	4.78	4.79	4.65	0.005
Mean no. of ladderings per plot[a]	2.33	2.87	3.40	2.94	0.000
Mean date of first weeding (DAT)[a]	25.21	27.23	31.92	28.58	0.000
Mean date of second weeding (DAT)[ab]	43.59	46.18	48.28	46.16	0.012
Adults per household (no.)	3.58	4.33	4.77	4.22	0.038
Area of T. aman per adult (ha)	0.13	0.22	0.44	0.30	0.000
Labor use for weeding (no. of plots)[a]					
Own	19	19	8	46	0.007
Hired	17	33	49	99	
Both	24	33	39	96	
Labor available for weeding on time (no. of plots)[a]					
Yes	42	62	55	159	0.026
No, no cash	11	9	18	38	
No, no labor	5	12	23	40	

Source: Aman survey (2000) (Orr and Jabbar 2002).

length of the working day, with women starting work later because they first had to cook and feed their families.

Profitability

Table 5 compares unit costs of production under four methods of crop establishment. Costs were highest (Tk 24,941 ha^{-1}) for transplanted rice without herbicide compared with TPR with herbicide, DSR with a lithao, and wet-seeded rice with a drum seeder (DWSR). The costs of land preparation, harvesting, and postharvest operations were similar for all four methods, as were the costs of chemical fertilizer and manure. The cost of insecticide was highest for TPR without herbicide, reflecting a tendency of overapplication. The main contrast in operating costs was in seed, crop establishment, and weeding. The cost of these items with DSR was significantly lower than with TPR. Overall, costs with DWSR were 64% lower than with TPR without herbicide.

Yields with all four methods were almost identical (Table 6). Results from OFTs in 2005 also showed no statistical difference in yields between DSR with a lithao and DWSR (Mazid et al, this volume). Despite identical yields, however, DWSR gave a higher net return than DSR with a lithao because of lower production costs. Consequently, the benefit-cost ratio was highest for DWSR. Farmers using DWSR obtained a 5% higher net return than those using TPR.

Table 5. Cost of MV T. aman rice cultivation under different methods of crop establishment, High Barind Tract, T. aman season, 2005.

Cost items	Method of crop establishment			
	TPR[a] (without herbicide)	TPR (with herbicide)	DSR[b] (with lithao)	DWSR[c]
	(Tk ha^{-1})[d]			
Seed/seedling raising	1,450	1,350	850	800
Bullock power/power tiller	4,100	4,225	4,225	4,225
Seeding/uprooting and transplanting	3,210	3,000	900	320
Weeding	3,600	1,200	1,680	900
Herbicide (including machine)	–	957	957	957
Fertilizer	3,600	3,897	3,897	3,897
Manure	815	1,010	800	700
Insecticide	1,125	700	705	705
Harvesting, carrying, and threshing	3,750	3,800	3,840	3,930
Winnowing, drying, and storing	1,200	1,200	1,200	1,300
Interest on operating capital	1,828	1,707	1,524	1,419
Total variable costs	24,678	23,046	20,578	19,153
Total fixed costs[e]	263	277	340	590
Total costs of production	24,941	23,323	20,918	19,743

[a]TPR = transplanted. [b]DSR = direct-seeded rice. [c]DWSR = drum seeder. [d]Tk 60 = US$1. [e]Refers to land cost (not included).
Source: BRRI T. aman survey, 2005.

Table 6. Costs and returns for MV T. aman rice under different methods of crop establishment, High Barind Tract, T. aman season, 2005.

Item	Methods of cultivation (Tk ha^{-1})			
	TPR (without herbicide)	TPR (with herbicide)	DSR (with lithao)	DWSR
Paddy yield (kg ha^{-1})	5,010	5,313	5,160	5,280
Gross returns[a]	49,499	52,762	50,981	52,166
Paddy	47,595	50,743	49,020	50,160
Straw	1,904	2,019	1,961	2,006
Total costs of production	24,941	23,323	20,918	19,743
Net returns	24,558	29,439	30,063	32,423
Benefit-cost ratio	1.98	2.26	2.43	2.64
Unit cost of production (Tk kg^{-1})	4.98	4.39	4.05	3.74

[a]Paddy price: Tk 10,182 ton^{-1}.
Source: BRRI T. aman survey, 2005.

Table 7. Labor requirements (days ha^{-1}) for MV T. aman rice under different methods of crop establishment, High Barind Tract, T. aman season, 2005.

Variables	Methods of cultivation (Tk ha^{-1})			
	TPR[a] (without herbicide)	TPR (with herbicide)	DSR[b] (with lithao)	DWSR[c]
Seedbed preparation	5	5	–	–
Seeding/uprooting and transplanting	35	33	10	4
Land preparation (plowing and harrowing)	9	10	10	10
Applying herbicide	–	11	11	11
Weeding	45	15	12	11
Harvesting, carrying, and threshing	42	42	43	44
Winnowing, drying, and storing	15	15	15	16
Total	151	131	101	96

[a]TPR = transplanted. [b]DSR = direct-seeded rice. [c]DWSR = drum seeder.
Source: BRRI T. aman survey, 2005.

Employment

Table 7 shows labor requirements under different methods of crop establishment. Seedling raising, seeding/uprooting, and transplanting and weeding (which includes herbicide application and measured mechanical weeding) are the major operations in which labor employment was reduced. The higher net return from DSR was due largely to savings in labor costs.

Regional benefits

A large area in the Barind Tract is planted to TPR with herbicide. But an estimated 7% is plain land considered quite suitable for DSR where TPR is planted without herbicide. Given the estimated yield benefit of the DWSR method, a total of 30,000 tons of paddy could be harvested in addition to the present yield, valued at Tk 34 million (Table 8). In addition, the cost savings from using DWSR are estimated at Tk 652 million.

Advantages and disadvantages

Tables 9 and 10 present farmers' perceptions and rankings of the advantages and disadvantages of DSR, amplified by verbal comments (Box 1). The tables show the sum of the ranks given to each variable. Remember that farmers ranked only the three most important advantages or disadvantages. For convenience, the results from these tables are discussed together.

- Ranks for advantages were more narrowly spread than for disadvantages. The two main advantages of DSR received 54% of the sum of the ranks, while the two main disadvantages received only 33%. This suggests that farmers

Table 8. Illustrative benefits to be derived by adopting DWSR over TPR without herbicide in the High Barind Tract, Rajshahi, 2005.[a]

Item	Method	
	TPR (with herbicide)	DWSR
Plain land area (ha)	123,498	123,498
Yield (t ha^{-1})	5.01	5.28
Total production (t)	618,725	652,069
Additional production (million t)	–	0.03
Additional returns (million Tk)	–	0.34
Additional returns due to cost savings (million Tk)	–	652.44

[a]7% of the total land is plain land, which is mainly highland or medium land that is suitable for the drum seeder. Total land area is 1.82 million ha.

Table 9. Farmer perceptions of advantages of DSR in aman season (n = 20).

Advantage	Agree	Disagree	Don't know	Sum of ranks[a]
Earlier rabi sowing	20	0	0	18.5
Saves labor for transplanting	19	1	0	10.7
Saves labor for seedbed	20	0	2	8.5
Higher yield	10	8	2	4.0
Early harvest gives higher price for grain and straw	19	0	1	3.5
Labor costs reduced	8	4	8	2.5
Can sow after little rain	20	0	0	2.0
Overcomes late drought at flowering	17	1	2	1.5
Reduces labor crisis at transplanting	16	1	3	1.5
Early harvest gives rice in hungry period	16	0	4	1.0
Crop does not die	3	0	17	0.1
Less plowing if dry-seeded	6	14	0	0.0
Earlier sowing	20	0	0	0.0
Earlier maturity and harvest	20	0	0	0.0

[a]Ranked 1, 2, and 3 with 3 for the most important.
Source: Farmer evaluation, 2005.

saw a few strong advantages to DSR but a wide range of disadvantages that they regarded as serious.

- Farmers' perceptions on yield were evenly balanced, with half the sample believing that yields were higher with DSR and half believing they were higher with TPR. Consequently, yield was not seen as a critical advantage or disadvantage of DSR. Yield ranked fourth in advantages and third in disadvantages. This suggests that farmer adoption of DSR is not based primarily on yield differences.

Table 10. Farmer perceptions of disadvantages of DSR (n = 20).

Disadvantage	Agree	Disagree	Don't know	Sum of ranks[a]
More weeds if herbicides not used effectively	17	3	0	10.1
More damage from pests (e.g., rats)	18	2	0	8.5
Lower yield	9	11	0	7.5
Cannot make plot boundaries properly if dry seeding	11	9	0	6.0
Too much rain delays sowing, if dry seeding	18	2	0	4.5
More damage from insects	18	2	0	3.5
Need to plow again if heavy rain after first plowing	19	1	0	3.0
Field must be level if using drum seeder	10	1	9	3.0
Cannot harvest/carry early because cart cannot reach the field	14	4	2	2.5
Lithao is hard to pull by hand	11	4	5	2.0
Heavy showers, cyclones, and high winds damage crop after flowering	15	3	2	2.0
Birds eat seed if wet seeding is used	9	4	7	2.0
No rain	5	0	15	1.5
Crop may be damaged if no rain after early sowing	10	9	1	0.5
More damage from diseases	4	16	0	0.0
Uses more seed	2	18	0	0.0

[a]Ranked 1, 2, and 3 with 3 for the most important.
Source: Farmer evaluation, 2005.

- Farmers saw the greatest advantages of DSR as allowing the earlier sowing of rabi crops (sum of ranks, 18.5) and saving of labor for seedbed preparation and transplanting (sum of ranks, 8.5 and 10.7, respectively). Interestingly, certain features of DSR that researchers consider important were not ranked very highly by farmers. These included the advantage offered by DSR of sowing after little rain (total score, 2) and overcoming late drought after flowering (total score, 1). Similarly, farmers did not view improved food security through earlier harvesting as a major advantage of DSR, perhaps because most farmers in the sample were already self-sufficient in rice.
- Farmers saw the most important disadvantage as greater damage from weeds if herbicides were not used effectively (sum of ranks, 10.1). This was followed by greater damage from pests (rats, goats, cattle), which had a sum rank of 8.5, and lower yields, which had a sum rank of 7.5.
- Farmers saw more disadvantages with dry seeding than with wet seeding. Dry seeding created problems with making plot boundaries (*ails*) to retain rainwater (sum of ranks, 6), delayed sowing caused by heavy rain and the need to re-plow, and damage to the crop if no rain occurred for a long period after sowing. In contrast, the only disadvantage associated specifically with wet seeding was that birds might eat the newly-sown seed.

- Disadvantages with pests and insects ranked high among farmers. This may reflect experience from OFTs when DSR was combined with early-maturing varieties such as BR39 (125 days), which exposed the crop to pests, and may not be true when DSR is used with Swarna, which has a longer field duration. Farmers may have found it difficult to separate the effects of using an early-maturing variety from the effects of using DSR.

Rice varieties

Preferences for varietal traits emerged strongly from the farmer evaluation in 2003, when DSR was used in combination with four different varieties (BR31, BR32, BR39, and Swarna). Farmers reacted negatively to BR39 because its short duration (125 days) made it susceptible to pest and insect attack, including rice bug, rats, birds, and ducks (see Box 2). Only BR31 received a favorable reaction from farmers. Farmers liked BR31 because of its high yield, seedling vigor, drought tolerance, better resistance to pests and disease (sheath blight), and earlier maturity (with DSR), which meant a higher market price. However, one farmer estimated that BR31 would fetch 2 Tk kg^{-1} less than Swarna because of its coarse grain type. Coarse varieties were also harder to sell because the most widely grown variety, Swarna, was fine-grained and buyers preferred to buy grain of the same quality in bulk.

Sharecropping

Farmer evaluations in both 2003 and 2005 provided evidence that sharecropping acted as a disincentive for the adoption of DSR. Sharecroppers were willing to participate in OFTs. Fourteen of the 20 farmers who participated in the 2003 evaluation were tenants, including two pure-tenants, and 15 of the 20 farmers who participated in the 2005 evaluation were tenants, including seven pure-tenants. But comments by sharecroppers indicated that they were generally unwilling to adopt DSR because of the fear that lower yields would result in eviction by their landlord (Box 1). Similarly, of the 15 tenant farmers who participated in the farmer evaluation in 2005, six specifically said that they would lose their rented land if DSR resulted in lower yields. In contrast, sharecropping was not perceived as a constraint to the adoption of herbicides because this protected yields. For example,

- A pure-tenant renting 0.5 ha used Machete herbicide for T. aman in 2003 with his landlord sharing half the cost of the herbicide, but this same tenant was reluctant to adopt DSR because his landlord was not in favor and he was afraid of losing his lease (Ramzan Ali, Godagari thana).
- An owner-tenant renting 3.1 ha paid a fixed rent in kind. He sprayed 2.4 ha with Ronstar but was reluctant to adopt DSR because he was afraid others might report to the landlord that he had “no labor” to cultivate rice (Golam Quibria, Nachole thana).
- A pure-tenant who rented 1.6 ha on a half-share basis in 2003, bore the full cost of inputs and did not apply herbicide. He wanted to try 0.3 ha with DSR and Ronstar next season. His landlord will not object because they have a good relationship (Abdul Jabbar, Porsha thana).

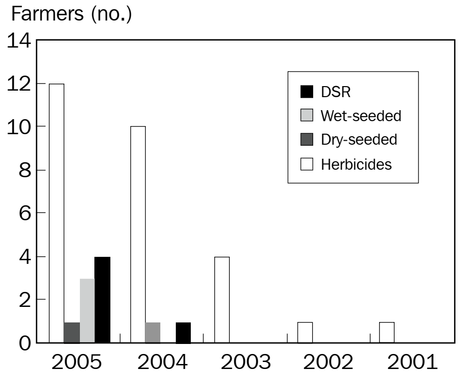

Fig. 1. Adoption of DSR and herbicides among sample OFT farmers (n = 20).

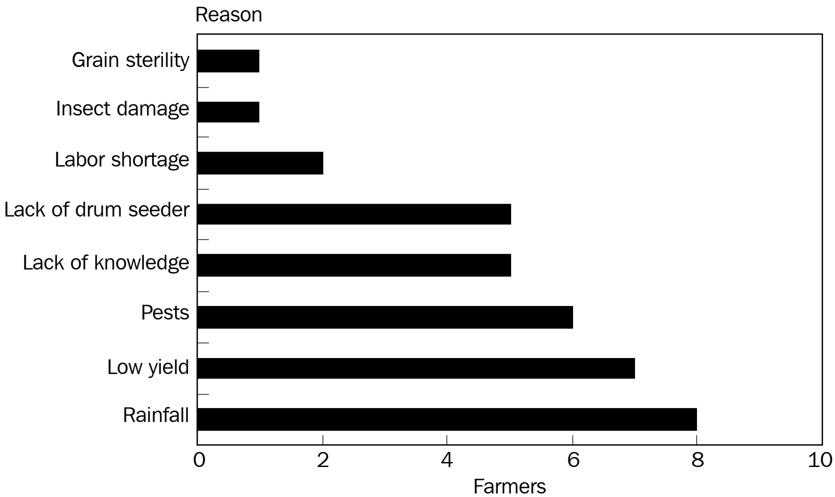

Fig. 2. Reasons for OFT farmers not trying DSR in own fields, T. aman, 2005.

Adoption

Figure 1 shows the adoption of DSR and herbicides among the OFT farmers sampled in the 2005 evaluation. Since 2000, 12 OFT farmers (60%) had adopted herbicides for T. aman. In contrast, only four (20%) of the same farmers had tried DSR on their own fields outside the trial plot. Farmers reported unpredictable rainfall that delayed dry direct seeding, lower yields, and greater damage from pests as the main reasons why they had not tested DSR in their own fields (Fig. 2). However, 10 of the 15 OFT farmers (67%) also reported that they had not tried DSR because of a lack of knowledge and access to a drum seeder.

Discussion

Socioeconomic research in the High Barind Tract revealed a clear economic rationale for DSR on the basis of three pieces of evidence:

- Late weeding of rice is the result of labor and cash constraints that prevent farmers from weeding on time, and force them to weed once rather than twice. Herbicide allows better weed management, particularly on large farms where weeding is delayed by a shortage of labor.
- DSR is more profitable than TPR because yields are identical but unit costs are lower. Both the economic and farmer evaluations gave the same message. Farmer evaluation ranked labor savings for seedbed preparation and transplanting among the top advantages of DSR.
- DSR was seen to allow earlier sowing of rabi crops. Farmers ranked this as the single most important advantage of DSR.

Adoption of DSR would therefore have substantial economic benefits in the High Barind Tract. Since yields remain the same as with TPR, DSR will have no direct impact on the productivity of land, though it may increase this indirectly by expanding the area that can be planted to rabi crops. The direct impact of technical change will be on the productivity of labor because DSR is a labor-saving technology.

The welfare implications of DSR adoption deserve careful consideration. Estimates based on data from OFTs suggest that DSR reduces labor requirements for crop establishment by 25–30 days ha^{-1}, while herbicides reduce labor for manual weeding by about 23 days ha^{-1}. Total labor requirements for DSR with a drum seeder fall by 36% over TPR without herbicide and 27% over TPR with herbicide. The impact on employment will be felt mainly by landless labor households, most which are Adivasis. Adivasi women will be particularly affected since they supply most of the hired labor for transplanting and for weeding in the High Barind Tract, whereas men supply labor for uprooting seedlings. The social cost of DSR can be reduced if labor is compensated by alternative employment. This is not a problem for the rural economy as a whole because nonfarm employment is growing rapidly. If nonfarm employment is not available locally, however, DSR will reduce employment for women, who are less mobile than men. Alternatively, employment could be created in agriculture if employers preferred to employ local rather than migrant labor, or if there were an increase in the labor required for rabi crops. Chickpea, for example, would provide an additional 31 days ha^{-1} of employment (Subbarao et al 2001). Hence, if DSR-rabi replaced TPR + herbicide followed by fallow there would be no net loss of employment.

Although DSR has the potential to raise agricultural productivity, adoption of this technology has so far been limited. Farmer evaluations gave several clues to the reasons for slow adoption.

On the supply side, technology for direct seeding has only recently become available. Until 2003, DSR in OFTs was sown by dibbling. This technique was so labor-intensive that it nullified potential cost-savings from DSR (Orr et al 2004). Neither the lithao, introduced in 2004, nor the drum seeder, introduced in 2005, is yet available commercially. Other OFT farmers had no access to herbicide sprayers. Had this equipment been available, some farmers who evaluated OFTs in 2005 reported that they would have tried DSR in their own fields. But even if this technology had been available, farmers would still have faced practical problems in implementation. Farmers who evaluated DSR identified numerous disadvantages. Practical problems were also amplified by socioeconomic research on farmer decision-making for DSR, which is not reported here (Orr et al 2005). On the demand side, three problems stand out:

- Dry-seeded DSR was problematic because of erratic premonsoon rainfall. Without presowing irrigation, this makes tillage for dry-seeded DSR unpredictable. With too little rain, tillage is delayed because the soil is too dry for plowing. With too much rain, tillage is delayed while farmers wait for the soil to dry out. If premonsoon showers are inadequate for dry-plowing, farmers may run out of time and opt for wet-seeded DSR when the full monsoon rains arrive. Similarly, rainfall dictated the time of application for preemergence herbicide that required specific soil conditions. This meant either waiting for rain to make the soil sufficiently moist or draining the field to make it sufficiently dry. Waiting for the right conditions could take time. If the wait is prolonged, weeds might start to appear that could not be controlled by preemergence herbicides.
- Early maturity for rice was a disadvantage if it increased yield losses from insects and pests. In the Barind Tract, OFTs initially combined DSR with short-duration varieties such as BR39. This made the crop more vulnerable to pests. In addition, early maturity incurred a yield penalty that reduced the total supply of rice for food-insecure households. Since rice is the staple food crop, any yield penalty discouraged DSR adoption. Subsequently, OFTs used DSR in combination with Swarna, a long-duration variety. This has reduced the risk of crop loss from pests but also reduced the window between rice harvesting and sowing rabi crops. Provided that Swarna was direct-seeded 30 days before TPR, however, it could be harvested 10 days earlier.
- The risk of lower yields with DSR is a powerful disincentive for sharecroppers. Where tenants pay owners with a share of the crop, any reduction in yield will be passed on to the landlord. OFT farmers reported that fear of eviction was an important reason for not experimenting with DSR. Tenants who pay a fixed rent may be more willing to experiment. But although the share of the rented area that pays fixed rents has grown, this expansion has been largely for irrigated rice. Share-contracts continue to dominate in the T. aman season when production is more risky. In a drought-prone environment such as the High Barind Tract, this system is unlikely to change in the near future.

In sum, farmers must overcome several obstacles if dry-seeded DSR is to be adopted on a large scale. Prospects for wet-seeded DSR seem to be brighter since this can be sown on saturated soil and the drum seeder is less laborious than sowing with a *lithao* and then line-seeding.

Conclusions

This evaluation of DSR in the High Barind Tract has given mixed results. On the credit side, DSR will improve farmers' weed management, particularly the problem of late and less frequent weeding caused by shortages of cash and labor. DSR is also more profitable than TPR and gives farmers a means of cutting costs without sacrificing yield. Finally, the earlier harvest of DSR may allow farmers to expand the area planted to rabi crops.

On the debit side, experience with OFTs has revealed practical problems with DSR in a drought-prone ecosystem. Supply-side problems have been overcome as researchers have learned more about the technology, but wider access to herbicides, *lithaos*, and drum seeders remains a precondition for DSR adoption. On the demand side, farmers have been slow to adopt DSR because of erratic premonsoon rains that prevent dry seeding, pest damage to early-maturing rice, and (among sharecroppers) the risk of lower yields. Wet seeding with long-duration varieties offers a way forward.

Box 1. Farmers' comments on DSR

Positive comments

"Direct seeding is useful in areas where there is drought or there is no certainty of rain. If rain comes after you've direct-seeded, you will get a good yield. It's a good strategy for a drought year." Md. Salauddin, Choygati village

"I've had good results with DSR for two years now and will try it on some of my own land next year. It's done better than transplanting. Earlier rice gets a higher price in the market and allows me to plant rabi crops earlier." Mujibur Rahman, Manikora village

"My landlord is my father-in-law. He lives in Sibganj about 30 km away and visits every two weeks. He has seen direct-seeded rice and thinks it's good. He won't object if I direct-seed." Abdullah, Adha village

"Initially, other farmers told me not to direct-seed. But I'm a farmer and I wanted to learn what is happening here, so I decided to cultivate. Now I want to try it on my own land." Abdul Jabbar, Barindra village

"The germination on my rice seedbed was poor and I didn't have enough seedlings. Direct seeding is good because it saves costs of seedbed preparation and I can plant without seedlings. I'll try direct seeding and Ronstar on 0.2 ha next year." Abdul Jabbar, Barindra village

Negative comments

"DSR is a problem because, when the land is dry, you cannot make the bunds properly. On sloping land, water goes through the cracks, so you lose water. It's better on level land." Md. Salauddin, Choygati village

"I know direct seeding from aus—it gives more weeds and you need more labor. You can have good management of direct-seeded rice on a small area, but not on a big area. It's not practiced here. I'll follow other farmers in the village." Golam Quibria, Lokipur village

"If I direct-seed rice instead of transplanting, others may tell my landlord that I don't have enough labor to cultivate properly, and he won't renew my lease." Golam Quibria, Lokipur village

Source: Farmer evaluation, T. *aman* season, 2003 (Orr et al 2004).

Box 2. Farmers' comments on rice varieties

"Swarna has a good stand and yields even in a drought year. I planted 0.5 ha of Swarna and stopped planting BRRI varieties. I'm a sharecropper and have to maximize the yield I give my landlord or he won't renew my lease." Ramzan Ali, Mullahpara village

BR39 is a good variety but it matures early and was damaged by rice-bug and lodged because it was sown early. It's better to transplant it later and after Parija in the aus season." Saiful Islam, Jumarpara village

"If you plant BR32 early in the aman season, it lodges. But if you grow it on irrigated land after Parija in the aus season, it doesn't lodge and the yield is good. If grown as a single crop, it's better to grow BR32 on lowland." Aynul Haq, Parbatipur village

"BR31 gave a good yield and didn't need insecticide. Swarna suffered from sheath blight and needed insecticide." Abdul Jabbar, Manikora village

"BR39 was attacked by rice bug because it tastes sweet and flowers early. It's better to plant BR39 later. It's better to transplant between 20 and 25 July so that flowering is similar to Swarna. Chickpea will be planted later but you will avoid damage from rice bug." Abdul Jabbar, Manikora village

"BR39 matures early and was damaged by rats and by goats. I can't get compensation for damage by goats because I want to avoid quarreling." Asraful, Chora Somashpur village

"BR39 is a sweet rice and rats like it. I applied insecticide but could not control them." Abdullah, Adha village

"BR39 isn't suitable for the aman season. Tillering is less because of high water level in the rains, and early maturity leads to rat damage. You get the same problem with rats if you plant Swarna early." Abdul Bari, Adha village

Source: Farmer evaluation, T. *aman*, 2003 (Orr et al 2004).

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Notes

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Long-term sustainability in weed management for direct seeding of rainfed rice

A.M. Mortimer, M.A. Mazid, and C.R. Riches

Successful weed management for direct-seeded rice depends on herbicide use to protect crop yields from weed competition. In irrigated cropping environments, this has a tendency to lead to progressive changes in the weed flora toward intransigent competitive rice weeds. A four-year comparative study of direct seeding and transplanting in the Barind indicated that the weed flora was responsive to an alteration in crop establishment method but that the composition of the target weed community under all methods had significant similarity. This is argued to be a consequence of seasonal variation in rainfall and flooding regimes. The implications for developing sustainable weed management practices with the use of early postemergence herbicides are discussed.

Direct seeding of rice (DSR) is well recognized as a "knowledge-intensive" technology (Rao et al 2007) and its adoption in Asia is commonly argued to be driven by a shortage of agricultural labor or water or both (Pandey and Velasco 2002). Successful rice cropping by DSR (whether by dry or wet seeding) is critically dependent on water management early in the life of the crop and also on prohibition of weed competition, at least until canopy closure. For wet seeding, this places reliance on timely flooding of rice seedlings established from broadcast or row-sown seed on an anaerobic puddled soil surface and the use of selective herbicides and attendant flooding regimes. Preplant tillage operations may contribute to reducing the size of the emerging weed community depending on the frequency and timing of rotovation (Azmi and Mortimer 1999). Similar precision is needed for dry-seeded rice, in which typically drill-seeded rice is sown in moist aerobic soil that is subsequently flooded and selective postemergence herbicides and manual weeding are applied (Mortimer et al 1997). Against the background of escalating costs, the switch from transplanting rice (TPR) to DSR is most easily managed in irrigated lowland where irrigation and drainage infrastructure are present and herbicide use is an established practice.

The northwest Barind in Bangladesh represents a highly variable cropping environment (Riches et al, this volume) in which farmers manage risk of crop failure in a diversity of ways—for instance, land tenure across a toposequence, cropping intensity and choice of a *rabi* crop in relation to the toposequence, and decision making in relation to weeding practices (Fujisaka et al 1993, Orr et al, this volume). Mazid et al (2006) reported that both wet and dry DSR in the Barind resulted in rice yields (seasonally dependent and ranging from 2 to 4 t ha^{-1}) that were similar to, or higher than, those with conventional transplanting (TPR) and advanced rice harvest by 7–10 days. Earlier harvest reduced the risk of terminal drought in rice at grain filling and increased the opportunity for establishing a high-value follow-on rabi crop on residual soil moisture in the dry season. Although DSR reduced the labor requirement at crop establishment, yield protection from weed competition by herbicide use was essential, which moreover further reduced rice production costs. However, the choice of direct-seeding method, or indeed transplanting, is dependent on monsoonal rainfall patterns. Saleh and Bhuiyan (1995) reported that, historically, TPR in the High Barind Tract is delayed every other year by 2 weeks and every 10 years by 1 month. Hence, dry-seeded DSR is favorable in "normal" years but early intense rainfall prior to the normal onset of monsoonal rain occurs once on average every three years (Brammer 1997), favoring wet seeding or TPR.

From a biophysical cropping perspective, on-farm adoption of direct-seeding rice practices therefore depends, not least, on detailed understanding of (1) soil type and land form as it affects water retention and drainage for rice cropping, (2) soil moisture availability for rabi cropping, (3) fertilizer management for both crops since Barind soils are typically nutrient-poor (Wade at al 1999), and (4) the use of flexible options of crop establishment (DSR and TPR), which require responsive modes of action as monsoonal rains develop for the rice crop in the Barind.

Minimizing the vulnerability of DSR to weed competition is essential particularly as interspecific selection in the weed community toward more competitive weed species, particularly grasses, is well known with the switch from TPR to DSR (Rao et al 2007). In the case of rainfed rice agriculture, the rate and trajectory of change in weed composition may vary for several reasons. Seasonal variation in rainfall and flooding both during crop establishment and early growth selectively influences weed recruitment (seed germination and weed seedling survival; Hill et al 2001), whereas early drought may reduce not only rice yield but also weed seed production. Changes in crop fertilizer regimes may influence relative weed species abundance in the long term by altering competitive interactions within the weed-crop community. The timing, and frequency, of subsequent rabi cropping may also have a potential impact on weed communities in both rabi and *kharif* crops. Tillage and land preparation associated with rabi crops may influence the return of dispersed rice weed seeds to the soil seed bank and also their dormancy status (Singh et al 2001, 2003). In consequence, the potential for variation in the weed flora both year to year and location to location can be, and often is, considerable, as observed earlier (e.g., Moody 1996). Understanding the relative magnitude of these ecological processes and their interactions is central to developing sustainable weed management practices for rainfed lowland rice production particularly where weed management practices cannot rely on the presence of standing water or timely manual weed management. Considerable yield losses due to the presence of competitive weeds occur in farmers' fields under these circumstances (Mazid et al 2001).

This paper explores the role of some of these ecological processes in influencing the structure of the weed community of rainfed rice and considers the implications for the development of weed control strategies. Although TPR and hand weeding have traditionally met the goal of minimizing weed presence, the use of early postemergence herbicides in DSR rarely achieves total weed control. Staggered weed emergence, variation in the length of the life cycle of weed species that persist after postemergence chemical control, and spatial escapes contribute to the need for further weed control, which is often manual. Identifying the factors determining the composition and size of this weed flora in relation to crop and weed management is important in the choice and cost of late postemergence weed control practices. This paper draws on observations and data analysis from a long-term cropping trial started in 1999 in the northwest Barind (Rajshahi District).

Materials and methods

Field experiment

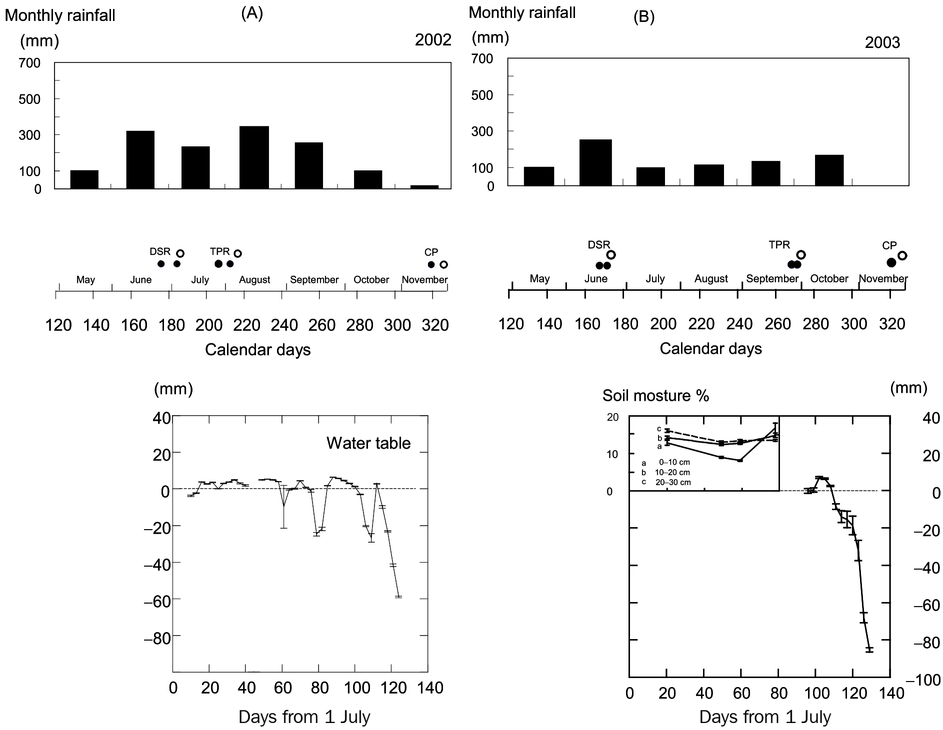
As described elsewhere (Mazid et al 2006; this volume), experimental comparison of rice establishment methods on rice yields and weed responses was made in successive years from 2001 to 2004. These methods were (1) transplanted rice—soil puddled prior to transplanting and plots hand-weeded twice at 30 and 45 days after transplanting (DAT); (2) direct-seeded rice (DSRm)—soil plowed prior to dry seeding (2001 and 2004) or plowed and puddled before direct seeding of pregerminated seed (2002 and 2003) in rows by hand with hand weeding at 21, 33, and 45 days after sowing; and (3) direct-seeded rice with chemical weed control (DSRh)—as above but with oxadiazon (375 g a.i. ha^{-1}) applied 2–4 days after seeding with one hand weeding at 33 days after sowing (DAS). With failure in development of the monsoon in 2003, transplanting was delayed substantially (Fig. 1) until September and the crop was established only for experimental purposes. Data from this experiment are discussed only for the 2002 and 2004 seasons.

Water regimes

Measurements of the water table began in the field experiment in relation to intensity of the onset of the monsoon with the use of fixed pizometers that extended 20 mm above ground. No standing water was observed prior to the first recorded measurement in each season.

Soil nutrient analysis

Four nutrient regimes were applied in factorial combination with other treatments in the field experiment. These were (kg ha^{-1}) (1) single superphosphate, 40 P + 40 K; (2) compound, 60 N + 40 P + 40 K; (3) farmyard manure (FYM) + inorganic fertilizer totaling 60 N + 50 P + 50 K; and (4) diammonium phosphate (18% N) + Guti slow-release urea (45% N) totaling 43 N + 40 P + 40 K. At the conclusion of the experiment, bulk soil samples were taken from individual plots to a depth of 20 cm and soil nutrient analysis was completed for total organic matter (combustion), potassium



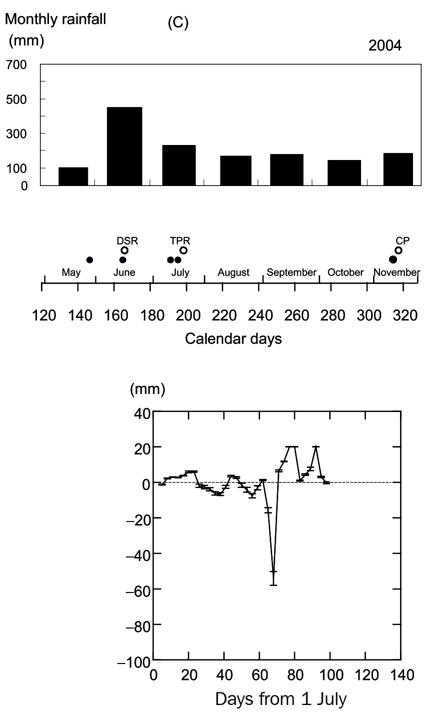


Fig. 1. Rainfall patterns, cropping calendar, and standing water status (mean ± S.E.) measured by pizometer in three successive cropping seasons. All data are aligned to a common time scale. In 2002 (A) and 2003 (B), wet seeding was used for sowing. In 2004 (C), rice was dry-seeded. Solid circles indicate dates of land preparation and open circles dates of sowing. DSR = direct-seeded rice, TPR = transplanted rice, CP = chickpea. In 2003, failure in development of the monsoon led to substantial delay in transplanting. % soil moisture for three soil depths is given after establishment of DSR.

(Olsen method, atomic absorption), total N (Kjeldahl), and phosphorus, sulfur, boron, and zinc (spectrophotometrically following acid digestion).

Soil seed banks

Three replicate soil samples (each 1,000 cm^3) were taken from individual plots on each of two occasions, after rice cropping in 2000 and 2002. Soil was then dried and samples pooled according to plot treatment with thorough mixing. Soil from the 2000 field sampling was stored until 2003. Samples (1 kg) of mixed soil for each sample year were then spread according to plot treatments in shallow trays that were watered to either permanently maintain saturated or aerobic conditions. Emerging seedlings were identified by species, counted, and removed. Soil was then stirred to promote a second and third flush. Data were pooled at the plot level to provide an overall estimate of the size of the seed bank for each recorded species.

Results and discussion

The weed flora in the study region was typically diverse, including grass, sedge, and broadleaf species (Table 1). These included ubiquitous major weeds of rice such as *Cyperus rotundus*, *C. iria*, *C. diffusa*, *Ischaemum rugosum*, *Echinochloa colona*, *E. crus-galli*, and *Monochoria vaginalis*.

Figure 1 illustrates the variation in water regimes and the presence of ponded water during three rice cropping seasons. In all years, DSR was established in advance of TPR with the onset of the monsoon and in 2002 and 2003 soil conditions precluded the drilling of rice and wet-seeded rice was sown, whereas in 2004 rice was drill-seeded. Ponded water was absent in the first 14 days after rice sowing and in transplanted plots standing water depths were shallow and temporally variable. There were no large differences in the weed flora between transplanted and direct-seeded plots (unweeded at 45 DAT/DAS when the principal phase of weed recruitment had occurred), although individual species differed in relative abundance and some species were absent in some instances. More noticeable differences in the composition of the weed flora between TPR and DSR would be expected if standing water had been deep and persistent (≥10 cm). However, species that required prolonged saturated soil conditions to promote germination and establishment (for example, *M. vaginalis*) were more abundant under TPR than under wet-seeded rice (WSR) in 2002 and 2003. Log rank abundance curves (Fig. 2) were either linear or log normal, S-shaped Ulrich and Ollik (2005), statistical analysis not shown). The presence of a log normal distribution (for example, in WSR and TPR in 2003) is suggestive of high habitat heterogeneity, whereas the occurrence of an upper tail indicates species that are disproportionately abundant. Among the dominant sedges, *Fimbristylis miliacea* was replaced by *F. dichotoma* in the relatively drier conditions of 2003 compared with 2002 and 2004 and *Cyperus difformis* exhibited greater abundance than *C. iria* under wet rather than dry seeding. These observations suggest subtleties in the germination ecology of these sedges. *Cynodon dactylon* was recorded in the weed flora in all three seasons under both crop establishment methods. The most diverse weed flora was recorded in 2004

Table 1. Weed species recorded at the study location. Species were identified by observation in the experimental area and by scouting in nearby farmers' fields.

Name	Species code
Aeschynomene indica L.	Aes_ind
Alternanthera sessilis (L.) R. Br. ex DC.	Alt_ses
Ammannia baccifera L.	Amm_bac
Commelina diffusa Burm. f.	Com_dif
Cyanotis axillaris (L.) D. Don ex Sweet	Cya_axi
Cynodon dactylon (L.) Pers.	Cyn_dac
Cyperus difformis L.	Cyp_dif
Cyperus iria L.	Cyp_iri
Cyperus rotundus L.	Cyp_rot
Cyperus haspan L.	Cyp_ten
Dopatrium junceum (Roxb.) Buch. Ham. ex Benth.	Dop_jun
Echinochloa colona (L.) Link	Ech_col
Echinochloa crus-galli (L.) P. Beauv.	Ech_cru
Eclipta prostrata (L.) L.	Ecl_pro
Eriocaulon cinereum R. Br.	Eri_cin
Fimbristylis miliacea (L.) Vahl	Fim_mil
Fimbristylis dichotoma (L.) Vahl	Fim_dic
Hedyotis corymbosa (L.) Lam.	Hey_cor
Hydrolea zeylanica (L.) Vahl	Hyd_zey
Ischaemum rugosum Salisb.	Isc_rug
Lindernia ciliata (Colsm.) Pennell	Lin_cil
Lindernia species	Lin_spp
Ludwigia adscendens (L.) Hara	Lud_ads
Ludwigia group	Lud_spp
Ludwigia hyssopifolia (G. Don) Exell	Lud_hys
Marsilea minuta L.	Mar_min
Monochoria vaginalis (Burm. f.) Presl C. ex Kunth	Mon_vag
Paspalum distichum L.	Pas_dis
Paspalum vaginatum Sw.	Pas_vag
Rotala species	Rot_spp
Sagittaria guayanensis Kunth	Sag_guy
Scirpus supinus L.	Sci_sup
Sphaeranthus indicus L.	Sph_ind
Sphenoclea zeylanica Gaertner	Sph_zey

in dry-seeded plots after three previous seasons of direct seeding, with *E. colona*, *E. crus-galli*, *I. rugosum*, and *C. rotundus* being present.

Figure 2 shows the influence of weeding by manual or chemical means at 21 DAS/DAT on the weed flora present 12 days later in 2004. Total weed biomass in plots was reduced by up to two orders of magnitude in comparison with biomass at 45 DAS/DAT in unweeded plots but neither method of weed control had achieved weed-free plots. More weed biomass was present in DSR plots than in TPR plots. In particular, the use of oxadiazon resulted in the dominance of *Cynodon dactylon* and *Paspalum distichum*.

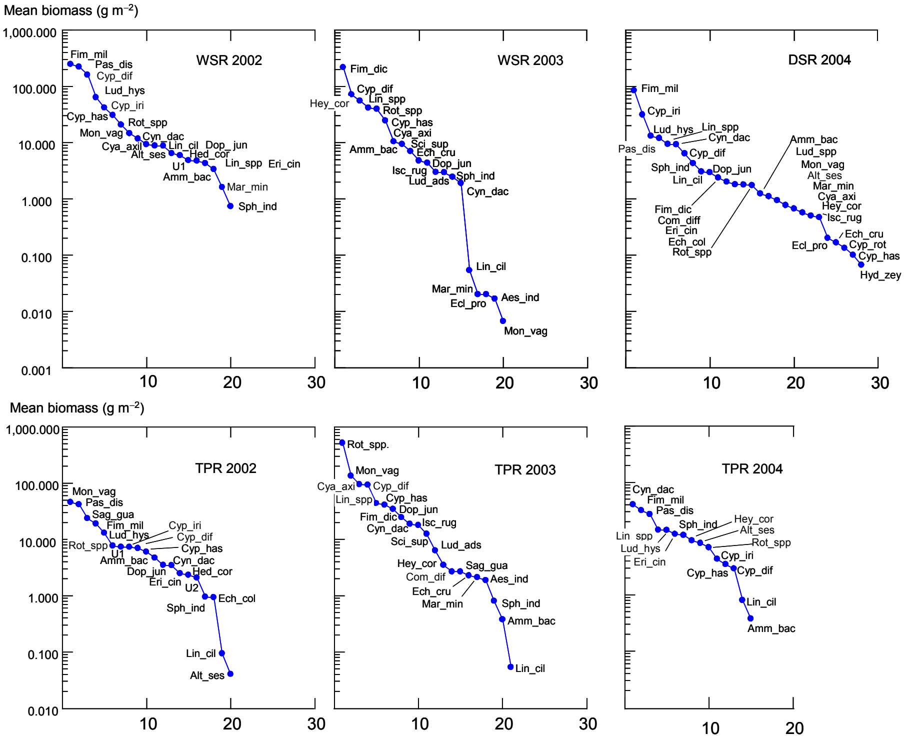


Fig. 2. Log rank abundance of weed species present in unweeded plots. Species are ordered in relation to mean biomass at 45 DAS/DAT. Species names are coded (see Table 1); U1 and U2 refer to species that were unidentified.

Observations on the composition of the soil seed bank suggest that the higher abundance of *C. dactylon* over other species may directly relate to buried seed longevity and the consequent size of the buried seed population. Comparison of the seedling weed flora emerging from soil samples taken in 2000 with those taken in 2002 and examined together in 2003 suggested that the seed of many species lost viability when stored in dried soil for 2 years. However, of the seven recorded species emerging from stored soil, *C. dactylon* was the most abundant (Table 2). In contrast, 26 species were recorded when seedling emergence trials started directly after sampling. Although such storage in dry soil represents an artificial treatment, the differential responses among weed species reflects the ability of some to persist in prolonged dry spells and potentially high soil temperatures. A further corollary of this observation is that the seed longevity of some weed species of rainfed rice in the soil may be relatively short, where rice crops are separated by a prolonged dry period. Autecological comparisons of species longevity in the buried seed bank and the flux among seed dormancy states will contribute to understanding the population dynamics of individual species and

Table 2. Species recorded from the soil seed bank sampled at two different occasions. Soil samples in 2000 were air-dried and stored for two years. Both sets of samples were then used for seedling emergence trials in 2003. Species are listed in order of decreasing abundance of total counts from submerged and aerobic emergence trials. See text for details.

Soil sampled in 2000	Soil sampled in 2002
Cynodon dactylon	*Cynodon dactylon*
Cyperus difformis	*Fimbristylis miliacea*
Dopatrium junceum	*Eclipta prostrata*
Cyperus haspan	*Ludwigia adscendens*
Lindernia species	*Lindernia* species
Cyanotis axillaris	*Cyperus difformis*
Echinochloa crus-galli	*Hedyotis corymbosa*
	Lindernia ciliata
	Aeschynomene indica
	Sphaeranthus indicus
	Monochoria vaginalis
	Scirpus supinus
	Ludwigia group
	Cyperus iria
	Ammannia baccifera
	Dopatrium junceum
	Cyperus rotundus
	Ischaemum rugosum
	Echinochloa colona
	Rotala species
	Cyanotis axillaris
	Paspalum distichum
	Commelina diffusa
	Eriocaulon cinereum
	Alternanthera sessilis
	Marsilea minuta

argues for more detailed experimental studies of buried-seed longevity under managed soil-water regimes.

Significant grain yield responses were recorded in response to fertilizer regimes, the most noticeable occurring under DSR with herbicide use (Mazid at al 2003). Analysis of residual soil nutrients showed statistically significant differences in soil phosphate (Table 3) in relation to fertilizer regimes and there was higher residual sulfur as a result of the use of the herbicide in DSR under the single superphosphate (PK) treatment alone (Table 4). There were, however, no directional trends over time. It is difficult to ascribe eco-physiological relevance to these changes in soil nutrients to both rice and individual weed species although the presence of N in three of the regimes was positively correlated with higher plant biomass and offers a plausible explanation for lower P concentrations under fertilizer regimes other than PK.

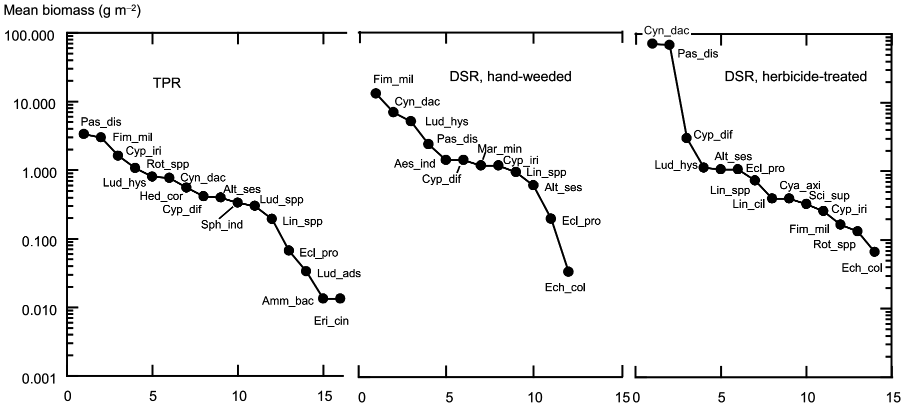


Fig. 3. Log rank abundance of weed species present at 33 DAT/DAS after earlier weeding, in 2004. TPR = hand-weeded; DSR = either hand-weeded or after herbicide application.

Table 3. The effect of fertilizer regime on mean residual soil phosphate (microgram/gram soil).

Establishment method	Fertilizer			
	PK	½ (NPK + FYM)	NPK	DAP + K + Guti
	24.2	20.5	19.9	22.3
Standard error of differences: 1.34				

Table 4. The effect of fertilizer regime on mean residual soil sulfur (μg g–1/soil) in relation to establishment method.

Establishment method	Fertilizer			
	PK	½ (NPK + FYM)	NPK	DAP + K + Guti
TPR	14.2	13.1	14.3	11.0
DSR	10.9	12.0	13.4	15.1
DSRh	16.8	11.9	13.2	14.2
Standard error of differences: 2.21				

Multivariate analysis (PCA) of weed seed abundance in the soil seed bank with cropping practice (coded 1, TPR; 2, DSRm; 3, DSRh) and fertilizer regimes (arbitrarily coded in relation to added total nutrient, kg ha^{-1}) indicated no statistically strong relationships ($P \leq 0.09$). However, the relative abundance of *Cyperus rotundus* was positively associated with the addition of nitrogenous fertilizers and *Ischaemum*

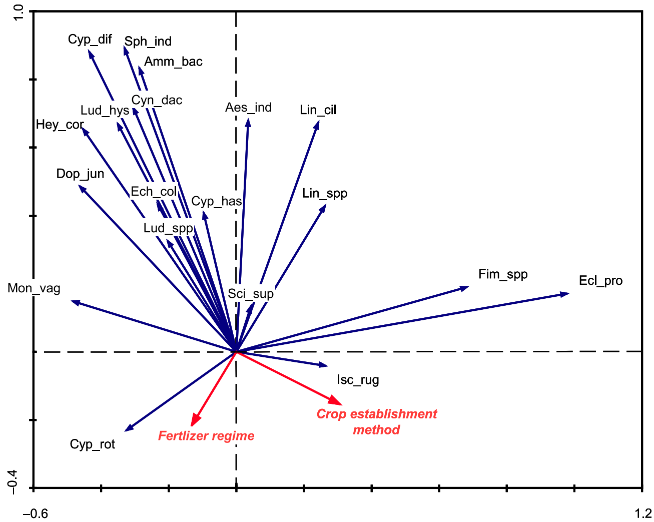


Fig. 4. Species-treatment biplot of the relationships between weed species abundance (emerged seedling count in 2004) in the soil seed bank and treatments from principal component analysis. Species codes are given in Table 1. Rare species (counts < 2) omitted. Fertilizer regime and crop establishment method were given linear scores. For establishment, TPR = 1, DSRm = 2, DSRh = 3; fertilizer regimes coded in relation to total added nutrient, kg ha^{-1}. Axis 1 (horizontal) correlations with fertilizer regime and crop establishment method were –0.13 and 0.31 and correspondingly for axis 2 (vertical), –22 and –0.15. The direction indicated by the vector for crop establishment method indicates DSR; thus, *Monochoria vaginalis* is associated with TPR and *Ischaemum rugosum* associated with DSR.

rugosum and, to a lesser extent, *Fimbrystilis* spp. and *Eclipta prostrata*, with direct-seeded plots. Close species associations in the biplot may be a consequence of the averaging effect of yearly variation in the abundance of individual weed species due in part to factors influencing seedling recruitment, as discussed above, and common occurrence in both TPR and DSR plots.

The implications for sustainable weed management in DSR in the Barind

Where farmers have limited control over field water regimes, as on shallow sloping land affording a toposequence, a diverse weed flora will result.

Site position on the toposequence and soil nutrient status (Pane et al 2000), coupled with patterns of seasonal variation in rainfall, have a marked effect on the recruitment of individual weed species and hence the composition of the weed flora competing with the emerging crop.

Attempting to simply attribute this composition to a particular method of crop establishment, for example, TPR or DSR, however, lacks precision and relevance (as attested by Fig. 2). Diversity in the weed flora results from differential patterns of flooding and drainage that selectively determine seed germination, seedling emergence, and survival. However, on poorly leveled fields with rain-dependent flooding to very shallow depths, heterogeneous soil surfaces will offer different depths of and duration of flooding, which will enhance diversity and potentially lead to similarity in the flora of transplanted and direct-seeded rice.

Interspecific selection of known strongly competitive weeds of rice such as *Ischaemum rugosum* and *Echinochloa* species is likely to occur with the serial use of direct seeding. Increased use of fertilizer to improve rice yield may influence this process, although further scientific evidence is needed.

The use of early postemergence herbicides that have broad-spectrum activity may, however, lead to the subsequent dominance of rhizomatous or stoloniferous weeds (e.g., *Cynodon dactylon*, *Paspalum distichum*), which require close attention in later manual weeding

Although it is clear that the introduction of DSR into the Barind has significant yield and economic advantages for farmers, sustainability of the production system will depend upon an awareness of the responsiveness of the rice weed flora to both crop establishment and management practices. Strategies of weed management must anticipate a change in target weed species against the background of high diversity and seasonal variation in the weed flora.

Experience elsewhere suggests that, when diversification of herbicide mode of action occurs in the market place, there are consequential responses in target weed species. This will continue to place reliance on manual weeding.

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Acknowledgments: This work was partially funded by the UK Department for International Development (Crop Protection Programme Project R8234). However, the views expressed are not necessarily those of DFID. The Consortium for Unfavorable Rice Environments, coordinated by the International Rice Research Institute, has also provided support. We are grateful for discussion with J.D. Janiya, D.E. Johnson, B. Khamarker, R. Lubigan, and L.J. Wade. Soil nutrient analyses were conducted by the Soil Resource Development Institute, Regional Laboratory, Rajshahi, Bangladesh.

Bangladeshi experiences with a drum seeder for direct wet seeding of rice

M.M. Husain, M.A. Islam, and M. Rashid

A plastic drum seeder, introduced from Vietnam in 2003, has subsequently been evaluated extensively in research-station and on-farm trials in Bangladesh. Direct wet-seeded rice using a drum seeder is an emerging technology that could improve grain yield by 10–15%, reduce seed requirements substantially, and reduce labor dependency. This paper discusses the performance of direct wet seeding with a drum seeder, discusses farmers' perceptions of the technology, and identifies keys to using the seeder successfully.

Rice production systems in Bangladesh are influenced by technological advances and changing socioeconomic conditions. About 1% of the agricultural land is lost to nonagricultural activities annually. In addition, migration of the agricultural labor force to nonagricultural sectors in search of better employment opportunities is resulting in labor scarcity in rice cultivation, thus increasing production costs. Mechanization of rice cultivation is a solution to these problems.

In Bangladesh, rice is traditionally established by transplanting, which requires sufficient rainfall in the monsoon season or irrigation for the boro crop in the dry season and involves high labor costs for seedling production, uprooting, and planting. Labor scarcity can prevent farmers from transplanting at the optimum time, thus reducing yield. Transplanted rice experiences a transplanting shock that prolongs growth duration. Added problems are that late transplanted rice can be damaged by flood water, particularly in lowland areas during the boro season, whereas transplanted *aman* rice often experiences drought at grain filling when the monsoon ceases before plants mature.

Direct wet seeding is an alternative method of crop establishment (Coxhead 1984) that requires less water and labor. With this method, pregerminated rice seeds are broadcast on puddled soil (Can and Xuan 2002). This method reduces growth duration by about 8 days compared with conventional transplanted rice (Husain et al 2003) because direct-seeded rice can escape transplanting shock and injury (Sattar et al 1996). Ding et al (1999) reported that direct-seeded rice gave about 15% higher grain yield than transplanted rice in China. Under continuous standing water, direct wet-seeded rice yielded 3–17% higher than transplanted rice and increased water-use efficiency by 25–48% in the Philippines (Tabbal et al 2002). In Bangladesh, direct-seeded rice produced 2–12% more grain yield than transplanting (Husain et al 2003). Sattar and Khan (1994) reported that direct wet-seeded rice required about 20% less water than transplanted rice. Isvilanonda (2002) reported that direct-seeded rice reduced production costs by up to 6% and increased net returns by 37% in irrigated boro rice.

However, it is difficult to control weeds by traditional manual methods in direct-seeded rice established by broadcasting. Using a drum seeder allows plant establishment in lines and thus allows mechanical weeding using push weeders. Row seeding using a drum seeder was reported to have increased grain yield by 0.43 to 0.75 t ha^{-1} and farmers' income by an average of 7.5% and 28%, respectively, compared with broadcasting and transplanting (Bautista and Gagelonia 1994). The option of a drum seeder is quite new in Bangladesh, with the first work on this approach being reported by Husain et al in 2004. This paper gives an overview of the introduction and performance of direct wet-seeded rice using a drum seeder and its adoption status, and discusses the constraints to up-scaling this technology in Bangladesh.

Introduction of the drum seeder in Bangladesh

A Vietnamese version of a plastic drum seeder was first tested in Bangladesh during the 2003 aman season, under both on-station and on-farm conditions in Gazipur. It was shown that direct wet-seeded rice (DWSR) outyielded conventional transplanted rice (TPR) by 14% to 22% (Husain et al 2004). Maturity of DWSR decreased by about 10 days. An economic analysis showed that DWSR would enable farmers to earn an additional income of about Tk 6,000 over TPR. Being encouraged by these results, on-farm validation of the performance of DWSR was undertaken over a wide range of irrigated environments throughout Bangladesh during 2004 boro with the support of an IFAD-BRRI/IRRI project. In almost all cases, the performance of DWSR was quite impressive, with a consistent increase in yield (2–25%), a reduction in maturity period (7–15 days), and a decrease in production costs.

The Ministry of Agriculture, Government of Bangladesh, allocated Tk 10 million for the procurement of drum seeders. Following this, the Department of Agriculture Extension (DAE) conducted a large number of demonstrations of DWSR in collaboration with BRRI. Some 2,500 drum seeders were imported from Vietnam by the DAE to be used in a nationwide demonstration program during the boro and aman seasons of 2005. At the same time, efforts were made to manufacture drum seeders in-country and these are now manufactured and marketed by several companies.

Performance of drum-seeded rice

Farmers' field trials were conducted on DWSR using both recommended high-yielding varieties and local improved rice cultivars. Table 1 shows that, averaged over 30 farmers' fields on medium land and highland in Chuadanga District, DWSR achieved a yield of about 7.0 t ha^{-1}, some 12% higher than TPR during the boro season. On

Table 1. Grain yield and crop duration of direct wet-seeded rice (DWSR) and transplanted rice (TPR) during boro 2005 under medium highland of Chuadanga.

Variety	Grain yield (t ha^{-1})			Crop duration (days)		
	DWSR	TPR	Increase in DWSR (%)	DWSR	TPR	Decrease in DWSR
BR14	7.41	6.81	8	139	160	21
BR26	7.37	6.59	11	133	158	25
BRRI dhan28	6.88	5.62	22	136	159	23
BRRI dhan29	8.37	7.76	7	163	178	15
BR4828	5.93	–	–	127	–	–
IR64	6.59	–	–	139	–	–
IT	7.60	–	–	130	–	–
Miniket	6.79	–	–	131	–	–
Kargil	6.87	–	–	131	–	–
Mean	7.09	6.70	12			

Table 2. Grain yield and crop duration of direct wet-seeded rice (DWSR) and transplanted rice (TPR) during boro 2005 under lowland.

Variety	Grain yield (t ha^{-1})			Crop duration (days)		
	DWSR	TPR	Increase in DWSR (%)	DWSR	TPR	Decrease in DWSR
BRRI dhan29	8.65	6.89	25	157	178	21
BR4828	6.18	4.94	25	148	158	10
Miniket	7.73	6.92	11	130	140	10
Noyon Moni	7.19	–	–	122	–	–
Mean	7.43	6.25	18	–	–	–

lowland in Chuadanga, DWSR produced 7.4 t ha^{-1}, which was 18% higher than yields of transplanted rice (Table 2). During the aman season in 2005, DWSR (with 8 varieties) produced a mean grain yield of 4.0 t ha^{-1}, about 20% higher than that from transplanting (Table 3). The lower yields of both DWSR and TPR were due to a period of submergence following heavy rainfall.

During the boro season of 2005, direct wet-seeded rice using a drum seeder was demonstrated in many locations of Bangladesh in collaboration with the DAE. Table 4 shows that, averaged over 5 districts, short-duration variety BRRI dhan 28 produced a grain yield of about 6.0 ha^{-1} when sown with a drum seeder. This yield was about 15% higher than that of transplanted rice. DWSR with long-duration BRRI dhan 29 yielded about 6.6 t ha^{-1}. Again, this was about 10% higher than the yields of TPR (Table 5). In another experiment conducted at the BRRI research farm, DWSR with

Table 3. Grain yield and crop duration of DWSR on medium land during T. aman 2005 in Chuadanga.

Variety	Grain yield (t ha^{-1})			Crop duration (days)		
	DWSR	TPR	Increase in DWSR (%)	DWSR	TPR	Decrease in DWSR
BR11	4.04	3.84	5	126	137	11
BRRI dhan 26	5.69	3.59	58	120	125	5
BBRI dhan 33	3.44	2.86	20	109	117	8
BRRI dhan 39	4.34	3.22	34	108	121	13
BRRI dhan 41	3.59	3.29	9	114	118	4
BRRI dhan 44	2.99	2.69	7	112	122	10
Shwarna	2.94	2.99	0	129	141	12
Gutka	5.49	4.59	19	105	124	19
Total	3.64	3.59	–	123	139	16
Mean	4.06	3.38	20	–	–	–

Table 4. Grain yield and growth duration of BRRI dhan28 in DWSR and TPR during boro 2005 under on-farm conditions in different locations of Bangladesh.

Name of upazilla	Name of district	Grain yield (t ha^{-1})		% yield increase over TPR	Growth duration (days)		Decrease in growth duration (days)
		DWSR	TPR		DWSR	TPR	
Paba	Rajshahi	5.89	4.82	22.20	133	146	13
Manda	Naoga	5.75	4.60	25.00	126	155	29
Khetlal	Joypurhat	6.54	6.32	3.48	133	151	18
Sadar	Comilla	6.50	5.68	14.44	120	131	11
Sadar	Rangpur	5.60	4.90	14.29	138	146	8
Mean		6.06	5.26	15.88	130	146	16

BRRI dhan 29 and BRRI dhan 36 produced about 15% higher grain yield than TPR (Table 6). Growth duration of all the varieties was shortened by direct wet seeding irrespective of the growing season. However, growth duration was reduced by 1 to 4 weeks depending on the rice variety (Tables 1 to 5).

Grain yield in relation to yield components under direct wet seeding and transplanting

Direct wet seeding resulted in higher yields mainly by increasing the number of panicles per unit area (Tables 7 and 8). DWSR produced significantly more panicles per m^2 than TPR. It was found that DWSR at different seeding densities produced

Table 5. Grain yield and growth duration of BRRI dhan 29 in DWSR and TPR during boro 2005 under on-farm conditions in different locations of Bangladesh.

Name of upazilla	Name of district	Grain yield (t ha^{-1})		% yield increase over TPR	Growth duration (days)		Decrease in growth duration (days)
		DWSR	TPR		DWSR	TPR	
Manda	Noaga	6.38	6.36	0.31	141	165	24
Modhukhali	Faridpur	6.32	6.00	5.33	156	167	11
Sadar	Mymensingh	8.12	7.60	6.84	146	159	13
Sadar	Jamalpur	7.20	6.45	11.63	140	159	19
Aditmari	Lalmonirhat	6.50	5.67	14.64	154	163	9
Sadar	Bogra	6.05	5.78	4.67	155	161	6
Damurhuda	Chuadanga	8.00	7.50	6.67	160	171	11
Sadar	B. Baria	5.65	5.36	5.41	150	158	8
Nesarabad	Pirojpur	5.40	4.40	22.73	143	158	15
Sadar	Sunamgonj	5.60	5.04	11.11	143	151	8
Shujanagar	Pabna	7.00	6.50	7.69	151	157	6
Shujanagar	Pabna	7.00	6.31	10.94	150	156	6
Sadar	Satkhira	6.80	6.30	7.94	149	159	10
Sadar	Rangpur	6.92	5.40	28.15	156	165	9
Mean		6.64	6.05	10.29	150	161	11

Table 6. Effect of seeding dates on mean grain yield of direct wet-seeded rice during boro 2004.

Variety	Method	Yield (t ha^{-1})			Average yield (t ha^{-1})	Yield increase over TPR (%)
		8 Dec	18 Dec	28 Dec		
BRRI dhan 29	DWSR	7.60	7.33	6.50	7.13	18
	TPR	6.39	6.27	5.43	6.03	
BRRI dhan 36	DWSR	7.06	6.25	6.22	6.50	15
	TPR	5.45	5.78	5.64	5.62	
LSD at 5%	0.35					

30–50% more panicles than TPR (Tables 7 and 8). However, the number of grains per panicle decreased under DWSR (Tables 7 and 9). Because grain size in rice is usually a stable parameter, grain yield is determined by the total number of grains per unit area (Husain et al 2003), which is the product of the number of panicles per m^2 and the number of grains per panicle. Figure 1 shows that grain yield is correlated with the number of grains per unit area.

Table 7. Effect of drum seeding on yield components during T. aman 2004.

Variety	Method	Panicles m^{-2}	Grains $panicle^{-1}$	Panicles m^{-2} increase over TPR (%)	Grains $panicle^{-1}$ decrease over TPR (%)
BRRI	DWSR-thin	307	82	30	19
dhan31	DWSR-thick	342	78	44	23
	DWSR-both	355	70	50	31
	Transplanted	236	102	–	–
BRRI	DWSR-thin	404	90	28	16
dhan41	DWSR-thick	423	86	34	20
	DWSR-both	416	84	32	22
	Transplanted	314	108	–	–

Table 8. Effect of seeding dates on number of panicles m^{-2} of direct wet-seeded rice during boro 2004.

Variety	Method	Panicles m^{-2}			Average panicles m^{-2}	Increase in DWSR over TPR (%)
		8 Dec	18 Dec	28 Dec		
BRRI dhan 29	DWSR	537	518	502	519	58
	TPR	332	340	315	329	
BRRI dhan 36	DWSR	510	492	468	490	63
	TPR	300	302	298	300	

Table 9. Effect of seeding dates on grains $panicle^{-1}$ of direct wet-seeded rice during boro 2004.

Variety	Method	Grains $panicle^{-1}$			Average	Decrease in DWSR over TPR (%)
		8 Dec	18 Dec	28 Dec		
BRRI dhan 29	DWSR	72	76	71	73	32
	TPR	97	98	102	99	
BRRI dhan 36	DWSR	79	72	71	74	39
	TPR	96	108	102	102	

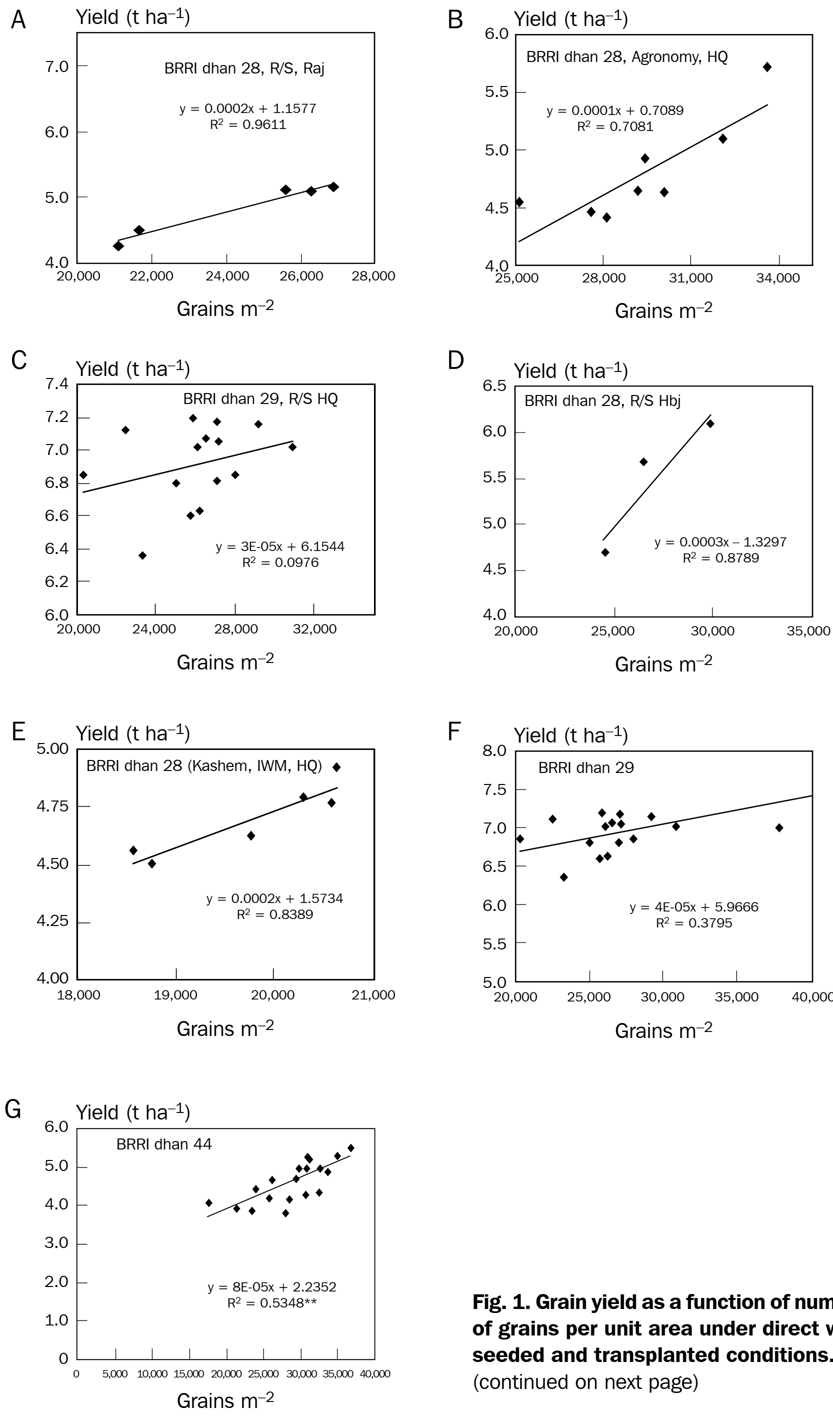

Fig. 1. Grain yield as a function of number of grains per unit area under direct wet-seeded and transplanted conditions. (continued on next page)

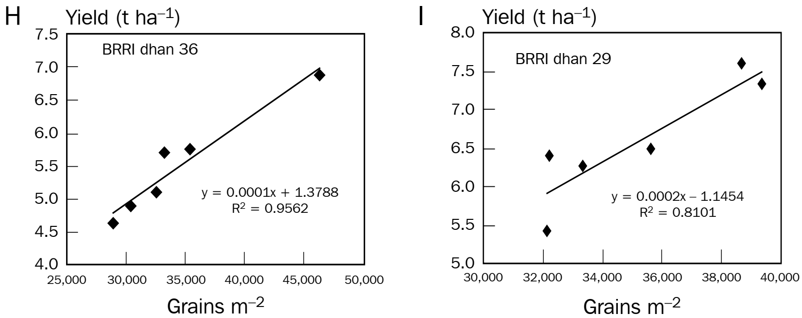

Fig. 1. Continued.

Table 10. Partial budget analysis for DWSR versus TPR method under single-cropped production environment during boro 2005 conducted for 50 farmers.

Item	Debit (Tk ha^{-1})	Item	Credit (Tk ha^{-1})
1. Cost of rice production under DWSR method	28,012	1. Return from rice production under DWSR method	55,605
2. Revenue forgone for not following TPR method	48,681	2. Cost saved for not practicing TPR method	29,875
3. Profit/loss	8,787		
Total	85,480		85,480

Socioeconomic aspects of direct wet-seeded rice

Experience from extensive field evaluations in Bangladeshi DWSR has demonstrated that rice established by a drum seeder has the advantage of giving significantly higher grain yield, but requires a reduced seed rate and lower labor requirement than transplanted rice. On the other hand, additional costs are involved in DWSR for better land leveling and weed control. Economic analysis was performed to assess the profitability of adopting DWSR compared with TPR. Adoption of DWSR will enable farmers to earn an additional income of about Tk 8,500 per ha over TPR in both the aman and boro seasons (Tables 10 and 11).

In addition to the economic analysis, farmers' perceptions on DWSR were also investigated. Most farmers agreed about the low cost, early maturity, and higher yields of DWSR (Table 12). However, the farmers were also able to identify higher weed infestation and unavailability of irrigation as the major constraints to the adoption of

Table 11. Partial budget analysis for DWSR versus TPR during aman season 2005 conducted for 30 farmers in Chuadanga.

Item	Debit (Tk ha^{-1})	Item	Credit (Tk ha^{-1})
1. Cost of rice production under DWSR	20,673	1. Return from rice production under DWSR	43,234
2. Revenue forgone for not following TPR	42,040	2. Costs saved for not growing TPR	27,865
3. Profit/loss	8,386		
Total	71,099		71,099

Table 12. Advantages and disadvantages of using a drum seeder for direct wet-seeded rice, boro 2005, as perceived by farmers.

Advantages and disadvantages		% of farms
Advantages	Cost savings	100
	Enhance maturity	83
	Promote higher yield	76
	Require less irrigation	3
	Low pest and disease infestation	3
	Easy for weeding by weeder	3
Disadvantages	High weed infestation	70
	Irrigation scheme does not start timely	40
	Need seeding before winter	10
	Need good land leveling	10
	Crop establishment in T. aman direct wet-seeded rice is difficult	100

this technology. In spite of these constraints, DWSR is being increasingly adopted by farmers. DWSR in the 2006 boro season covered about 3,000 ha (Fig. 2).

Constraints

The suitable sowing time for DWSR in boro is mid-November to mid-December. Seeding during the severe cold spell in late December may result in seedling mortality and eventually poor crop establishment. During the aman season, (monsoon) heavy rainfall may damage and disrupt plant establishment. However, if the crops can escape rainfall for about 24 hours after seeding, this is less of a problem.

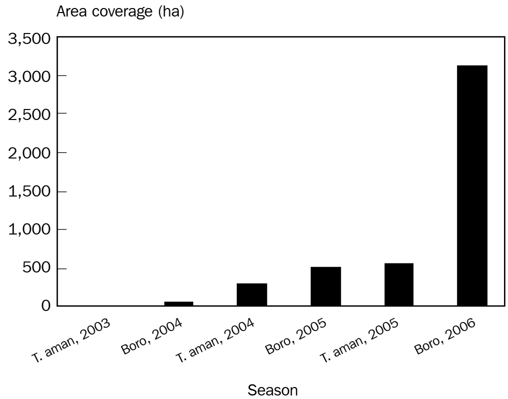

Fig. 2. Area coverage of direct wet-seeded rice in Bangladesh as reported by the Department of Agriculture Extension.

Keys to using DWSR successfully

Direct wet seeding of rice using a drum seeder is a knowledge-intensive technology. Success of the technology therefore largely depends on farmers being aware of some key components, which are considered below:

1. *Land preparation.* The land should be well prepared by plowing, with sufficient time prior to seeding to allow decomposition of weeds and stubble. Before seeding, the land should be leveled and any standing water should be drained from the field.
2. *Seed preparation.* Healthy seeds should be used for DWSR. To ensure uniform and adequate germination, seeds should be soaked in water for about 24 hours before incubating. The plumules should be approximately 3–5 mm long. Before sowing, sprouted seeds can be dried in shade for 1–2 hours to remove excess water.
3. *Water management.* Seed should be sown onto saturated soil. Subsequently, irrigation water will be needed after 4–5 days. The land should be soaked before any cracks are formed. Irrigation should then be applied as the seedlings grow and later 5–7 cm of standing water should be maintained.
4. *Weed management.* Weeds are perhaps the major problem in DWSR. For efficient control of weeds, an integrated approach should be adopted. This includes land selection and land preparation, quality seeds, manual weeding and mechanical weeding, and the use of herbicides. The BRRI push weeder is appropriate for use in rice established by a drum seeder. The use of herbicides may be necessary to keep DWSR weed-free.

Conclusions

Direct wet-seeded rice using a drum seeder is an emerging technology that could improve grain yield by 10–15%, reduce seed requirements substantially, and reduce labor dependency. In addition, reduction of growth duration by 1 to 3 weeks may aid in the timely establishment of subsequent crops. The adoption of DWSR technology is taking place fast. However, DWSR using a drum seeder is a knowledge-intensive technology and is likely to be disseminated slowly. Therefore, constraints to the dissemination of DWSR should be minimized.

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Notes

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Improved weed management for transplanted *aman* rice

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Rainfed transplanted rice grown in the monsoon *aman* season accounts for more than 50% of the total area planted to rice in Bangladesh. Because of rising input costs, including labor, farmers are searching for ways to maintain income, by either increasing yields or reducing costs or both. On-farm trials in the High Barind Tract indicated that one-third of the farmers would be able to gain 0.5 t ha^{-1} or more additional grain by undertaking more intensive or timelier weeding than is usual under current management practices. Higher yields were observed on-farm from a preemergence application of butachlor (1.25 kg a.i. ha^{-1}) compared with hand weeding twice. In Comilla District, trials of a range of weed management practices demonstrated that the yield advantage over the farmers' practice, either one or two hand weedings, was on average 355 ± 18 kg ha^{-1} for Rifit (pretilachlor), 281 ± 39 kg ha^{-1} for Machete (butachlor), and 210 ± 34 kg ha^{-1} for Ronstar (oxadiazon), each followed by one hand weeding in aman 2003. Partial budgets calculated for inputs and returns showed that hand weeding was less profitable than herbicides in rainfed rice, incurring US$72 ha^{-1} lower return. Use of a push weeder plus one hand weeding was less profitable than herbicides, incurring $49 ha^{-1} lower return. To date, herbicides have been largely promoted for irrigated rice in Bangladesh. The trial results demonstrate that under rainfed conditions early in the aman season, water levels are adequate for herbicides to work effectively. The use of herbicides allows timely weed control when there is a shortage of labor and avoids transaction costs, such as the provision of meals and time needed to source laborers. Herbicides are likely to be adopted by growers experiencing labor shortages, particularly on large farms and for farmers seeking to reduce input costs. Sharecroppers and tenant farmers who pay rent are primarily concerned about obtaining a high aman yield, so innovations that raise aman yields (such as herbicides that will have a similar effect as a timely first weeding) are also likely to be adopted on sharecropped plots, even when costs are not shared between the landlord and tenant.

A 178% increase in rice production in Bangladesh since the early 1960s has been achieved in part by an expansion in the area of irrigated cropping in the dry season and also by the widespread adoption of high-yielding, fertilizer-responsive cultivars. To keep pace with internal demand, Hossain and Shahbuddin (1999) projected that rice production would need to increase at 2.2% a year from 1992 until 2010, and then at 1.9% a year until 2020. Although plant breeding will continue to play an important role, there has already been extensive adoption of high-yielding cultivars. In Comilla District, for example, which has long been in the forefront of the adoption of modern rice production practices, 80% and 100% of monsoon and irrigated crops, respectively, were planted to modern cultivars by 1999 (BBS 1999). Future increases in rice production will therefore also depend on improvements in the efficiency with which inputs are used. Closing the gap between the yields achieved by the best farmers and those with only average yields has now become a priority. Reducing this yield gap will largely depend on improvements in farmers' management practices.

Nationally, rainfed transplanted rice grown in the monsoon *aman* season accounts for 52% of the total area planted to rice (Nur-E-Elahi et al 1999). Productivity of the transplanted aman (T. aman) crop is therefore of critical importance to the income and food security of rural producers throughout the country. It is of even greater significance across 100,000 ha of the High Barind Tract, where T. aman grown from June to October, when 80% of annual rainfall occurs, followed by fallow during the dry season, is the major cropping pattern. With many households transplanting rice over a relatively short time, it can be difficult for farmers to obtain sufficient labor to weed on time, at 20 to 25 days after transplanting. Against a background of rising input costs, including labor, Bangladeshi rice farmers are searching for ways to maintain income, by either increasing yield or reducing costs or both (Ahmed et al 2001). This paper summarizes yield losses due to weeds in the current system, characterization of the weed flora, farmers' perceptions of weed management issues, and the results of on-farm evaluation of improved weed management practices that will allow growers to produce high-yielding crops of T. aman profitably. We report on a series of studies in the High Barind, supported by evidence of the value of improved weed management in T. aman in Comilla District in eastern Bangladesh. Rice is grown there on 57% of the area in both the aman and dry season, when rice is irrigated (Nur-E-Elahi et al 1999).

Methods

Yield loss due to weeds

The study was conducted in Nachole, Tanore, and Rajabari *thanas* (administrative areas) in Rajshahi District in 2000. Eighteen farmers in one village of each thana provided a field for a yield-gap study. Six were on each of three toposequence positions, identified by farmers as "upper," "medium," and "low," covering little more than 5 m difference in elevation. Two plots of 25 m^2 were marked out in each field after farmers had transplanted. One plot was left unweeded and the other was maintained weed-free for the first 50 days after transplanting (DAT) by hand weeding at 21, 33, and 50 DAT in addition to any weeding done by the farmer. The farmer determined the timing and frequency of weeding on the rest of the field and other crop management practices for the whole field, including cultivar, time of transplanting, and nutrient management. Rice yield data were collected from subplots of 10 m^2 and from a third plot of this size from the part of the field where the farmer determined the timing and frequency of weeding. Data were analyzed using a mixed model design, farms being nested within villages, and toposequence being considered a fixed effect. The abundance of the five most prevalent weed species in unweeded plots was ranked at each site at 110 DAT on a 1–5 scale.

Characterization of existing weed management practices

A survey questionnaire was used in early 2001 to collect household-level information on socioeconomic variables and information on rice weed management from 119 households sampled from five Barind villages, including those where yield-gap plots were located. For comparison, data were also collected from 90 farms in three thanas in Comilla District. The questionnaire was designed to allow a characterization of existing weed management practices, and to determine the causes of untimely weeding and how land tenure may effect adoption in alternative practices.

Field evaluation of chemical weed control in T. aman rice

In 2003, a trial was planted by 91 farmers at sites covering 15 extension blocks in 9 thanas distributed through Chapai Nawbgonj, Naogaon, and Rajshahi districts to evaluate timely weed control in aman rice with the granular herbicide Machete (active ingredient butachlor 5%). At each site, two plots were planted with cultivar Swarna and two with BRRI dhan 31. One plot of each variety was weeded twice by hand at 20 and 35 DAT. Machete (butachlor 1.25 kg a.i. ha^{-1}) was applied to the other plot within 3 days of transplanting and a follow-up hand weeding was undertaken at 35 DAT. On-farm trials of weed management practices were also carried out in T. aman of 2003 and 2004 at 20 sites per year across three thanas in Comilla District. Treatments were superimposed on fields managed by farmers' choice of cultivar, planting date, and nutrient management. All herbicides were applied within 5 days of transplanting by knapsack sprayer, except for granular Machete that was broadcast, and a follow-up hand weeding was undertaken at 30 DAT. The following treatments were applied:

1. Rifit (pretilachlor 470 g a.i. ha^{-1}) + one hand weeding
2. Argold (cinmethalin 7.5 g a.i. ha^{-1}) + one hand weeding
3. Machete (granular butachlor 1.25 kg a.i. ha^{-1}) + one hand weeding
4. Hand weeding at 15 and 30 DAT
5. BRRI rotary push weeder at 15 DAT + one hand weeding at 30 DAT
6. Farmers' practice of weed management—this was weeding either once or twice by hand with variable timing between sites
7. No weeding

Table 1. Components of yield gaps due to weeds on plots with no weeding, farmer weed management, or when farmer-managed plots are kept weed-free for 50 DAT. Mean yields (t ha^{-1}) in 18 fields of three villages—range of yield gap components shown in parentheses.

Village	Weed-free yield	Potential yield gap with no weeding	Yield gain with farmer weeding practices	Additional yield gain with intensive weeding
Tanore	3.82	0.79	0.43	0.36
	(2.45–4.72)	(0.43–1.20)	(0.41–0.76)	(0.11–0.53)
Nachole	3.99	0.94	0.47	0.47
	(3.43–4.72)	(0.08–1.23)	(0.29–0.67)	(–0.48–0.861)
Rajabari	3.59	0.61	0.33	0.29
	(2.21–4.42)	(0.10–1.68)	(–0.01–1.01)	(0–1.31)
Standard error of means	0.087	0.046	0.029	0.035

Results

Yield loss due to weeds

When weed competition was completely removed by frequent weeding for the first 7 weeks after transplanting, rice yield ranged from 2.2 to 4.7 t ha^{-1} (Table 1). The mean yields of sites in individual villages were not significantly different ($P \leq 0.005$). For the 2000 aman season, the potential level of yield farmers could have achieved with currently grown cultivars, nutrient management, and other agronomic practices was more than 3 t ha^{-1} on 85% of the fields used in this study. The potential yield gap due to weeds, the yield lost when there is no weeding, differed significantly between villages. The mean yield gap was lowest in Rajabari, which also had more fields with yield gaps of below 0.5 t ha^{-1}. Across all villages, 54% of the yield gaps were between 0.5 and 1 t ha^{-1} and on 26% of the fields the gap was above 1 t ha^{-1}. The yield that farmers gained through current levels of weed management varied from 0.33 t ha^{-1} for fields at Rajabari to 0.47 t ha^{-1} at Nachole. On average, farmers gained more by weeding low toposequence fields (0.51 t ha^{-1}) than those at upper (0.35 t ha^{-1}) or medium (0.37 t ha^{-1}) positions ($P \leq 0.05$). At 65% of the sites studied, farmers' existing weed management gained up to 0.5 t ha^{-1}, whereas the return to farmer weeding was greater elsewhere. There was no significant difference between villages or toposequence positions in the mean yield that could be achieved in the 2000 season when additional weeding was applied to farmer-weeded plots. This yield gap due to weeds under existing levels of management varied from 0.29 t ha^{-1} at Rajabari to 0.47 t ha^{-1} at Nachole. More than 0.5 t ha^{-1} could be gained by additional weeding at 34% of the sites studied.

Characterization of existing weed management practices

During group discussions, farmers perceived the annual sedge *Fimbristylis miliacea* and the perennial grass *Cynodon dactylon* to be problematic weeds on upper topose-

Table 2. The five most abundant weeds in rice at three positions on the toposequence in Rajshahi District. Observations were taken in unweeded plots at 110 DAT.

Rank	Position on toposequence		
	Upper	Medium	Lower
1	*Fimbristylis miliacea*	*F. miliacea*	*F. miliacea*
2	*Cyperus halpan*	*C. halpan*	*Paspalum distichum*
3	*Cyperus difformis*	*Paspalum distichum*	*Cynodon dactylon*
4	*Cynodon dactylon*	*C. dactylon*	*Leersia hexandra*
5	*Paspalum distichum*	*Cyperus iria*	*C. halpan*

quence land. In general, fewer weeds were identified in the medium toposequence. On low toposequence fields, the perennial grass *Paspalum distichum* was identified by all focus groups as problematic. These species were included among the five most abundant weeds observed at the yield-gap trial sites (Table 2). *Fimbristylis miliacea* was the most abundant species on all land types. Low fields were infested by up to three potentially difficult to control perennial rhizomatous grasses, *Cynodon dactylon, Paspalum distichum,* and *Leersia hexandra.*

Across surveyed farms in Rajshahi District, an average of 1.1 ha of rice was planted to T. aman, with 60% of households planting up to 1.0 ha and a further 42% planting between 1.0 and 3.2 ha. The mean date of first weeding in Rajshahi District at 28 DAT was almost 2 full weeks later than in Comilla (Table 3). Farmers in both areas have a similar perception of the weediness of their plots and of the yield loss due to weeds. The data suggest that differences in weed management are related to

- *Land type and water depth.* Table 3 shows a greater range of land types (position on the toposequence) in Rajshahi than in Comilla, where virtually all plots were at medium height. Water status was also more favorable in Comilla, where most plots had standing water at the time of first weeding.
- *Tillage practices*, with farmers in Comilla relying almost exclusively on tractors and power tillers. This significantly reduced the number of plowings and ladderings given before T. aman. However, mechanized tillage was less effective in removing weeds, and farmers in Comilla weeded more frequently than in Rajshahi.
- *Labor availability*, with 95% of the farmers in Comilla reporting timely availability of labor for first weeding compared with 67% in Rajshahi. Unlike their counterparts in Rajshahi, farmers in Comilla have much greater access to migrant labor for weeding.

Timeliness of the first weeding was not significantly associated with tillage practices (Table 4). It appears to be positively associated with medium land type, presence of standing water in the plot, ownership of the plot, use of family labor, and number of

Table 3. Weed management in Comilla and Rajshahi districts, aman 2000.

Item	Comilla	Rajshahi	Significance ($P >$)
Farms (no.)	90	119	
Mean date of first weeding (DAT)[a]	15.14	28.06	0.000
Mean date of second weeding (DAT)[a]	31.51	46.16	0.000
Farmers' perception of *aman* yield loss from late weeding (%)	33.23	40.77	0.000
Adults per household (no.)	5.26	4.22	0.001
Toposequence (no. of plots)[a]			
- High	9	100	0.000
- Medium	105	82	
- Low	0	61	
Land preparation (no. of farms)			
- Animals only	0	50	0.000
- Machines only	81	23	
- Both	9	27	
Mean no. of plowings per plot[a]	2.02	4.66	0.000
Mean no. of ladderings per plot[a]	1.71	2.85	0.000
Mean no. of weedings per plot[a]	2.14	1.86	0.000
Weeding method (no. of plots)[a]			
- Hand	67	242	0.497
- Other	1	0	
Water status (no. of plots)[a]	0	15	0.000
- No water	–	–	
- Saturated water	41	125	
- Standing water	73	71	
Weeds (no. of plots)[a]			
- More than average	38	82	0.953
- Average	49	100	
- Less than average	27	60	
Labor use (% of plots)[a]			
- Own	27	46	0.421
- Hired	49	99	
- Both	38	96	
Labor available on time? (no. of plots)[a]			
- Yes	105	159	0.000
- No, no cash	4	38	
- No, no labor	1	40	

[a]For subsample of plots cultivated in aman 2000 (n = 357).

Table 4. Factors effecting timeliness of weeding between farms starting weeding at various times in Comilla and Rajshahi districts, aman 2000.

Variable	Tercile 1 (n = 70)	Tercile 2 (n = 70)	Tercile 3 (n = 69)	Sig. level (*P* >)
Mean date of first weeding (DAT)[a]	13.31	21.76	32.57	0.000
Mean date of second weeding (DAT)[ab]	28.94	36.46	31.11	0.011
Area planted to T. aman (ha)	0.6	0.9	1.3	0.000
Toposequence (no. of plots)[a]				
- High	6	41	62	0.000
- Medium	83	54	50	
- Low	0	25	36	
Weediness (no. of plots)[a]				
- More than average	29	40	51	0.959
- Average	39	52	58	
- Less than average	21	28	38	
Tenure (no. of plots)[a]				
- Owned	89	73	72	0.000
- Sharecropping	10	38	64	
- Other	15	9	11	
Water status (no. of plots)[a]				
- No water	–	3	12	0.000
- Saturated water	30	68	68	
- Standing water	59	32	44	
Adults per household (no.)	5.13	4.83	4.03	0.013
Labor use (no. of plots)[a]				
- Own	25	13	35	0.020
- Hired	38	58	52	
- Both	32	52	50	
Labor available on time (no. of plots)[a]				
- Yes	84	97	83	0.000
- No, no cash	3	9	30	
- No, no labor	1	9	31	

[a]For subsample of plots cultivated in aman 2000 (n =357).
[b]For plots that were weeded twice.

adults per household and overall labor availability. Timeliness is negatively associated with farmers' perceptions of weediness.

In Rajshahi District, 43% of the plots on surveyed farms were obtained by either a fixed rent or sharecrop contract. Sharecropped plots with 50:50 output share were divided into plots for which input costs were shared between the landlord and tenant (21%) and those for which input costs were not shared (10%). Table 5 shows that land tenure had a significant effect on weed management practices. In particular,

- First weeding was earliest on owned plots and latest on plots where tenants paid fixed rent.
- The average number of weedings was highest on owned plots and lowest on fixed-rent plots.

Table 5. Weed management practices in Rajshahi District, by land tenure, aman 2000.

Variable	Owned	Share-rent, with shared inputs	Share-rent, without shared inputs	Fixed rent	Sig. level ($P >$)
Sample size (n)	127	70	25	18	
Toposequence[a]					
- High	47	34	11	6	0.767
- Medium	46	20	9	7	
- Low	34	16	5	5	
Mean no. of plowings[a]	4.69	4.49	4.82	4.91	0.361
Mean no. of ladderings[a]	2.93	2.55	3.69	3.61	0.000
Number of weedings	1.90	1.85	1.66	1.46	0.000
Date of first weeding (DAT)[a]	26.83	28.69	31.76	33.78	0.000
Date of second weeding (DAT)[ab]	44.54	45.79	51.29	54.50	0.000
Labor used for first weeding[a]					
- Own	15	20	8	2	0.001
- Hired	71	15	5	6	
- Both	39	35	12	10	

[a]For subsample of plots cultivated in aman 2000 (n =177).
[b]For plots that were weeded twice.

- Timeliness of first weeding between owned and sharecropped plots where landlords and tenants shared input costs differed by just 3 days.
- Use of hired labor was higher on owned plots.
- The number of ladderings was lower on owned plots than on sharecropped plots where input costs were not shared between the landlord and tenant, and on fixed-rent plots.

Field evaluation of chemical weed control in T. aman

Overall, Swarna (4,137 ± 49 kg ha^{-1}) produced a higher mean yield than BR 32 (3,681 ± 51 kg ha^{-1}) ($P < 0.0001$) in the Barind in 2003. Plots treated with herbicide and one hand weeding (3,979 ± 52 kg ha^{-1}) yielded better ($P = 0.03$) than those that were hand-weeded (3,839 ± 53 kg ha^{-1}). There was no cultivar by weed control practice or district by weed control interactions demonstrating the use of butachlor to be a robust weed control technology that can save farmers expenditure for labor.

The combined analysis of data from Chowara, Parara, and Zaforganj villages in Comilla for 2003 and 2004 indicated a significant effect of weed control practice ($P > 0.001$), year of trial ($P = 0.02$), and a year by village interaction ($P > 0.001$). Differences among weed control practices can be explained by the low yield from no weeding (2,855 ± 136 kg ha^{-1}) compared with any other option (Fig. 1). Most importantly was no significant difference in the performance of weed control practices, including herbicide options, between villages or years. Again, this demonstrates that herbicides and the push weeder are robust options for the T. aman crop.

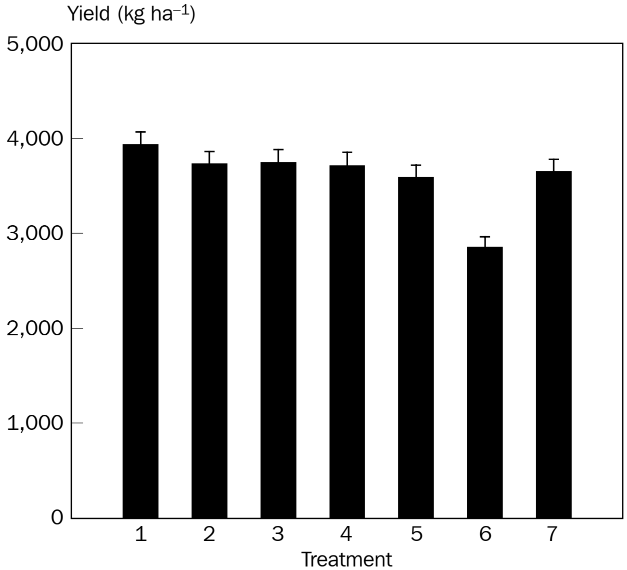

Fig. 1. Mean rice yields following various weed management practices on farms in Chowara, Paruara, and Zaforganj villages in rainfed aman rice in 2003 and 2004. 1 = Rifit, 2 = Argold, 3 = Machete, 4 = two hand weedings, 5 = BRRI weeder and hand weeding, 6 = no weed control, 7 = farmers' practice.

Table 6. Mean water depth at herbicide application and after 7 days at on-farm trial sites in rainfed aman 2003 and 2004.

Year	Water depth (cm)			
	At application		After 7 days	
	Mean	Range	Mean	Range
2003	3.3	5.0	2.2	5.5
2004	2.5	3.3	1.6	4.0

For optimal effect, each of the herbicides tested needs to be applied into 1.5 to 3 cm of standing water, with this maintained for 1 week to avoid weed emergence. Conditions were favorable for herbicide application in both seasons but water levels had fallen by 7 DAT (Table 6).

In 2003, a 1-cm increase in water depth 7 days after herbicide application reduced weed dry biomass at 25 and 45 DAT by 0.29 and 0.15 g m^{-2}, respectively (Table 7). In 2004, differences in water depth at both herbicide application and after 7 days had an effect on subsequent weed infestation levels. A 1-cm increase in water depth at the

Table 7. Significance ($P\ H_o$) of the effects of covariates and water depth at herbicide application and 7 days after on weed density and biomass at 25 and 45 DAT in rainfed aman 2003 and 2004. ns = not significant.

Variable	2003		2004	
	At application	At 7 days	At application	At 7 days
Weed density at 25 DAT	ns	ns	ns	0.027
Weed biomass at 25 DAT	ns	0.024	0.014	ns
Weed density at 45 DAT	ns	ns	ns	ns
Weed biomass at 45 DAT	ns	0.028	0.050	ns

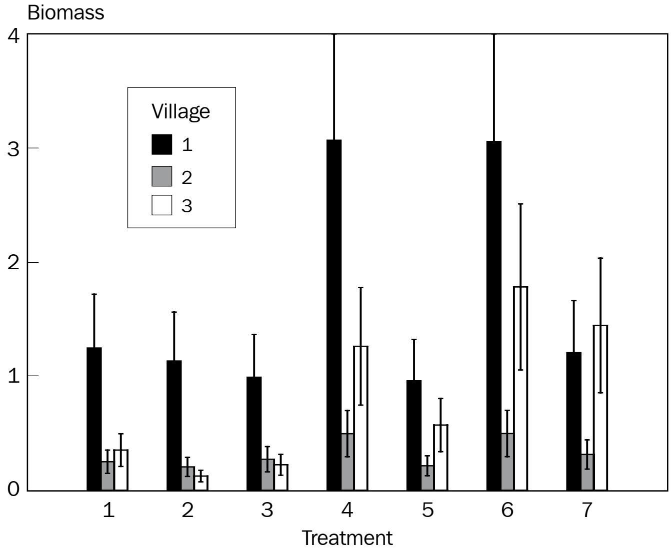

Fig. 2. Weed biomass (g m–2 dry weight) at 25 DAT in Chowara (village 1), Paruara (village 2), and Zaforganj (village 3) in aman 2003 following various weed control treatments. 1 = Rifit, 2 = Argold, 3 = Machete, 4 = two hand weedings, 5 = BRRI weeder and hand weeding, 6 = no weed control, 7 = farmers' practice.

time of herbicide application reduced weed biomass by 0.5 g m^{-2} at 25 DAT, while a 1-cm increase at 7 days reduced weed density by 1.9 plants m^{-2}. Effects were also seen in 2004 at 45 DAT when increased water depths significantly reduced weed density at 7 days after herbicide application.

Figure 2 demonstrates the effectiveness of the herbicide treatments in reducing weed infestation levels early in the season below those associated with the farmers' practice, hand weeding, or use of the push weeder. Following herbicide application, a supplementary hand weeding was undertaken at 25 to 30 DAT compared with weeding with the push weeder or by hand in cultural weed control treatments at 15 DAT. The latter were clearly less efficient than using a herbicide.

Discussion and conclusions

Across the toposequence, 30% of the farmers in this study lost more than 0.5 t ha^{-1} of rice yield due to weeds in the T. aman season. Differences in the timing of the first weeding reflected a mix of economic and noneconomic factors. Earlier weeding was associated with topography and rainfall, and weeding was earlier on low-lying plots and on plots with standing water, which facilitated weeding. Early weeding was also associated with tillage. Land preparation with tractors or power tillers required fewer passes but also required earlier and more frequent weeding. Early weeding was also associated with labor supply, as measured by the use of family labor for weeding, availability of labor on time, and a smaller area planted to T. aman. Finally, timely weeding was associated with land ownership, with first weeding given later on rented plots.

It is noteworthy that farmers' perceptions of yield losses from untimely weeding were inversely related to timeliness of the first weeding. Farmers in Comilla and Rajshahi districts appear to have different concepts of the optimum dates for first weeding. Earlier first weeding in Comilla District may reflect long exposure to modern variety rice technology and superior knowledge of crop management. This suggests that providing farmers in Rajshahi with information about yield losses due to weeds and improved practices might improve their weed management and particularly the timing of the first weeding. The first weeding on large farms in Rajshahi District started on average 1 week later than on small farms. Later weeding on larger farms reflects a combination of factors but shortage of labor is important. Mechanization will not necessarily reduce labor constraints because large farms cultivate a higher share of low-lying land that is unsuitable for rotary weeders. Herbicides seem a more appropriate option. Because weeding is later on larger farms, the introduction of herbicides in Rajshahi should result in large productivity gains.

Survey results suggest that farmers give priority to their own plots for first and second weeding. Farmers were more likely to rely exclusively on hired labor to weed their own plots although plots weeded exclusively by hired labor were weeded later than those weeded using only family labor. Later weeding on fixed-rent plots may reflect the fact that they were rented by larger farms that may have had greater difficulty obtaining hired labor. The use of herbicides will allow timely weed control even when there is a shortage of labor as well as avoiding transaction costs, such as provision of meals and time needed to obtain laborers. Herbicides are therefore likely to be adopted by growers experiencing labor shortages, particularly on large farms and by those seeking to reduce input costs. Our findings also suggest that farmers are primarily concerned about obtaining a high aman yield on their sharecropped plots, so innovations that raise aman yield (such as herbicides that will have a similar effect as timely first weeding) are likely to be adopted on sharecropped plots, even when the costs are not shared between the landlord and tenant.

Since 2000, there has been an increase in the number of herbicides registered for use on rice in Bangladesh from 4 to more than 30. Product sales have been increasing at 40% to 60% per year. Company representatives have emphasized the use of herbicides in irrigated *boro* rice in the dry season as it is easier for farmers to manage water depths at the time of herbicide application in irrigated fields. However, our on-farm trial results demonstrate that under rainfed conditions early in the aman season there are adequate water levels for herbicides to work effectively and there can be sufficient water for flooding to augment the effect of the herbicide.

Demonstrations of a range of weed management practices have also been undertaken across Comilla District. The yield advantage over farmers' practices, either one or two hand weedings, was on average 355 ± 18 kg ha^{-1} for Rifit (pretilachlor), 281 ± 39 kg ha^{-1} for Machete (butachlor), and 210 ± 34 kg ha^{-1} for Ronstar (oxadiazon), each followed by one hand weeding in aman 2003. The level of yield gains reported here are on the order of magnitude of yield losses due to weeds in farmer-managed rice crops previously observed in Comilla (Ahmed et al 2001). Partial budgets calculated for inputs and returns used in the trials showed that hand weeding was less profitable than herbicides in rainfed rice, incurring a $72 ha^{-1} lower return. The use of a push weeder plus one hand weeding was less profitable than herbicides, incurring a $49 ha^{-1} lower return.

Considerable risk is associated with rainfed rice production. In 2004, for example, flooding destroyed a large area of the crop in Comilla and lengthy periods of submergence reduced yield where rice survived. However, losses were less on plots where herbicides had been applied as these cost 50% to 65% less than hand weeding, depending on the product used. The timing and duration of standing water in rice fields early in the season influence weed infestations by the time a supplementary hand weeding is undertaken by 30 DAT. An important component of the knowledge that farmers need to use herbicides effectively, particularly in aman, is the need for timely follow-up hand weeding. This is particularly important on fields where perennial weeds, particularly the rhizomatous grasses *Cynodon dactylon, Paspalum distichum,* and *Leersia hexandra* are abundant, as observed at several locations in the Barind, as these are not controlled by herbicides.

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Acknowledgments: This work was partially funded by the UK Department for International Development (Crop Protection Programme Project R8512). However, the views expressed are not necessarily those of DFID.

Identifying varieties for the High Barind Tract of Bangladesh with farmers

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We describe the testing of varieties with farmers in the High Barind Tract of Bangladesh from a client-oriented breeding program carried out in Chitwan, Nepal. The two best lines, Judi 582 and Judi 567, yielded 19% to 50% more during the T. *aman* season and the yield advantage over check varieties during the *aus* season was even greater. These varieties were preferred by farmers for their suitable agronomic traits and quality. The new varieties were adapted to all three rice-growing seasons and to varying amounts of inputs. This could be explained by the breeding method: the generations were advanced in two contrasting seasons and each generation was grown in a different farmer's field under different management and with a difference in planting date. The success of these varieties lies in that farmers were involved both during the product design phase (in Nepal) and during the variety testing phase in Bangladesh. Another important contribution of the participatory research is in shortening the breeding cycle by nearly half and making participatory research cost-effective.

We have tested simple changes in public-sector plant breeding approaches to make them more farmer participatory and to develop crop varieties more relevant to clients. This process is described in the commonly used term participatory plant breeding (PPB). However, it is more useful to describe this as client-oriented breeding (COB) to explain the *purpose* of achieving high client orientation (Witcombe et al 2005). We have also modified breeding methods to make them simpler while keeping the methods closely in line with plant breeding theory (Witcombe and Virk 2001).

The research was carried out in the High Barind Tract (HBT) in northwestern Bangladesh (Fig. 1). This area comprises uplifted weathered alluvium of high clay content, which is not subject to annual flooding by the major river systems. The undulating HBT covers some 2,200 km^2 to the west of this region (Edris 1990). Soils have an acid surface horizon (pH 4.5–5.5 at 0–10 cm) but are neutral to alkaline with depth (pH >6 below 20 cm). The bunded fields are generally left fallow for the remainder of the year although rainfall averages 1,285–1,400 mm per year. Hence, enough water remains in the soil profile to sustain a short-duration crop if rice is harvested early enough.

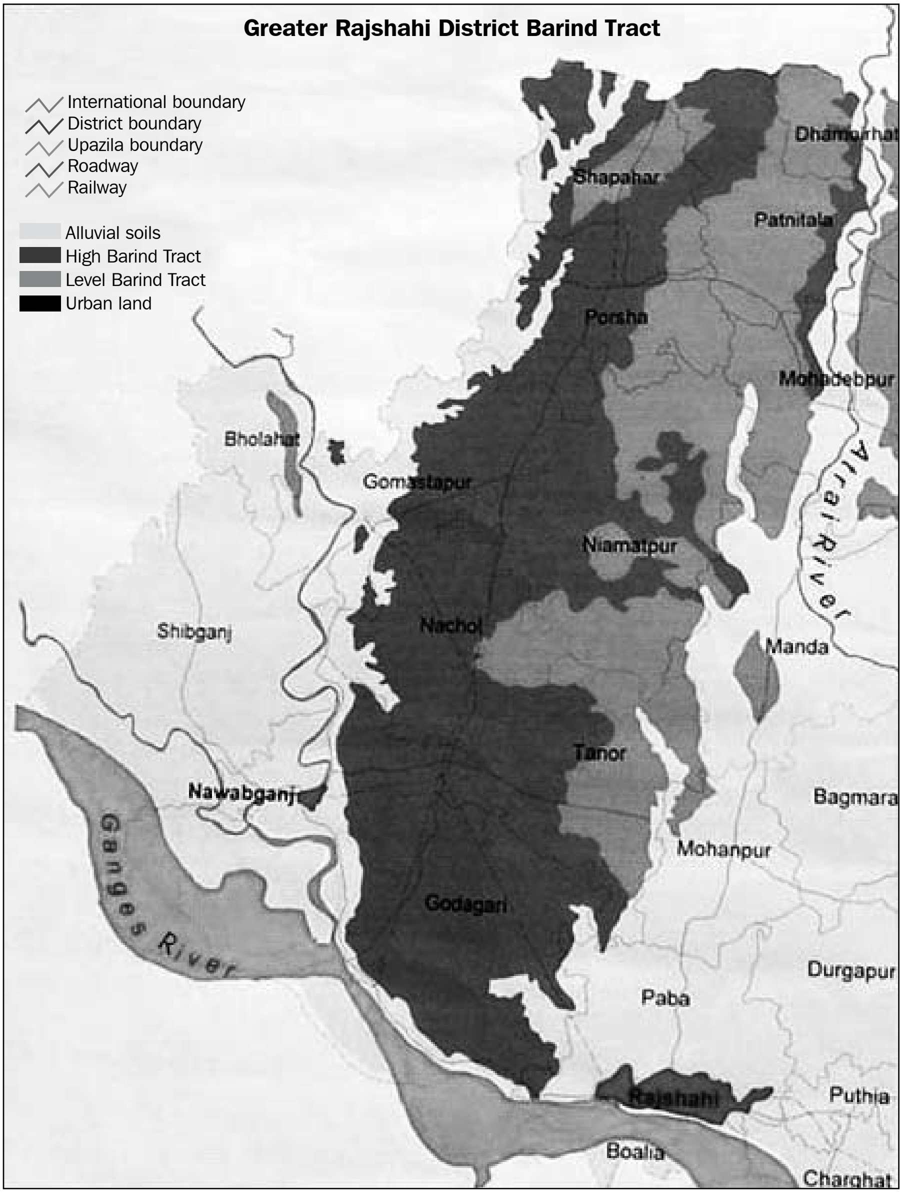

Fig. 1. Project districts in the High Barind Tract (HBT) of Bangladesh.

Table 1. Rice varieties bred by client-oriented breeding in Nepal and introduced into Bangladesh between 2002 and 2004.

Year of introduction	Rice variety	From
2002	Judi 582	Radha 32/Kalinga III
2003	Judi 565, Judi 566, Judi 567	Kalinga III/IR64
2003	Barkhe 2001, Sugandha 1	Outcrossed Pusa Basmati-1 population
2004	Ashoka 228, Ashoka 200F, Judi 141F, Barkhe 3004, Super 3004	Kalinga III/IR64
2004	Barkhe 1006	Outcrossed Pusa Basmati-1 population

Bangladesh has three distinct rice seasons: *aus,* a short-duration crop that is broadcast-seeded in March-April using the premonsoon rainwater and harvested in August-September; transplanted *aman* (T. aman), a monsoon crop grown from June-July to October-December, which, in some areas, is harvested after the floods recede; and *boro* dry-season rice, an irrigated crop from November-January to April-May. Short-duration T. aman varieties are required so that winter crops such as chickpea, other legumes, oilseeds, and wheat can be sown early. It is particularly important for wheat to complete its growth cycle before the high temperatures of the ensuing spring (Timsina et al 2001). With the development of groundwater irrigation, modern varieties of boro rice have expanded rapidly at the expense of the less profitable aus and broadcast aman. It is estimated that boro rice production has grown substantially (6.7%), while aman production has grown at a much lower rate (1.4%) and aus production has declined (–2.2%) (Baffes and Gautam 2001). Although significant efforts have been made to develop newer generation modern varieties (MV), the results in the field have not been encouraging. At least 18 releases of semidwarf and short-duration varieties have been unpopular because of lower yield potential as well as agroecological constraints (Hossain 1996). The most popular variety, BR-11 (introduced in 1980), currently covers about three-quarters of MV rice area (Baffes and Gautam 2001).

Methodology

Varieties from a highly client-oriented breeding program in Nepal and a few from India were introduced into this area through formal channels (Table 1). Other varieties were also introduced that had been bred in the formal sector in India or were popular in Nepal (BG1442, Ekahattar, Pant Dhan 10, PNR 381, and Sarwati) but these are outside of the subject of this paper and none of them performed as well as the best entries introduced from the COB program in Nepal.

The trials were conducted by farmers collaborating with the People's Resource-Oriented Voluntary Association (PROVA) in a system of multivariety trials (mother trials) and single intervention trials (baby trials) of one variety against the local check.

The names mother and baby trials follow the nomenclature of Snapp (1999). The mother trials contained all of the test entries and checks and each trial was a single replicate of randomized entries and replication was provided by repeating the trial in dispersed fields with different farmers. Trials were conducted in all three seasons but most were in the T. aman season.

These entries were tested in mother trials in three subdistricts (*upazillas*), Godagari, Nachole, and Porsha, from 2002 to 2004. New rice varieties were compared with Swarna and BRRI dhan 32 (data are not presented for varieties introduced into Bangladesh from conventional breeding: PNR 381, Pant Dhan 10, Ekahattar, and BG 1442; and for aromatic variety Sugandha 1, but the results are discussed). In the mother trials, grain yield data in 2003 were measured in each plot from 5 quadrats of 1 m^2. In 2004, yield data were measured from 30-m^2 plots (whole-plot harvest).

For baby trials, yield data were estimated from the 200-m^2 plots by interviewing farmers for both test and check varieties during postharvest evaluation for all 45 trials in which Judi 582 was evaluated. In 2003, 19 farmers (68% of the 28 collaborators) were selected and interviewed for their perceptions, who came from all three upazillas. In 2004, all 17 farmers were interviewed.

The mother trial data were analyzed by the method of Freeman and Perkins (1971), with all of the data combined across years. Although Pant Dhan 10 was not included as a variety in the analysis, it was allowed to contribute to the environmental index to make it more independent. Data from one of the 23 locations were removed where Judi 582 was found to be a high-yielding outlier (residual > 2 standard deviations from the fitted regression line). All of the data are therefore presented on the basis of 22 trials. In addition, analysis of variance was done for various quantitative and qualitative traits.

In the baby trials, a regression analysis was done between the yields of Judi 582 and Swarna and two points were removed, using the same statistical criteria as in the mother trial, although in these two cases Judi 582 was a low-yielding outlier.

Results

Performance in T. aman

Judi 582 consistently outyielded BRRI dhan 32 and Swarna in the mother trial from 2002 to 2004 (Table 2). Although the difference was not significant in 2002 (as there were only two trials), all others were significant. The grain yield advantage of Judi 582 over the three years was 0.9 t ha^{-1} (35%) over Swarna and 0.8 t ha^{-1} (30%) over BRRI dhan 32. In the 2004 trials, the yield difference of Judi 582 with both check varieties was more than 1 t ha^{-1}, with more than a 50% increase in grain yield without any change in the amount of inputs and crop management. Yields were lower in 2003 as below-average and erratic rainfall with long dry spells badly affected rice growth and yield. Judi 582 was consistently superior for grain yield over the check varieties across all environments (Fig. 2). It showed stability equivalent to that of BRRI dhan 32 but responded more to higher-yielding environments than did Swarna (Fig. 2). The mother trials were under farmers' amounts of inputs over a wide range of land

Table 2. Grain yield advantage of Judi 582 rice over two checks in 22 mother trials in T. aman in the High Barind Tract, Bangladesh, 2002-04.

Rice variety	Mean grain yield (t ha^{-1})			
	2002	2003	2004	Overall
Judi 582	4.0	2.8	3.5	3.2 ± 0.17
BRRI dhan 32	3.7	1.9	2.3	2.4 ± 0.19
Swarna	3.3	2.0	2.3	2.3 ± 0.13
Trial mean	3.7	2.2	2.7	2.9 ± 0.10
S.E.D.	±0.56	±0.30	±0.26	
Yield advantage (%)[a]	14	42	53	39
Number of trials	2	8	12	
Probability	ns[b]	<0.05	<0.001	

[a]Yield advantage of Judi 582 over mean of two checks. [b]ns = nonsignificant.

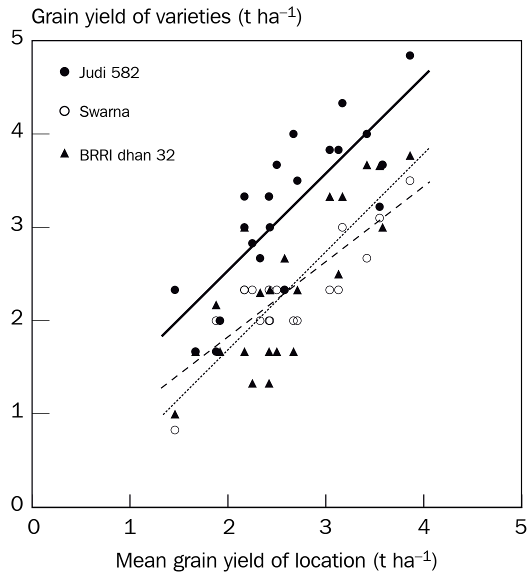

Fig. 2. Yields of Judi 582 rice and two check varieties, BRRI dhan 32 and Swarna, against location mean grain yields across 22 locations in the High Barind Tract, Bangladesh, 2002 to 2004. (Solid line = Judi 582: b = 1.04, a = 0.48; dotted line = BRRI dhan 32: b = 1.06, a = –0.41; dashed line = Swarna: b = 0.81, a = 0.21.)

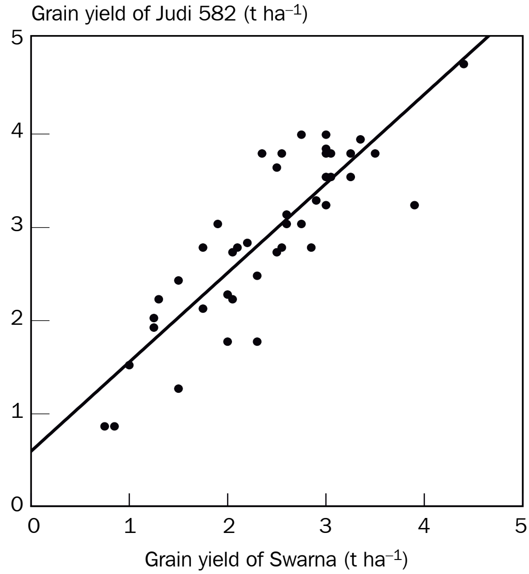

Fig. 3. Yield superiority and yield stability of Judi 582 versus Swarna rice in 43 baby trials in the T. aman season in the High Barind Tract, Bangladesh, 2003-04. $y = 0.58 + 0.95x$; $R^2 = 0.74$.

types and management regimes, so these responses are likely to be representative of the High Barind Tract.

Baby trials sampled more diverse conditions than the mother trials as they were more dispersed, with bigger plot size and larger in number so they can be considered to provide a more realistic picture of the yields achieved by farmers. Without changes in input amounts or management practices, Judi 582 produced 2.9 t ha^{-1}, 0.46 t ha^{-1} (19%) more than Swarna, the most widely grown check variety, in the baby trials (Fig. 3).

Farmers considered the height of Swarna as ideal and the height of Judi 582 was similar to that of Swarna, whereas BRRI dhan 32 was considered too tall and therefore prone to lodging under more fertile conditions or in the event of high winds. Judi 582 was 33 days earlier to mature than Swarna and 8 days earlier than BRRI dhan 32, although in the latter case the difference was not significant (Table 3). Early maturity was greatly liked by farmers as it provided more time to carry out agricultural operations between crops and provided opportunities to reduce labor costs.

Participating farmers in both the mother and baby trials and the neighbors of those farmers preferred Judi 582 over the two check varieties (Table 4). There were significant preferences for all of the traits measured and a great majority of the farmers would grow Judi 582 again. The only trait that varied between the two years was market price (Joshi et al 2007). Swarna was the least preferred variety and BRRI

Table 3. Plant height and crop duration of Judi 582 rice compared with those of two check varieties in 12 seven-entry mother trials (four each at Godagari, Porsha, and Nachole) in the T. aman season in the High Barind Tract, Bangladesh, 2004.

Rice variety	Plant height (m)	Crop duration (days)
Judi 582	0.91	114
Swarna	0.85	147
BRRI dhan 32	1.21	122
Trial mean	0.95	116
S.E.D.	±0.05	± 7
Probability	0.000	0.000

Table 4. Farmers' preference ranking in 23 trials over two years in the T. aman season, 2003-04.

Variety	Mean rank 2003[a]	Overall rank order 2003	Mean rank 2004[b]	Overall rank order 2004
Judi 582	1.3	1	1.2	1
Pant Dhan 10	1.7	2	2.3	4
BRRI dhan 32	6.7	6	6.2	6
Swarna	5.7	9	6.5	7

[a]Ranked on a 1 to 9 scale (nine-entry trial with 1 best and 9 worst). Mean of 9 trials. [b]Ranked on a 1 to 7 scale (seven-entry trial with 1 best and 7 worst). Mean of 12 trials.

dhan 32 had a low rank. These perceptions were made postharvest, so the rankings accounted for all of the important traits.

Another rice variety from COB, Judi 567, performed very well in shallow rainfed conditions of the HBT. It yielded 47% (P = <0.000) over the mean grain yield of the three check varieties (Table 5). This high yield was exceptional given its shorter duration. Judi 567 also gave significantly higher straw yield than all the check varieties. The grain yield of BRRI dhan 32 was the lowest in the trial (Table 5).

The eight farmers that grew the mother trials, along with 61 other farmers, showed an overwhelming and highly significant preference for Judi 567 over all the checks in all the eight locations (Joshi et al 2007). BRRI dhan 32 was consistently the least preferred across all the locations and it also produced the lowest grain yield at Nachole. In only one case (Swarna at Nachole) was a check entry in the top three of the rankings.

Performance in aus

Judi 582 also yielded more than the checks in the aus season. There was a yield advantage of 1.8 t ha^{-1} (i.e., a 105% yield increase) over the widely grown variety Vadhai (Joshi et al 2007). However, Judi 582 was nearly 1 month later than Vadhai. Farmers

Table 5. Varietal characteristics of Judi 567 rice in a seven-entry trial compared with three check varieties in mother trial 2 (8 trials in the T. aman season, High Barind Tract, Bangladesh, 2003).

Rice variety	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Crop duration (days)
Judi 567	3.5	4.7	102
Judi 566	2.7	3.7	99
Judi 565	2.6	3.6	99
Barkhe 2001	2.5	3.9	115
Swarna	2.5	4.1	128
BRRI dhan 39	2.5	4.1	116
BRRI dhan 32	2.1	3.7	115
Trial mean	2.7	4.0	111
S.E.D.	±0.32	±0.3	±2.2
Advantage (%)[a]	48.3	18.4	17.6
Probability	0.011	0.022	0.001

[a]Judi 567 over the mean of the three checks.

reported that the longer time to maturity was not a problem for an aus variety as long as it can be harvested before the end of September. Therefore, a 116-day variety can fit easily into this period (April-May to September). Farmers can grow boro rice but generally vegetable crops such as early-planted tomato are grown after aus rice because they fetch a higher price in the market.

Performance in boro

Although the varieties were initially targeted only for the T. aman season, they were also evaluated in the boro season through farmers' innovations. Farmers retained seed or obtained it from other farmers and grew Judi 582 in the boro season. Many farmers did so within two seasons of participating in or observing the mother and baby trials in the T. aman crop.

In-depth interviews were held with farmers who were known to have grown the new varieties in the boro season. Two examples are summarized below.

Rojab Ali (B) owns 2.3 ha of rice land in Chabishanagar and initially grew Judi 582 in T. aman 2003 on about 300 m^2 of land from 1 kg of seed supplied by PROVA. He grew the variety again, from farm-saved seed, in boro 2003-04. He described it as "*sundar dhan,*" meaning beautiful rice. He observed that there was no seedling mortality in the nursery compared with an appreciable mortality in BRRI dhan 28; it tolerated drought and gave a high yield in spite of late seeding (no reasonable harvest could be expected from other varieties planted equally late), and the crop was very uniform with synchronous flowering. Unlike BRRI dhan 28, it did well even under the moderate fertility conditions in which he had grown Judi 582.

The postharvest traits were generally superior: it had more attractive grains and less chaff than other boro varieties. The grains of Judi 582 were heavier, that is, they had a higher weight per volume (a trait appreciated by farmers); it required less cook-

Table 6. Summary of adoption and spread of Judi 582 rice in the High Barind Tract, Bangladesh, 2005.

Households surveyed	Number of farmers		Number of		Quantity of seed distributed (kg)	
	Growing Judi 582	Willing to grow next season	Adopters distributing seed	Recipients	Total	Av
68	22	40	13	23	632	27.5

Source: Pandit (2005).

ing time than BRRI dhan 28 and gave better quality of *bhat* (steamed rice), and even *basi bhat* (leftover rice) from it was better than from other varieties. The market price for Judi 582 was similar to that of Parija.

Kurban Ali owns 1.2 ha of land in Parmanandpur and got 1 kg of seed of Judi 582 in T. aman 2003 and planted, from farm-saved seed, about 800 m^2 in the boro season. This yielded about 6 t ha^{-1}, about 35% more than variety Minikit (4.5 t ha^{-1}). He intended to grow Judi 582 in the next T. aman season on 0.7 ha. He reported that it had better seedling-stage cold tolerance and better seedling vigor than BRRI dhan 28, it did well even in moderate fertility conditions, it did not lodge because of its stiffer plants and medium height, and it had fewer disease and insect problems. For postharvest traits, he mentioned its good milling recovery, better quality of *bhat*, and shorter cooking time than BRRI dhan 28.

Adoption and seed spread

By 2005, within two years of the first introduction, the rice varieties were adopted by 65% of a random sample of farmers in randomly selected villages where PROVA had at least some activities in introducing the varieties (Pandit 2005). Judi 582 was grown by 22 (32%) of the 68 surveyed households. Another 60% of the respondents, who were aware of the variety but had no seed, expressed a desire to grow it in the coming season (Table 6).

The variety spread from farmer to farmer but amounts were limited by the relatively small quantities of seed available. On average, half of the farmers distributed seeds to nearly two other farmers and the average quantity of seed received by an individual household (Table 6) was enough to transplant more than 0.5 ha of rice (Pandit 2005).

Discussion

Value of participatory research

There has been much discussion on the value of participatory research. Johnson et al (2003) found evidence that farmer participation led to more relevant technologies and greater economic impact, especially when participation was early in the research process. Sall et al (2000) agreed and argued that the inputs of farmers to rice breeding are more important during variety development than evaluating the variety at the end of the research process. Although farmer participation accelerated and aided the process of varietal selection (Sumberg and Reece 2004) in the case of Bangladesh, it was the involvement of farmers in setting the breeding goals in Nepal, that is, in helping to design the product (Witcombe et al 2005), that led to the creation of suitable varieties such as Judi 582. No amount of participation at the varietal identification stage can compensate for a dearth of appropriate varieties and participation of farmers at the product design stage is essential. The results here provide convincing additional evidence that farmer involvement at the early stages of plant breeding is effective (e.g., Virk et al 2003, 2005, Witcombe et al 2003). Judi 582 and Judi 567 are the most extensively tested varieties, but nine other varieties from the client-oriented breeding program in Nepal have also been tested in Bangladesh: all nine have performed better than the best locally available or recommended varieties. Two of these varieties, Barkhe 3004 and Super 3004, are suitable for the semideep rainfed lowlands, so varieties have been produced that are suitable for most of the rice-growing environments in Bangladesh.

Other COB varieties, such as Barkhe 1006 and Judi 572 from Nepal and Ashoka 200F from India, produced significantly more grain than Vadhai during the aus season, with a yield advantage of 35–106%. Interestingly, Ashoka 200F, which had the same crop duration as Vadhai, produced 35% more grain.

One of the greatest contributions of participatory research to cost-effectiveness is the shortened time span between the initial development of the product and its marketing. There is usually a long lag phase of about 7–8 years between variety development and appreciable adoption by farmers in conventional breeding (Morris et al 1994). This process has been greatly truncated in the participatory research described here and this has economic benefits (Pandey and Rajatasereekul 1999).

Given the much higher grain yields of Judi 582 and Judi 567, these varieties could have an impact on rice production not just at the household level but also at a district and national level. Farmers exposed to these introductions have expressed a high preference for them and there is evidence of early and rapid adoption through the farmers' innovation system. It is proposed that existing formal varietal release systems examine this model as a means of more comprehensively evaluating potential germplasm and then rapidly disseminating varieties preferred by clients.

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Acknowledgments: This document is an output from Plant Sciences Research Programme projects R6748, R7122, R7542, R8071, and R8269 funded by the UK Department for International Development (DFID) and administered by CAZS Natural Resources for the benefit of developing countries. The views expressed are not necessarily those of DFID. The authors would like to thank all the participating farmers in Nepal and Bangladesh for their essential role in this research. Many other staff from LI-BIRD, PROVA, and NRRP greatly contributed to this research.

Opportunities for improving *rabi* crop production in the High Barind Tract

Farmer-friendly technologies to improve chickpea production in the High Barind Tract

D. Harris, C. Johansen, and A.M. Musa

Research in the High Barind Tract (HBT) of Bangladesh to alleviate the effects of drought, pests, and micronutrient deficiencies on the production of chickpea is described. On-farm seed priming, whereby seeds are soaked in water for 8 hours before being sown, was tested by farmers during four consecutive years from 1998-99 to 2001-02 and this increased grain yield consistently in all four years, with a mean increase of 37%. A lack of molybdenum (Mo) was shown to limit the nodulation, and hence the nitrogen nutrition and yield, of chickpea. Adding Mo and *Rhizobium* to soils increased nodulation and yield but was expensive and somewhat impractical. Adding Mo and *Rhizobium* to seeds during the priming operation was shown to be a less costly and more viable alternative that increased mean nodulation score in farmers' trials by more than 70% and mean grain yield by 20%.

The components of a simple integrated pest management package were tested, separately and together, in farmers' fields. Bird perches, to facilitate access of insectivorous birds to the infested crop, reduced significantly the incidence of larvae of pod borer (*Helicoverpa armigera*) and the number of pods damaged by the pest. Use of *Helicoverpa* nuclear polyhedrosis virus was similarly effective, as was growing chickpea as an intercrop with linseed or barley. However, reduced pest incidence was not consistently associated with increased yield because of other constraints such as *Botrytis* gray mold and terminal drought. Nevertheless, the simple farmer-friendly interventions tested proved to be effective and would contribute to increasing the productivity and profitability of chickpea production in the HBT.

Growing chickpea (*Cicer arietinum* L.) on residual soil moisture following the harvest of rainfed transplanted *aman* (T. aman) rice has become more popular recently with farmers in the High Barind Tract (HBT) of Bangladesh (Islam et al 1994, Saha 2002, Socioconsult 2006). The market price of chickpea makes it an attractive crop to grow (Yusuf Ali et al 2007) but, although potential yield in the area is > 2 t ha^{-1}, actual yields are generally below 0.8 t ha^{-1} (Musa et al 2001). Major constraints to higher yields are drought, particularly around the time of crop establishment when the surface layers of the soil dry out, but also at the end of the season if extended crop duration exhausts

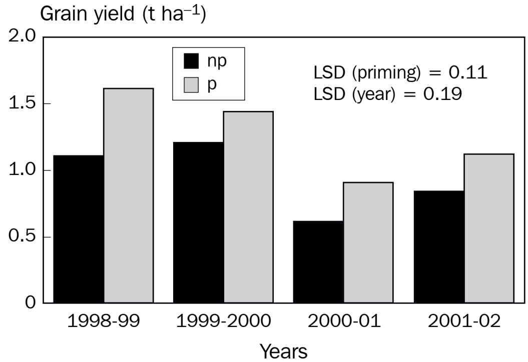


Fig. 1. Effect of priming seeds overnight with water on mean grain yield of chickpea in four years in the High Barind Tract of Bangladesh. np = not primed, p = primed. Results of farmer-implemented paired-plot trials in 1998-99 (30 trials), 1999-2000 (99 trials), 2000-01 (101 trials), and 2001-02 (50 trials).

the water available in the soil; pests and diseases, in particular damage by pod borer (*Helicoverpa armigera*); and soil nutrient deficiencies. In this paper, we describe some of the on-farm research that was implemented to alleviate these three major constraints and to increase the productivity and profitability of chickpea in the HBT.

Minimizing the effects of drought on chickpea yield

Johansen et al (this volume) showed that early sowing, preferably in November rather than in December, is a major determinant of chickpea yield and they discuss ways to manipulate other components of the cropping system (e.g., direct seeding of rice, the use of short-duration rice varieties, minimum tillage) to achieve this. The introduction of short-duration chickpea varieties to the HBT using participatory varietal selection (PVS) also addresses the problem of end-of-season drought (Johansen et al, this volume). Johansen et al also note that seed priming (soaking chickpea seeds in water for 6–8 hours before sowing) mitigates somewhat the negative effects of late planting. Figure 1 shows the effect of priming, over four seasons from 1998-99 to 2001-02, in 310 farmer-implemented paired-plot trials. There was no significant interaction between priming and year—priming increased yield consistently in all four years: by 46% in 1998-99, by 19% in 1999-2000, by 48% in 2000-01, and by 34% in 2001-02. Additional measurements made in the trials in 1998-99 and 1999-2000 showed that this positive response to priming was associated with faster emergence, more rapid seedling establishment and higher plant stands, more vigorous growth, earlier maturity, and thus escape from end-of-season drought (Musa et al 2001). Priming also reduced plant losses due to stem diseases (38% averaged over the two years) and increased the degree of nodulation by 48% (measured only in 1999-2000). Seed priming has been extensively tested by farmers in the HBT and is a low-cost, low-risk technology that has been adopted widely as a recommended practice (Saha 2002) on its own merits but also as a means to address other constraints (see below).

Integrated pest management

The biotic stresses that affect chickpea in the HBT include collar rot (caused by *Sclerotium rolfsii*), *Fusarium* wilt, *Botrytis* gray mold (BGM, caused by *Botrytis cinerea*), and pod borer (*Helicoverpa armigera*). The extent of genetic resistance to these pests and diseases in chickpea genotypes is discussed by Johansen et al (this volume), but simple agronomic interventions can help to reduce losses. For instance, seed priming was shown to reduce the incidence of collar rot (Musa et al 2001) and appropriate plant spacing facilitates good canopy ventilation that reduces the development of BGM (Bakr et al 2002). Pod borer, however, is the major biotic source of yield loss in chickpea. PROVA estimates yield losses of 10–50% caused by this pest each year in the HBT and pod damage is particularly apparent to farmers, who repeatedly list it as an important constraint to chickpea production (see, for example, Saha 2002). In 2001-02, preliminary trials by PROVA showed the efficacy of spraying *Helicoverpa* nuclear polyhedrosis virus (HNPV) in controlling pod borer on chickpea (Musa and Johansen 2003b). This virus is specifically lethal only for *Helicoverpa armigera* and is thus an environmentally safe means of managing the pest, in contrast with the use of chemical insecticides with all of their adverse side effects (Grzywacz et al 2004). It was therefore decided to develop an HNPV-based integrated pest management (IPM) system suitable for chickpea in the HBT. Simple interventions were tested, separately and in combination, in a series of field trials between 2002 and 2005.

In the 2002-03 season, three separate subexperiments were conducted on the effects of (A) bird perches, (B) HNPV spraying, and (C) mixed cropping. Five replications each of the following treatments were superimposed on existing chickpea crops and mixed crops in the first week of February 2003:

A. *Bird perches*

Sixteen T-shaped perches were placed at 5-m intervals (i.e., 4 × 4 = 16) within a 25 × 25-m area of existing chickpea. A similar uniform area of 25 × 25 m without bird perches was identified within 10–20 m of the first plot.

B. *HNPV spraying*

Chickpea in selected areas of 25 × 25 m was sprayed with either HNPV (250 larval equivalents ha^{-1}) or with a chemical insecticide (Ripcord, using 1 mL active ingredient L^{-1} water) when small larvae (<1.5 cm long) were first detected, followed by a second spray 2–3 weeks later, depending on larval buildup, and a third spray if infestation continued. A third 25 × 25-m area, with no HNPV or chemical spray applied, was designated nearby.

C. *Mixed cropping*

In existing farmers' fields, adjacent areas of 25 × 25 m containing sole chickpea or chickpea grown mixed with either barley or linseed were chosen.

In each of the plots, numbers of *Helicoverpa armigera* larvae on chickpea were counted in 5 × 1-m^2 quadrats per plot at three times. Counts were made at 3–4 days after spraying of HNPV and Ripcord. Spraying times were 4 and 22 February and 22 March 2003. Plant numbers of all crop species per 5 × 1-m^2 quadrat were also measured on 22 March. Chickpea suffered severe damage by BGM in this season so counting of damaged pods and estimation of grain yield were not done.

In the 2003-04 season, subexperiments and treatments were the same as in the previous season but with an additional subexperiment comparing a combined IPM treatment (bird perches + HNPV + mixed cropping) with a nonprotected control. There were five replications and in this season the plots were purpose-sown (rather than superimposed on existing plots as in the previous year). At maturity, plant number, the percentage of damaged pods, and grain yield of chickpea were recorded in 10 randomly located 1-m^2 quadrats.

In the 2004-05 season, combined IPM treatments were tested against nonprotected control treatments in both sole crop and mixed crop (with linseed only) situations. The control for the mixed crop was a sole chickpea crop without HNPV spraying or placement of bird perches. Ten paired comparisons were placed in adjacent 25 × 25 m plots in farmers' fields in Godagari and Nawabganj Sadar *upazillas*.

Results of IPM trials

In the 2002-03 season, the presence of bird perches significantly reduced larval numbers at the second and third samplings (Table 1). We believe that this is probably the first recorded quantification of this effect on chickpea. Plant population was not significantly different between the treatment plots, ranging from 22 to 37 plants m^{-2}. Observation by farmers indicated that the perches did indeed attract birds, which ate the larvae. As noted above, it was not possible to estimate any treatment-related differences in yield or yield components because of the severe damage to the crop by BGM.

Application of HNPV was at least as effective as the best locally available chemical insecticide, Ripcord, in minimizing larval numbers (Table 1). Larval numbers were significantly higher without application of either of these sprays. Plant populations were similar between treatments, in the range of 18–33 plants m^{-2}.

There were significantly fewer larvae on chickpea in mixed crops with barley or linseed as compared with sole crops (Table 1). Mixed crops can have lower densities of chickpea plants relative to sole crops but that was not the case in these trials. Mean chickpea density in the sole crop was 27.6 plants m^{-2} and not significantly different from the 28.6 plants m^{-2} in the mixed crop. This result confirms in farmers' fields that mixed cropping discourages *Helicoverpa* pod borer damage to chickpea, consistent with the previously reported results found in small-plot on-station trials.

The positive effects of the use of bird perches, HNPV application, and mixed cropping in numbers of *Helicoverpa* pod borer larvae on chickpea were confirmed in operational-scale plots in farmers' fields. They thus remain worthy components of an IPM package for chickpea. However, treatment-related effects on yield could not be measured due to overriding damage to the crop caused by BGM.

Table 1. Effect of IPM components on pod borer larval numbers m^{-2} in chickpea in the Barind, 2002-03.

Variable	Treatment	Sampling date		
		7 Feb	26 Feb	30 Mar
Bird perches	No perch	3.0	6.0	50.6
	Perch	2.6	2.0	19.2
	Significance[a]	ns	**	ns
HNPV	No spray	5.2	4.6	42.6
	Chemical	3.0	2.4	18.4
	HNPV	1.8	1.4	12.8
	Significance	**	*	*
Mixed cropping	Sole	4.0	5.4	56.8
	Mixture	2.4	2.6	19.2
	Significance	*	**	***

[a]ns = not statistically significant; * = significant at $P<0.05$; ** = significant at $P<0.01$; *** = significant at $P<0.001$.

In the 2003-04 season, each of the treatments alone and in combination significantly reduced pod damage (Table 2). However, grain yields were not significantly affected by treatment, although there was a trend toward higher yield when HNPV was used and to lower yield in the combined IPM treatment where a mixed crop was used. It is possible that the reduced pod damage in the mixed crop was counteracted by the reduced chickpea population.

In the 2004-05 season, there were fewer larvae and less damage to pods in the combined IPM treatment (Table 3). Yields were also slightly, but significantly, greater with combined IPM in the sole crop but in the mixed crop yields were lower with IPM. As in the previous season, it seems that the lower chickpea population in the mixed crop counteracted the effect of lower pod damage here. A detailed study is necessary to investigate the relative profitability (and risk) associated with sole crops and intercrops as farmers often grow mixed crops in the HBT.

The on-farm evaluations indicate that the presence of bird perches, spraying with HNPV, and mixed cropping effectively reduce larval numbers and pod damage caused by *Helicoverpa* pod borer. However, in mixed crops, yields can be lower because of the reduced chickpea population. For the other treatments, yields are not always improved because of other factors, such as disease or drought, influencing yield. A recommended package for IPM for chickpea in the HBT would have the following components:

- Use of sole crops because of chickpea population being less in a mixed crop
- Monitoring of the crop from preflowering for egg-laying and small larvae
- Placement of bird perches

Table 2. Effect of IPM components on the incidence (%) of bored pods and on grain yield of chickpea in the Barind, 2003-04.

Variable	Values			*P* value
Bird perches	No perches	Perches		
Bored pods (%)	17.8	7.9		0.05
Grain yield (t ha^{-1})	0.70	0.70		0.99
HNPV	No spray	Chemical	HNPV	
Bored pods (%)	26.9	14.2	8.6	0.001
Grain yield (t ha^{-1})	0.39	0.67	0.81	0.109
Mixed cropping	Sole crop	Mixed crop		
Bored pods (%)	20.4	10.3		0.031
Grain yield (t ha^{-1})	0.45	0.41		0.251
Combined IPM	No IPM	All IPM		
Bored pods (%)	15.0	7.8		0.041
Grain yield (t ha^{-1})	0.61	0.36		0.229

Table 3. Effect of IPM on the incidence of larvae (no. m^{-2}), percentage of bored pods, and grain yield of chickpea in the Barind, 2004-05.

Variable	Sole crop			Mixed crop		
	No IPM	IPM	*P* value	No IPM	IPM	*P* value
Larvae (no. m^{-2})	1.71	0.27	<0.001	2.2	0.25	<0.001
Bored pods (%)	15.9	5.9	<0.001	14.5	5.9	<0.001
Grain yield (t ha^{-1})	0.57	0.66	<0.002	0.54	0.47	<0.005

- Timely, need-based application of HNPV spray
- Repeated application if there is rain or continued infestation

Addressing soil nutrient deficiencies

Diagnostic trial, 2001-02

An experiment using a subtractive experimental design with the following treatments was conducted:

1. Control—no seed treatment or minor element addition.

2. Seed-treated control—seed priming (soaking of seed in water for 8 h overnight prior to sowing), inoculation with *Rhizobium*.
3. Full nutrient control (All)—treatment 2 with the following elements added to the soil (kg ha^{-1}): 1.0 B + 0.5 Mo + 5 Zn + 20 S. Reagent-grade salts were used.
4. Treatment 2 with Mo + Zn + S; i.e., All – B.
5. Treatment 2 with B + Zn + S; i.e., All – Mo.
6. Treatment 2 with B + Mo + S; i.e., All – Zn.
7. Treatment 2 with B + Mo + Zn; i.e., All – S.

The experiment was implemented in a farmer's field at Chabbishnagar village, Godagari upazilla, Rajshahi District. A complete randomized block design was used with four replications. Plot size was 1.8 × 2.0 m, with 6 rows, 2 m long, of chickpea variety BARI chola 5 sown 30 cm apart. The land was plowed and leveled on 16 November 2001 and test fertilizers were added and seeds sown on 17 November 2001. Phosphorus, as triple superphosphate (TSP), was also added at 20 kg P ha^{-1}. Spray irrigation through a hose was applied to ensure even germination. After establishment, the crop was grown rainfed, with only 16 mm of rainfall falling on the crop during January-Febuary 2002. Plots were thinned to give a within-row spacing equivalent to 10 cm at 20–30 days after sowing. No weeding was necessary. Sprays of *Helicoverpa* nuclear polyhedrosis virus were given to the crop on 5 and 23 January 2002 to control pod borer (*Helicoverpa armigera*) (Musa and Johansen 2003b), and pod damage was negligible. The central two rows of each plot were harvested at maturity on 22 March 2002.

Multilocation Mo experiments, HBT 2002-03

It had previously been established that responses of chickpea to *Rhizobium* inoculation in the HBT were inconsistent, even though plants commonly showed symptoms of N deficiency. It was therefore necessary to determine how widespread Mo deficiency was across the HBT, and if a *Rhizobium* response could be found in the presence of Mo. Trials were implemented using a randomized block design in farmers' fields with five dispersed replications each at three locations with acid surface soils: (a) Porsha upazilla, Naogaon District (northern HBT); (b) Gomostapur upazila, Chapai Nawabganj District (central HBT); and (c) Amnura, Nawabganj Sadar upazila, Chapai Nawabganj District (central-southern HBT). Treatments were applied as follows:

1. Control—recommended agronomic practices for chickpea (Musa and Johansen 2003a), including seed priming, 20 kg P ha^{-1} as TSP, hand broadcasting, cross-ways plowing, rainfed, IPM for pod borer, etc.
2. As for control but Mo added to the soil, mixed with river sand, as sodium molybdate at the rate of 500 g Mo ha^{-1}.
3. As for control but with Mo added and *Rhizobium* inoculation with inoculum from the Bangladesh Institute of Nuclear Agriculture (BINA), including lime pelleting after coating seed with sticker and inoculum.

Unit plot size was 10 × 10 m and the three treatment plots of a replication were placed near each other in the same field. Chickpea variety BARI chola 5 was sown at Porsha on 25 November 2002, at Gomostapur on 26 November, and at Amnura on 27 November. Nodulation was scored according to a visual ranking scale, on 8 February at Amnura and on 9 February at Porsha and Gomostapur. Five plants per plot were dug up and ranked. Plots were harvested as follows: Porsha—5 April 2003; Gomostapur—3 April 2003; Amnura—6 April 2003. At harvest, 5 × 1-m^2 quadrats were cut from each plot and plant number, and grain and residue yields, estimated after air drying.

Mo × priming experiments, HBT 2003-04

Although there were clear responses to Mo applied to the soil in the 2002-03 season (see below), this is not practical for farmers because compound fertilizers containing Mo are not available in Bangladesh and because it is difficult to apply evenly the small rates of Mo salts required to the soil. Earlier pot trials (Harris et al 2005) had shown that chickpea seeds could be effectively inoculated with *Rhizobium* by adding the culture to the priming solution. To determine whether seed priming with Mo and *Rhizobium* could be effective and practical in the field, on-farm trials with the following treatments were established at three locations in the HBT in the 2003-04 season:

1. Control—recommended agronomic practices for the HBT (Musa and Johansen 2003a), that is, seed priming, 20 kg P ha^{-1} as TSP, hand broadcasting, cross-ways plowing, rainfed, IPM for pod borer, etc.
2. As for control but Mo added as sodium molybdate at the rate of 500 g Mo ha^{-1}, mixed with river sand and spread on the soil surface prior to plowing.
3. As for control but Mo at 0.5 g sodium molybdate L^{-1} added to the water used to prime seeds for 8 hours before sowing.
4. As for control but with both Mo and *Rhizobium* (BINA inoculum) added in the priming solution (*Rhizobium* inoculum at 4 g L^{-1} priming solution).

The experiment was laid out in a randomized block design in farmers' fields with five dispersed replications each at three locations (Porsha, Gomostapur, and Tanor) with acid surface soils. Unit plot size was 7.07 × 7.07 m (50 m^2). The four treatment plots of a replication were placed next to each other in the same field. Chickpea variety BARI chola 5 was sown at Porsha on 30 November 2002, at Gomostapur on 29 November, and at Tanor on 1 December. The crops were grown rainfed following the practices recommended by Musa and Johansen (2003a). Nodulation was estimated (see above) on 5 February 2004 at all locations and plots were harvested at Porsha and Gomostapur on 29 March and at Tanor on 28 March.

Farmer assessment of adding Mo and *Rhizobium* through priming, 2004-05

On-farm evaluation of Mo response conducted in the previous seasons had been researcher managed. To determine whether farmers themselves could implement the procedure of seed priming with Mo and *Rhizobium*, 10 volunteer farmers were selected in each of Porsha, Shapahar, Gomostapur, Nachol, and Tanor upazillas, giving a total of 50 on-farm evaluations. In 2004-05, sites were chosen on the basis of the surface soil being acidic (pH<5.5). Farmers and participating DAE block supervisors were given training in the techniques required in November 2004. The farmers were provided with sachets of Mo and *Rhizobium*, seeds of chickpea variety BARI chola 5, and TSP, together with the protocol for implementing priming. Two treatments were chosen, to be implemented in adjacent paired plots in the same field of 0.13-ha area:

1. Priming in water only (the widely accepted practice in the HBT).
2. Priming with Mo and *Rhizobium* added to the priming solution.

Three kg of seed and 6.5 kg of TSP were used in each plot of 0.065 ha. In treatment 1, farmers soaked 3 kg of seed in 3 L of water for 8 h overnight prior to sowing. In treatment 2, they did the same but also added 6 g of sodium molybdate ($Na_2MoO_4.2H_2O$) (35.68 g Mo ha^{-1}) and 12 g of peat-based *Rhizobium* inoculum. Treatment 2 buckets were frequently stirred to dissolve the Mo and maintain a suspension of *Rhizobium.* All of the water was absorbed by the seed by the end of the soaking period. Primed seed and TSP were hand-broadcast on undisturbed soil following harvest and removal of T. aman rice and the soil then immediately cultivated by bullock-drawn plow (2 × crossways, 1 × laddering) or power tiller. Sowing time was at the end of November and early December and the chickpea was grown rainfed. Farmers were advised to follow currently recommended agronomic practices for chickpea, taking particular precautions against *Helicoverpa* pod borer and BGM (Johansen and Musa 2004a,b). PROVA and DAE staff recorded nodulation score at 40–50 days after sowing, observed symptoms, and took 5 × 1-m^2 quadrats for yield estimation at crop maturity. Farmers also recorded whole-plot yields. However, 7 of the 50 plots sown had to be abandoned because of either poor establishment or damage by grazing animals.

Results of trials addressing soil nutrient deficiencies

Diagnostic trial, 2001-02: Yields of chickpea were unaffected by omitting zinc, boron, and sulfur from the trial, whereas omitting molybdenum reduced both grain and straw yield relative to the control treatment (Fig. 2). Molybdenum seems to be limiting chickpea yield at this representative HBT site, a conclusion justifying the trials implemented in subsequent years.

Multilocation Mo experiments, HBT 2002-03

By early February 2003, treatment differences were apparent at all locations, with more yellowing/reddening and less vigorous growth in the control treatment. At Porsha and Gomostapur, treatments with Mo were a bright, dark green, consistent with nitrogen adequacy. At Porsha only, there appeared to be a further response to the addition of *Rhizobium*. Nodulation was poor in the control treatment at all locations, and consistent with the apparent N-deficiency symptoms (Fig. 3A). Addition of Mo alone caused a significant increase in nodulation over the control at all three sites. Addition of *Rhizobium* caused a further nodulation response only at Porsha, consistent with the relatively low *Rhizobium* population found there (data not shown), but combined

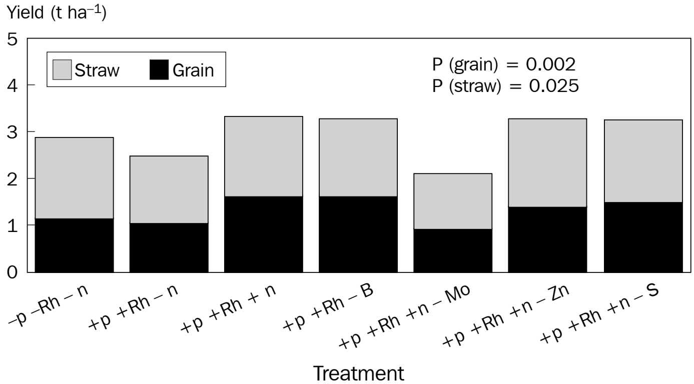


Fig. 2. Effect on chickpea straw and grain yield of withholding various micronutrients at Chabbishnagar, High Barind Tract of Bangladesh. p = priming, Rh = *Rhizobium*, n = complete nutrient mixture, B = boron, Mo = molybdenum, Zn = zinc, S = sulfur.

analysis showed a significant overall additional effect. *Rhizobia* were able to nodulate chickpea at all sites but addition of Mo was required for proper nodule functioning.

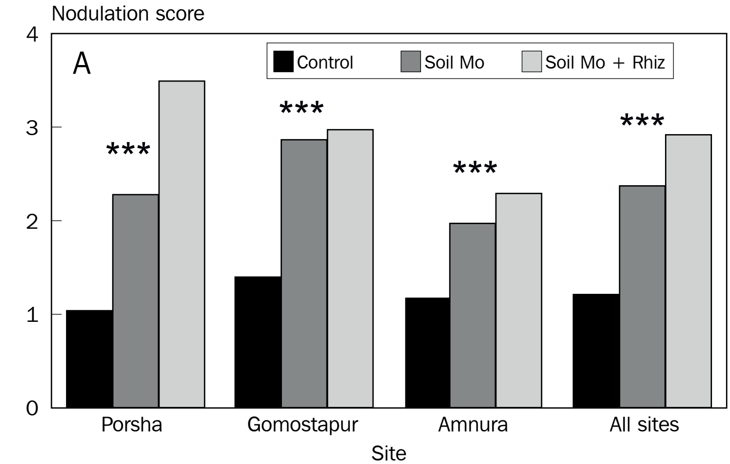
Unusually excessive rain in March and April 2003 resulted in an unprecedented severe infestation of BGM and promoted pod borer damage, thereby generally lowering yields. This effect of excess moisture was most severe at Gomostapur. Nevertheless, responses of grain yield to Mo were apparent at all locations (Fig. 3B). The overall Mo response across sites was also significant, but only at Gomostapur was there an additional response to application of *Rhizobium*.

Mo × priming experiments, HBT 2003-04

Nodulation was poor in control treatments at all locations. However, there was a significant treatment effect at all sites. The most effective treatment in promoting nodulation at all sites was priming with Mo and *Rhizobium* (Fig. 4A). In contrast to the previous season, there was no rain during the chickpea growing period and crops suffered terminal drought stress, with a consequent yield reduction. Only at Gomostapur was grain yield significantly (P<0.01) improved by the addition of Mo to the soil and by priming seeds with Mo and *Rhizobium* (Fig. 4B). Addition of only Mo to the priming water did not significantly increase yield above the control. These trends were similar at the other locations but statistical significance was not reached. However, the overall response across sites was significant (Fig. 4B).

Farmer assessment of adding Mo and *Rhizobium* through priming, 2004-05

Nodulation and grain yield were significantly increased by adding Mo and *Rhizobium* to the priming water at all five sites in the 2004-05 season (Fig. 5). Averaged over all five sites, nodulation score was 73% higher when Mo and *Rhizobium* were added, and mean grain yield increased by 20%.



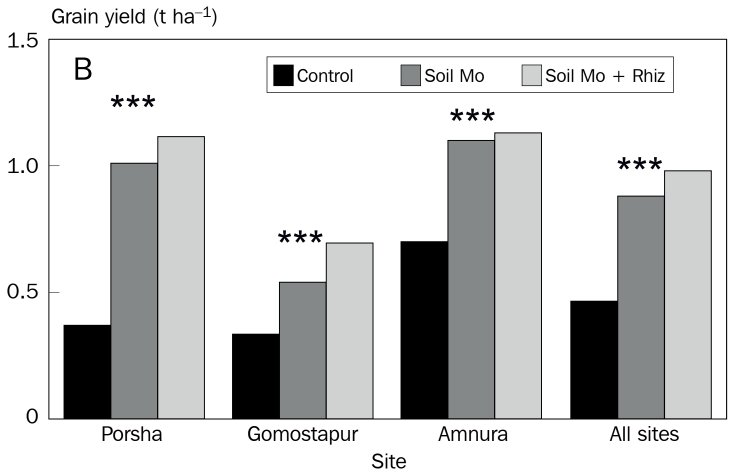
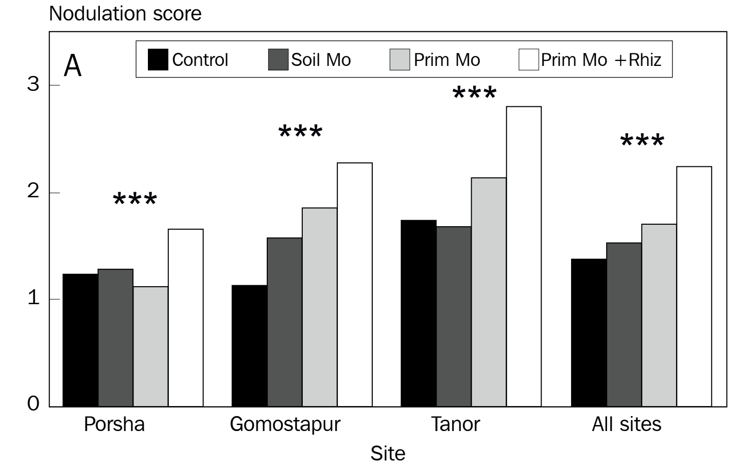


Fig. 3. Effect on the nodulation (A) and grain yield (B) of chickpea of adding molybdenum and *Rhizobium* to the soil at three sites in the High Barind Tract of Bangladesh. Data from 2002-03 season.

Conclusions

Although chickpea is a popular and potentially profitable crop with farmers in the HBT (Socioconsult 2006, Yusuf Ali et al 2007), there are numerous constraints to its production (see various articles, this volume). In this paper, we have summarized recent research that has examined some of these constraints. The solutions pursued have one thing in common—they are all low-cost interventions that should be readily adopted by the resource-poor farmers growing rainfed chickpea in the HBT. Priming seeds with water before sowing has already been widely adopted (Saha 2002) on the basis of its demonstrated potential to increase yield under the marginal conditions of



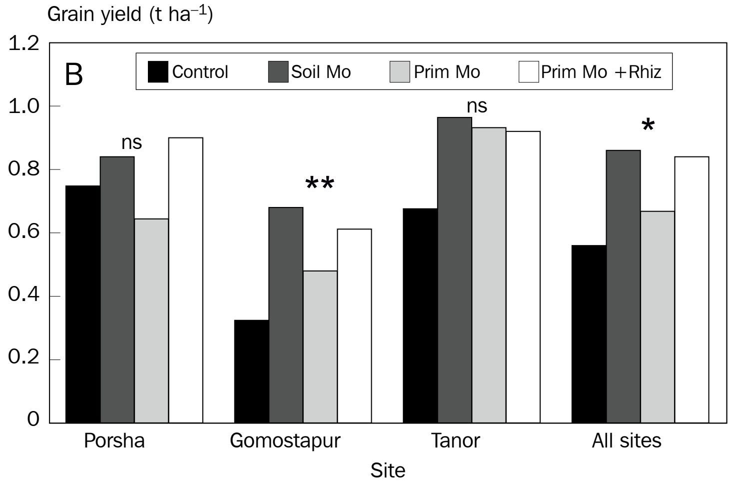


Fig. 4. Effect on the nodulation (A) and grain yield (B) of chickpea of adding molybdenum to the soil and molybdenum and *Rhizobium* to the priming water at three sites in the High Barind Tract of Bangladesh. Data from 2003-04 season.

the HBT (Fig. 1) and its ability to reduce risk of crop failure (Musa et al 2001). Good crop establishment is an absolute prerequisite for obtaining good yields.

A lack of molybdenum in the relatively acidic surface layers of HBT soils has been clearly established (Fig. 2) and we have demonstrated that chickpea responds positively to the addition of Mo to soils (Fig. 3), with a synergistic effect of providing Mo together with *Rhizobium*. However, the high cost and practical difficulty of adding Mo to soils is a problem for resource-poor farmers in the HBT. Seed priming seems to provide a useful vehicle for supplementing Mo and *Rhizobium* relatively easily and at a reduced cost (Figs. 4 and 5; Johansen et al 2005a).

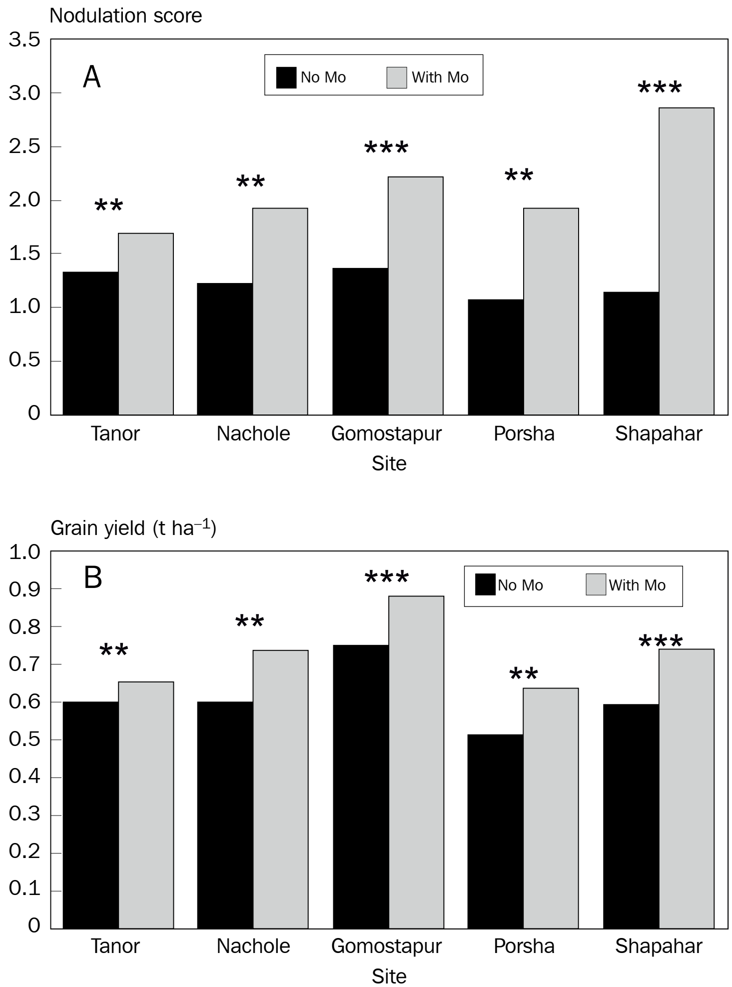


Fig. 5. Effect on the nodulation (A) and grain yield (B) of chickpea of adding molybdenum to the priming water at five sites in the High Barind Tract of Bangladesh. Data from farmer-implemented paired-plot trials in the 2004-05 season.

Integrated pest management means many things to many people but is often synonymous with integrated crop management (ICM) or best agronomic practice. For instance, the IPM package advocated for chickpea by Pande et al (2002) in Nepal is a comprehensive, best practice approach that includes the use of chemical seed dressings and fertilizers and alleviation of micronutrient deficiencies (boron). The approach is entirely appropriate in areas with a high production potential. In the HBT, however, we have focused on easily-adoptable technologies from which farmers can benefit even at low levels of production. Bird perches cost little and are effective (Tables 1–3) alone and combined with the other simple interventions. Intercropping is a common practice in the HBT and, while pod borer larvae are less abundant in mixed crops, the consequences of mixed cropping on yield are less distinct. More study is required to assess the net benefit to farmers of growing chickpea with another crop.

HNPV is technically very effective and has many attractions relative to the use of more broadly toxic chemicals, yet both share problems related to availability, quality control, and cost (Johansen et al 2005b). Our efforts, not presented here, to sustain village-level production of HNPV as advocated by Ranga Rao and Shanower (1999) were not successful and currently HNPV is being produced under more controlled conditions at Rajshahi University. It remains to be seen whether this is a commercially viable approach, but a high demand from eager chickpea growers will be essential. The research findings presented in this and other papers in this volume suggest that a range of options is available to meet the demand for appropriate technologies to support the rice-fallow crop system in the HBT.

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Integration of chickpea and other *rabi* crops into rainfed rice-based systems of the High Barind Tract

C. Johansen, A.M. Musa, D. Harris, M. Shafiqul Islam, and M. Omar Ali

This paper examines some of the major constraints to developing rainfed rice-*rabi* cropping systems in the High Barind Tract (HBT) and suggests means of alleviating them. Traditional rainfed rice cultivation in the HBT does not readily synchronize with the subsequent cultivation of rainfed rabi crops primarily because of the creation of soil conditions unfavorable to the following crops and the delayed sowing of rabi crops. For chickpea, there is a gradual linear decline in yield with a delay in sowing from early November to mid-December. However, there are instances of poor yields with early sowing and high yields with sowing in December, depending on the relative incidence of the biotic and abiotic stresses that affect chickpea. If these can be adequately managed, high yields are also possible with December sowing. The advent of direct seeding of rice and the use of short-duration rice varieties widen the sowing window and decrease the cultivation risk of chickpea and other rabi crops. A wider range of cropping options becomes possible, thus diversifying the risk associated with any one crop.

The possibilities for genetic improvement of chickpea for the High Barind Tract (HBT) were considered by soliciting farmer feedback on their preferences for traits and varieties through a participatory varietal selection (PVS) program. A farmer-researcher ideotype was thus formulated suggesting the traits required to improve upon the currently most preferred chickpea variety in the region, BARI chola 5. Such traits included shorter duration and tolerance of cold, drought, soil fungal diseases, and *Helicoverpa* pod borer. However, continued cultivation of chickpea on the same land is not recommended due to the inevitable buildup of chickpea diseases, and rotation with other rainfed rabi crops is required. The relative profitability of rainfed wheat, barley, rapeseed mustard, linseed, and coriander was compared in farmer-implemented trials in operational-scale plots. Yields of all crops, including chickpea, varied markedly over space and time, which could be attributed mainly to surface soil moisture status during crop establishment. It is suggested that this risk could be markedly reduced by using mechanized minimum tillage with uniform seed placement, as would be possible with the further development of seeders attached to power tillers. In favorable soil moisture conditions, wheat, barley, and mustard could match the profitability of chickpea, and thus provide a viable option for diversifying rainfed rabi crops. Although increased rabi cropping will improve livelihoods in the HBT, it is suggested that substantial improvements will depend on diversification of the entire agricultural production system (including vegetable production, animal husbandry, fisheries, forestry, etc.), with particular attention paid to improving water-use efficiency.

The traditional cropping system of the HBT of Bangladesh has been rainfed rainy-season rice, cultivated during June to December, with the land remaining fallow for the rest of the year (Hamid and Hunt 1987). The advent of deep tube well irrigation in the 1980s has substantially increased postrainy-season (*rabi*) cropping opportunities in the HBT but it is currently estimated that this form of irrigation will not extend to beyond 50% of the HBT area. Declining water tables suggest that there may indeed be a decline in irrigated area in the future. Therefore, there is a large scope for cropping in rice fallows, using mainly the residual soil moisture remaining after the harvest of rice.

Integrating other crops with rice into a rice-based cropping system is difficult. Soil conditions conducive to rice cultivation are unfavorable to crops requiring an aerobic root environment. With annual plowing and soil puddling for rainfed rice cultivation, a hard pan with high bulk density and low permeability to water develops at 10–15-cm depth. On the one hand, this hard pan helps retain water at the surface for rice cultivation but, on the other hand, it impedes root penetration of other crops (Samson and Wade 1998). Deep plowing to improve root penetration of aerobic crops would be detrimental to maintaining flooded conditions for subsequent rice crops. However, when surface soil in the HBT remains moist, at or near field capacity, it is possible for roots of some rabi crops, such as chickpea (*Cicer arietinum* L.), to readily penetrate the hard-pan layer and reach depths of >1 m, despite the high bulk density of the hard-pan layer as well as the soil at deeper layers (Ali et al 2002).

Another difficulty in establishing a rainfed rice-rabi crop system is that the duration of the rice crop often extends beyond the optimum time for planting of the rabi crop. Swarna is currently the most common rice variety grown in the HBT in the rainy season and it is normally harvested in late November or early December. Optimum planting time for most rabi oilseed and pulse crops in Bangladesh is considered to be before mid-November (Huda and Hussain 1989). Delayed sowing of these crops results in yield penalties due to limited biomass formation before the winter period when growth is minimal (December-January) and receding residual moisture from the soil surface. A further problem in establishing rice-rabi cropping systems is that rice, being the major staple food crop, attracts disproportionately more economic incentives, infrastructure support, and research attention than rabi crops with which it can be grown in rotation, ultimately discouraging the cultivation of rainfed rabi crops.

The purpose of this paper is to examine some of the major constraints to developing rainfed rice-rabi cropping systems in the HBT and to suggest means of overcoming these constraints. Chickpea has proven to be the most suitable rainfed rabi crop to follow rice (Islam et al 1994) but, in order to diversify the system, prospects of other rabi crops will also be examined.

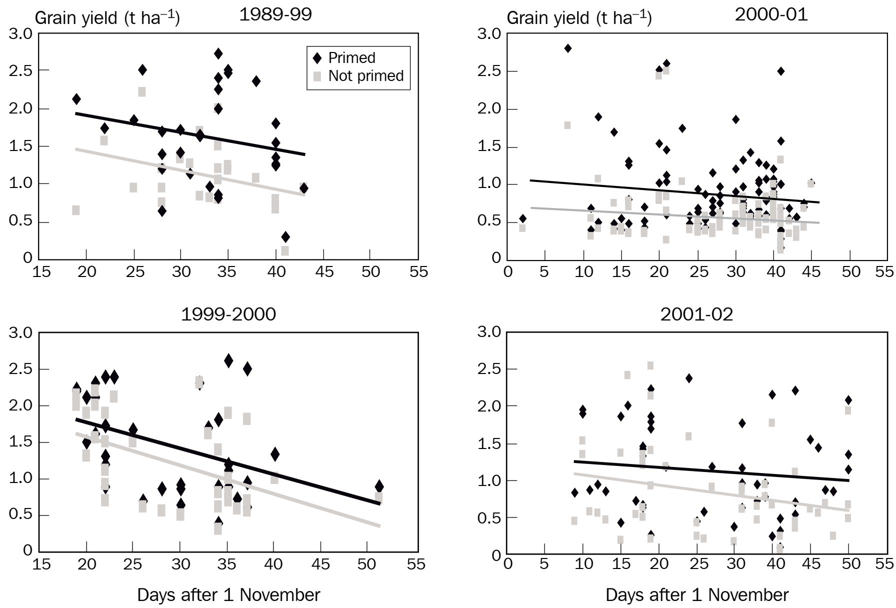

Fig. 1. Effect of sowing date on grain yield of chickpea, as measured in seed-priming trials conducted across the HBT during 1998-99 to 2001-02 (see Musa et al 2001). Fitted trend lines are shown.

Effect of sowing date on chickpea yield

The effect of delayed sowing on chickpea in South Asia is well established, with yield decreasing as the shortest day is approached (Saxena 1987). The reasons why this should also occur in the HBT include slow seedling growth due to declining temperatures into winter, drying of surface soil, delayed flowering and podding, which increases the risk of terminal drought and heat stress, damage by chickpea pod borer (*Helicoverpa armigera*), and storm damage from mid-March. A comprehensive set of on-farm trials to measure the effect of seed priming (soaking seed in water overnight prior to sowing) on chickpea growth and yield (Musa et al 2001) offers an opportunity to quantify the effect of sowing date on chickpea yield specifically for the HBT. The trials were conducted in paired plots of 666-m^2 plot size in farmers' fields across the HBT. There were 30 trials in 1998-99, 99 in 1999-2000, 101 in 2000-01, and 50 in 2001-02. Sowing dates ranged from early November to mid-December.

Yield tended to decrease in each season (Fig. 1). With seed priming, yields were higher (see Harris et al, this volume) and the decline in yield with sowing date was less. However, there was a large scatter of points, with some early-sown crops giving low yields and some late-sown crops high yields. This scatter could be attributed to other factors besides sowing date that affect yield, such as suboptimal moisture at sowing, biotic stresses including collar rot (caused by *Sclerotium rolfsii*), *Fusarium* wilt, *Botrytis* gray mold (BGM, caused by *Botrytis cinerea*) and pod borer, and nutrient deficiencies (e.g., N, P, and Mo). Reasons for low yield with early sowing could include collar rot (which affects early-sown crops more), excessive vegetative growth inducing BGM or early attack of pod borer, and nutrient deficiencies limiting biomass formation. High yields with late sowing could be attributed to sowing in niches where soil moisture remained favorable throughout growth, escape from pod borer attack, and adequate soil fertility with good nodulation.

The data of Figure 1 do confirm the general benefit of being able to sow chickpea within November, thus showing the value of growing rice that can be harvested earlier in November, whether it be direct-seeded rice or short-duration rice varieties. However, the decline in chickpea yield with sowing date is linear and gradual, and it is not necessarily disastrous for chickpea to be sown into December, for example, after the harvest of Swarna. In conditions of favorable soil moisture and with sound agronomic management, it is possible to achieve good yields of December-sown chickpea. Likewise, good agronomic management is also necessary if high yields are to be obtained from November-sown chickpea.

Increased cropping options through earlier harvest of rice

The prospect of being able to harvest rice earlier, through direct seeding (see Mazid et al, this volume) or short-duration varieties (see Joshi et al, this volume), increases cropping options in the HBT. Under a purely rainfed system, harvest of rice by early November would make it feasible to grow lentil (*Lens culinaris* Medik) and rapeseed mustard (*Brassica juncea* L. Czerni et Cosson), crops that require earlier sowing than chickpea in Bangladesh (Fig. 2). Early harvest of rice would also increase yield prospects for chickpea and rainfed cereals such as wheat and barley. The use of short-duration rice varieties (e.g., <100 days) would permit cultivation of a rainfed crop, such as aus rice or mung bean, in the premonsoon season, during April to July, while still allowing time for a rabi crop to follow transplanted *aman* (T. aman) short-duration rice (Fig. 2). If planting of the T. aman crop is delayed by drought or flooding, there would still be time for sowing a rabi crop if a short-duration rice variety were used (Fig. 2). There would also be advantages to using short-duration T. aman if irrigation were available. It would be possible to include a short-duration aus rice crop to have three cereal crops per year (Fig. 3). But it would be more desirable to fit nonrice crops, such as vegetables or mustard, between T. aman and boro rice (Fig. 3).

Improving the chickpea component

The potential yield of chickpea in the HBT is >2.5 t ha^{-1}, as has occasionally been obtained with BARI chola 5 in particular plots in the HBT where biotic and abiotic constraints were minimal. However, such yields are rarely achieved; they are usually in the range of 0.5–1.0 t ha^{-1} due to these constraints. Thus, the challenge is to close

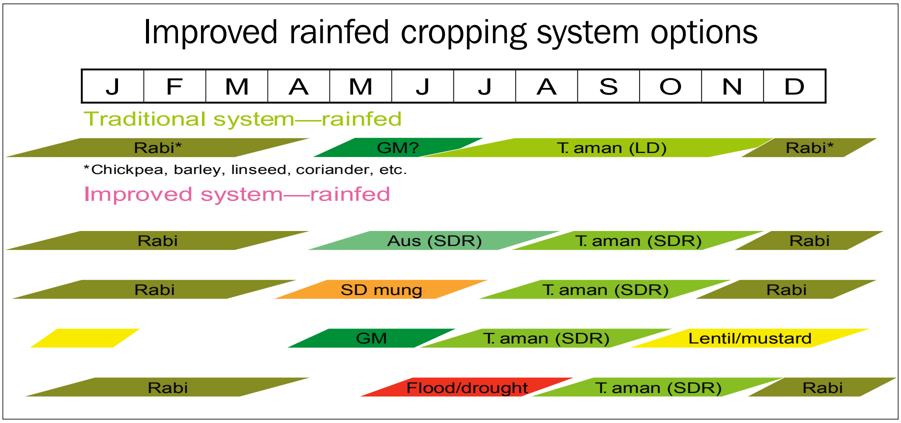

Fig. 2. Possible cropping options in rainfed agriculture in the HBT through the use of short-duration rice varieties. LD = long duration, SD = short duration, SDR = short-duration rice, GM = green manure crop.

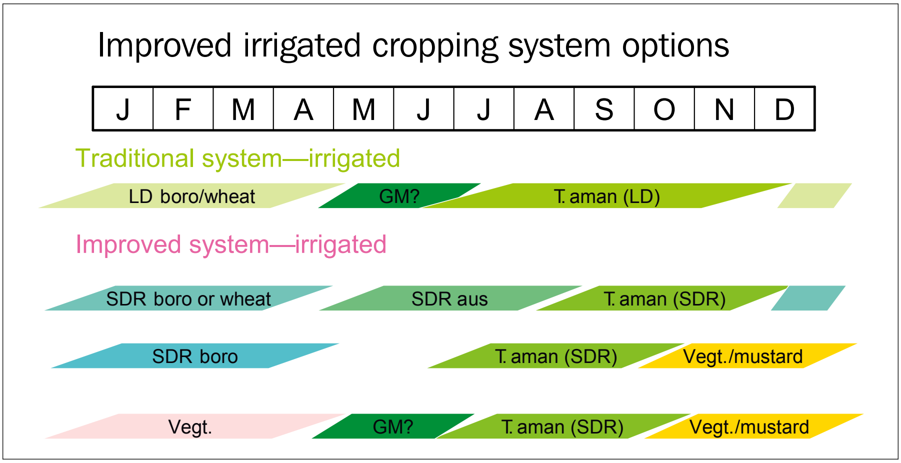

Fig. 3. Possible cropping options in irrigated agriculture in the HBT through the use of short-duration rice varieties. LD = long duration, SD = short duration, SDR = short-duration rice, GM = green manure crop, vegt. = vegetable crops.

the yield gap by agronomic means or by genetic modification of the crop such that it can better cope with the various stresses. Agronomic options for improving chickpea cultivation have been discussed in this volume by Harris et al, Salam et al, and Musa et al. They include seed priming; timely sowing into seedbeds with adequate moisture; need-based application of P, Mo, and *Rhizobium;* implementation of integrated pest management techniques; and appropriate seed harvesting and preservation techniques.

Prospects for the genetic improvement of chickpea for higher and more reliable yields in the HBT are discussed here.

It has been argued, and demonstrated for several crops, that adequate consideration of client orientation is necessary for the efficient and effective identification of improved crop varieties that will be adopted by resource-poor farmers (Stirling and Witcombe 2004, Witcombe et al 2005). We have thus used participatory varietal selection (PVS) techniques to guide chickpea introduction and breeding programs appropriate for the HBT. The prime aim was to determine farmers' preferences for traits and varieties to ensure client orientation. We also assessed whether varietal and trait preferences varied across the HBT.

A series of mother trials was conducted in 2003-04 and 2004-05 by PROVA and the Pulses Research Centre, BARI, Ishurdi. The objective was to compare performance and obtain farmer feedback on a range of chickpea genotypes under identical farmer-managed conditions in farmers' fields. Seven chickpea varieties adapted to the region but varying in traits were evaluated in 2003-04 and 9 were evaluated in the next season. Either 3 or 4 replications were sown around a village at locations representative of the northern, central, and southern HBT. There were 9 replicates in 2003-04 and 12 in 2004-05. Plot size was 5 × 5 m in 2003-04 and 5 × 10 m in 2004-05. The crops were grown rainfed with farmer implementation, but with the farmers given prior training in recommended agronomy. Groups of farmers, including those implementing the trials and others from nearby, were surveyed for their opinions on traits and varieties, near crop maturity and after harvest. Farmers were asked to rate the varieties in terms of various traits, and overall preference, on a scale of 1 to 7 or 9 (depending on the number of varieties under test), with the highest number indicating most preferred and 1 indicating least preferred.

Baby trials were conducted to assess farmer opinions across a wide area on improved or promising varieties compared with the varieties they normally grow. In 2003-04, 77 baby trials compared BARI chola 2, 4, 7, or Annigeri with farmer-used varieties, which were either "Local" or BARI chola 1 (released as Nabin in 1987 and adopted by farmers in the HBT during the 1990s). In 2004-05, there were 50 baby trials, comparing BARI chola 7 or Annigeri with either Local or BARI chola 1 or 5. After training in recommended chickpea cultivation techniques, 2.5 kg of test seed lots were distributed to farmers for growing in 666-m^2 plots next to a plot of the same size of their normally cultivated variety. Crop cultivation was entirely implemented by farmers and they were interviewed for their ratings on traits and overall performance after harvest.

Table 1 shows the outcome of pre- and postharvest assessments for the 2003-04 season. BARI chola 4, 5, and 7 were the most preferred for preharvest traits, followed by BARI chola 2 and Annigeri, with BARI chola 8 and Local the least preferred. For postharvest traits, BARI chola 2, 4, 5, and 7 were equally preferred, with Annigeri intermediate and BARI chola 8 and Local least preferred. Similar information was obtained in 2004-05 (trait data not shown) and the farmers' expectations of yield in both seasons corresponded with the actual plot yields measured (Table 2). BARI chola 8 is a kabuli type with large white seeds of high potential market value. However, it

Table 1. Preharvest and postharvest assessment of chickpea mother trials in the HBT, 2003-04 (1 = worst, 7 = best).

Trait	Chickpea variety							Significance[a]
	BARI chola					Annigeri	Local	
	2	4	5	7	8			
Preharvest								
Seedling establishment	4.0	5.9	7.0	7.0	1.4	3.6	3.2	***
Seedling disease resistance	3.9	5.8	7.0	6.7	2.8	3.9	1.9	***
Growth habit	4.0	6.6	6.8	6.7	1.9	4.8	2.1	***
Wilt resistance	4.8	6.2	7.0	6.3	2.6	4.4	4.0	***
Pod borer tolerance	3.8	6.2	6.8	6.7	1.6	4.4	4.0	***
Expected yield	4.6	6.2	7.0	6.8	2.2	3.7	1.8	***
Postharvest								
Grain size	6.8	6.3	6.9	5.8	2.7	5.4	2.3	***
Grain color	7.0	6.6	6.9	6.6	3.2	6.0	2.9	***
Grain shape	6.7	6.6	7.0	7.0	2.3	5.8	3.7	***
Cooking quality	6.9	6.9	6.9	6.9	4.1	6.4	5.0	***
Taste	7.0	7.0	7.0	7.0	3.2	7.0	5.3	***
Market price	6.9	6.9	6.9	6.9	3.1	6.3	3.4	***

[a]Differences between varieties significant at $P<0.001$ for each trait.

Table 2. Farmers' expected yields (rank; 1 = worst and 9 = best) at the preharvest survey and actual yields (kg ha^{-1}) in chickpea mother trials in the HBT in 2003-04 and 2004-05.

Season	Chickpea variety									
	BARI chola						BINA chola 3	JG 74	Anni-geri	Local
	2	3	4	5	7	8				
Farmers' expected yields (rank)[a]										
2003-04	5.7	–	7.0	7.0	6.8	2.4	–	–	3.7	1.8
2004-05	7.6	7.7	4.7	8.8	7.9		3.8	2.4	5.2	1.7
Actual yield (kg ha^{-1})[a]										
2003-04	612	–	628	774	577	292	–	–	605	510
2004-05	678	630	524	600	652	–	456	583	634	527

[a]Difference between genotypes in expected yields significant at $P<0.001$ and differences in actual yield not significant at $P = 0.05$.

Table 3. Preferences of 21 farmers who evaluated BARI chola 2 in baby trials in the HBT in 2003-04.

Trait	BARI chola 2 preferred	Both varieties equally preferred	Local preferred
Establishment	20	1	0
Time to maturity	3	18	0
Grain yield	20	0	1
Grain quality	14	7	0
Market price	15	6	0
Grow next season?	21	0	0
Overall preference	17	4	0

performed poorly due to poor seed-keeping quality (resulting in low germination and suboptimal plant population) and the attractive seeds encouraged theft. Local was often a mixture of genotypes with poor germination and disease susceptibility and thus its performance was poor. The exotic varieties Annigeri and JG 74 were preferred less than the locally developed BARI chola 2, 4, 5, and 7 and BINA chola 3 was of too long duration for this environment.

In baby trials, farmers showed an overwhelming preference for the improved variety over Local or Nabin for most traits. Table 3 presents an example, for BARI chola 2 in 2003-04. In 2004-05, when a test variety (BARI chola 7 or Annigeri) was compared with BARI chola 5, farmers ascertained little difference in ranking between varieties. Within the mother and baby trials, there was no clear difference in varietal or trait preference in different parts of the HBT but we have otherwise noted that, in the northern HBT, there is a preference for BARI chola 2 over BARI chola 5.

With this farmer input of varietal and trait preferences, it is possible to assemble a farmer-researcher ideotype for chickpea improvement in the HBT. Ideotypes, or ideal plant types, have previously been used by plant breeders and physiologists to summarize breeding objectives, specifying the traits that need to be incorporated into existing varieties in order to breed superior varieties. The use of PVS broadens the ideotype concept by also incorporating the ideas of the major clients, the farmers. Thus, to improve upon BARI chola 5 in the HBT, the following characteristics are needed:

- Shorter duration, to escape terminal drought and heat stress that occurs from early March, but without reduced yield potential.
- Cold tolerance to permit earlier flowering and pod set, and hence earlier maturity.
- Improved ability for seedlings to establish at low seedbed moisture.
- Deep rooting to capture moisture.
- Greater resistance to collar rot (caused by *Sclerotium rolfsii*) and fusarium wilt (caused by *Fusarium oxysporum*).

- Greater resistance to *Helicoverpa* pod borer.
- Seed characteristics resembling those of the old variety Nabin (BARI chola 1).

Higher yield potential under ideal conditions is not a priority. A client-oriented breeding (COB) approach (Witcombe et al 2005) is recommended for further improvement of chickpea varieties for the HBT with

- Farmer involvement in the selection of entries and segregants;
- On-farm, rather than research-station, evaluation of entries and progeny;
- Environmentally targeted to variations within HBT, including geographical (north, south) and location on the toposequence; and
- Continuous farmer interaction and feedback from parental selection to varietal release.

Rainfed crops alternative to chickpea

There are dangers in the continuous cultivation of the same crop on the same land. For chickpea in the HBT, the main problem is the buildup of the soil-borne diseases fusarium wilt and collar rot (Haware 1998). Recent BARI chickpea releases have obvious resistance to fusarium wilt in the HBT compared with older varieties such as Nabin, but resistance to fusarium wilt in chickpea breaks down over time. Despite comprehensive screening at ICRISAT, no resistance to collar rot of chickpea has been identified, only degrees of susceptibility (Nene and Reddy 1987). In order to disrupt the life cycles of these diseases, and other pests and diseases perhaps yet to be diagnosed, it is necessary to rotate chickpea with other rainfed rabi crop alternatives. However, farmers will only grow such alternative crops if the returns on them match those of chickpea. We therefore evaluated the profitability of rainfed crops alternative to chickpea in operational-scale plots under farmer management.

Earlier work of OFRD-Barind, BARI, had identified some rainfed rabi crops that can grow under rainfed conditions in the HBT, albeit with lower yields than can be obtained in alluvial soil areas of Bangladesh (Islam et al 1994, PROVA 2004). These crops were mustard (*Brassica juncea*), wheat (*Triticum aestivum* L.), barley (*Hordeum vulgare* L.), linseed (*Linum usitatissimum* L.), and coriander (*Coriandrum sativum* L.). Farmers do indeed grow small areas of "local" varieties of these crops in the HBT as intercrops in various combinations, including with chickpea. These crops, along with chickpea, were grown in operational-scale plots of 267 m^2 in dispersed replications in farmers' fields in 2003-04 and 2004-05; there were four dispersed replications in both Godagari and Nachole *upazillas* in each season. Farmers were apprised of the most recent recommendations for cultivation of these crops (varieties, sowing conditions, fertilizers, etc.) but they cultivated the crops themselves.

Grain yields of all crops were highly variable in each season (Table 4). Wheat, barley, and mustard yielded higher than chickpea (except mean yield in 2004-05) but linseed and coriander yielded lower. Yield variability could be attributed primarily

Table 4. Grain yields (kg ha^{-1}), with standard deviation (SD) of the mean and highest yield achieved, of rainfed rabi crops in the HBT in the 2003-04 and 2004-05 seasons.

Crop	2003-04 season			2004-05 season		
	Mean	SD	Highest	Mean	SD	Highest
Wheat	1,039	814	2,410	1,588	783	2,333
Barley	1,476	851	3,100	898	496	1,600
Mustard	952	492	1,580	491	260	900
Linseed	389	201	650	364	162	533
Coriander	511	66	680	339	249	800
Chickpea	646	491	1,570	660	125	860

Table 5. Input costs and profitability (t ha^{-1}) calculated for mean and maximum yields of rainfed rabi crops in the HBT in the 2003-04 and 2004-05 seasons.

Crop	Input cost in both seasons	2003-04 season		2004-05 season	
		Profitability (mean yield)	Profitability (maximum yield)	Profitability (mean yield)	Profitability (maximum yield)
Wheat	17,545	39	23,202	9,338	21,849
Barley	18,571	5,324	31,649	–4,023	7,349
Mustard	12,029	13,051	29,683	907	11,731
Linseed	10,216	41	6,879	–617	3,855
Coriander	13,383	12,713	21,413	4,015	27,553
Chickpea	11,800	14,850	52,570	15,260	23,460

to soil moisture availability at sowing, with low yields due to suboptimal seedbed moisture. Under favorable soil moisture conditions, reasonable yields, according to national averages under rainfed conditions, could be achieved for all crops (Table 4). Under certain conditions, the profitability of wheat, barley, mustard, and coriander could match that of chickpea, but not consistently (Table 5).

To reduce the risk of low yield or failure of all of these crops sown after rice in the HBT, a prime requirement is the ability to more precisely sow seed into seedbeds of adequate moisture status. For most of the plots sown in these studies, the land was cultivated with power tillers, which resulted in shallow tillage and disturbed soil exposed to soil evaporation. Improvements should be possible with minimum tillage and more precise and uniform placement of seed. Minimum-tillage seed drills that can be attached to power tillers are under development in Bangladesh (Bodruzzaman et al 2004). To improve and stabilize the yields of these alternative crops, there is also much scope for evaluating different varieties of these crops using PVS techniques, especially varieties selected elsewhere under drought-prone conditions (e.g., rainfed wheat varieties). There is also scope to refine the agronomic requirements of these crops as current recommendations are based on their cultivation in alluvial soils in Bangladesh where seedbed moisture conditions are generally favorable.

Conclusions

The possibilities for earlier harvest of T. aman rice, through the use of short-duration varieties or direct seeding, without yield loss to rice, substantially widen the sowing window for rainfed rabi crops. This is of particular benefit to mustard and lentil, for which early sowing, before mid-November at the latest, is essential. In expanding the cultivation of rainfed rabi crops in the HBT, it is necessary to focus on reducing yield risk, at minimal input cost. A prime consideration in this regard is to be able to sow into seedbeds that will maintain adequate moisture during the seed germination and seedling establishment process. There is scope for achieving this through mechanized minimum-tillage techniques. It is also necessary to meet the particular nutrient needs of each crop, such as the Mo requirement of legumes and the B requirement of oilseeds. Care is also needed in managing the biotic constraints of each crop. An advantage of the crops alternative to chickpea studied here is that they are, now at least, relatively less affected by biotic constraints than chickpea, whose yield can be drastically reduced by fusarium wilt, collar rot, BGM, and pod borer.

The major constraint to rainfed rabi cropping in the HBT continues to be inadequate soil moisture. Where tube-well irrigation is not possible, there is scope for expanding supplementary irrigation, in the form of watershed catchments, plastic hose-pipe irrigation from ponds and dams, and the use of drip irrigation. However, this would be suitable only for water-use-efficient crops, to maximize water-use efficiency (WUE) of the crops sown. Substantial livelihood improvement in the HBT depends on diversification of agricultural enterprises and income sources in the region, such as through increased cultivation of vegetables, trees, livestock, fisheries, etc. This in turn depends on improving the overall WUE of the entire production system.

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Developing seed systems for dissemination of chickpea and rice lines appropriate to the High Barind Tract

A.M. Musa, K.D. Joshi, and C. Johansen

A shortage of good-quality seed of improved varieties of chickpea is a major constraint to increased production and yield of chickpea in the High Barind Tract (HBT), as well as elsewhere in Bangladesh. Farmers mostly grow "local" varieties with seed of poor quality. This shortfall is not likely to be made up by publicly funded seed production enterprises or by large-scale commercial seed producers. Therefore, the development of small-scale village-level seed production seems the most viable solution. However, the adverse conditions of temperature, humidity, and pest susceptibility characteristic of the rainy season in Bangladesh mitigate against the production of good-quality chickpea seed. Nevertheless, there are procedures of seed processing for storage that can effectively overcome these problems, at minimal financial cost to resource-poor farmers.

From the late 1990s, the NGO PROVA has been conducting chickpea seed production and farmer training programs, first to bulk up sufficient seed of improved varieties to meet the needs of on-farm research and development programs and second to promote village-level entrepreneurship in chickpea seed production and marketing, to meet local seed requirements. In the 2004-05 season, 330 farmers were reached and 45.7 t of good-quality seed was produced. Key factors for chickpea seed preservation are adequate seed drying; sealing in plastic bags with naphthalene added; storage of bags in cool, dry, well-aerated locations; monitoring for rodent and insect damage to storage bags; and germination testing. After training, farmers could readily adopt the recommended procedures. Prices of chickpea seed and grain have been rising markedly in recent years, making chickpea seed production and marketing a profitable enterprise, if properly conducted. However, further guidance to farmers is required in methods of packaging, labeling, advertising, and local-level retailing of chickpea seed.

Because of the need to identify short-duration rice varieties that would allow timely planting of chickpea to be grown on residual soil moisture after the rice harvest, PROVA implemented a participatory varietal selection program for short-duration rice introductions. This required rapid bulking up of seed of test entries for wide-scale farmer evaluation across the HBT. Therefore, rice

seed production and preservation techniques were also imparted to farmers, following the methods used for chickpea but with fewer precautions necessary to maintain seed quality.

More widespread farmer training in seed production, preservation, storage, and marketing techniques will be required if the rate of adoption of improved varieties of chickpea and rice is to increase. Increased farmer knowledge of seed technology stimulates farmer demand for further knowledge of improved agronomic techniques in general, as seed is considered as a vehicle for several components of improved agronomy. Training in improved seed systems and technology should be directed at entire rural families as women and children are usually heavily involved in postharvest activities.

Seed is a dominant input of annual cropping systems. The lack of good-quality seed is a major reason for the slow spread of improved crop varieties and technologies in South Asia, especially for resource-poor farmers. Seed is a sensitive, living commodity, requiring scientific management if it is to produce an optimum crop stand. One reason for the pervasive problems of seed systems suffered by resource-poor farmers is because seed management is knowledge-intensive. In mechanized, commercial, capital-intensive agriculture, farmers usually buy their seed from commercial organizations, which follow state-of-the-art procedures of seed storage, treatment, and distribution, according to predetermined government standards. In subsistence and partially commercialized agriculture in South Asia, commercial seed organizations are interested only in seeds for which there would be a high return, such as hybrid and vegetable seeds. Public sector seed production schemes have attempted to meet the seed requirements of the major subsistence crops, which usually have seeds of lower value than would interest commercial organizations. However, public sector schemes have been able to meet only small proportions of national requirements for the major crops, such as rice, and even lesser proportions of minor crops, such as pulses. For example, the Bangladesh Agricultural Development Corporation (BADC), with a mandate for national seed supply, could by 1998-99 supply only 3.4% of the rice seed required in Bangladesh and only 0.8% of pulse seed requirements (Hossain 1999). If resource-poor farmers are to have access to seed of good quality of the best available varieties of the major subsistence crops, there needs to be improvement in seed production, processing, storage, and dissemination techniques operating at the village level.

In view of the limited opportunities for an external supply of good-quality seeds to resource-poor farmers, it becomes necessary to disseminate information about optimum seed production and preservation requirements of the major crops grown among the farming community. Although this knowledge is science-based, various practical and effective methods of seed storage that are suitable for use by resource-poor farmers have evolved, but they are not always widely known among potential users. As women and children are often involved in seed-processing activities in and around the homestead, it is important to include this group in the learning process.

This paper describes attempts to empower farmers of the High Barind Tract (HBT) with the knowledge to be able to meet their needs of good-quality seed of improved varieties of chickpea. It also describes procedures followed to multiply seed of short-duration varieties of rice recently introduced for the purpose of farmer evaluation of these varieties.

Constraints to the availability of chickpea seed

Chickpea is a relatively new crop for the HBT, grown on residual soil moisture after the harvest of transplanted rainy-season rice (T. *aman* rice). With the development of suitable postrice cultivation techniques and the identification of suitable chickpea varieties, such as Nabin (BARI chola 1), the area under chickpea in the HBT expanded during the 1990s, to reach an estimated 10,000 ha by the turn of the century. Farmer interest in chickpea was aroused by the availability of improved varieties and the advent of such simple techniques as seed priming, which could substantially increase yields with little additional input (Musa et al 2001). This created a demand by farmers for good-quality seed of improved chickpea varieties, but this demand could be addressed only marginally. Five years ago, only about 5% of chickpea seed sown in the HBT was considered to be good-quality seed of an improved variety. The remainder was considered as Local, which was an unknown variety or mixtures of varieties with poor seed quality. Most of the chickpea seed sown was saved by the same farmer from the previous season's crop; little chickpea seed was traded.

The major constraints to the availability of good-quality seed of improved chickpea varieties were

- Lack of public sector provision of improved seed or an effective seed distribution system even if seed stocks were available.
- Lack of interest of commercial seed producers in chickpea.
- The particular susceptibility of chickpea seed, compared with seeds of other crops, to spoilage when stored during the hot, humid summer and rainy season (April-October).
- As with other pulses, the susceptibility of chickpea seed to bruchid damage while in storage.
- Inadequate farm household knowledge of appropriate chickpea seed storage methods.
- No local-level, organized chickpea seed marketing arrangements.

As a result of a lack of an effective seed production and distribution system for chickpea, farmers were obliged to sow mixtures of seed with low and variable germination percentage. Germination testing prior to sowing, so that farmers could adjust their seed rate if the germination percentage was low, was generally not done and so suboptimal crop stands were usual. Particularly in this moisture-limited environment, plant population is a major determinant of grain yield.

Recommended chickpea preservation methods

Despite the sensitivity of chickpea seed to spoilage in the climate of Bangladesh, measures can be taken that effectively alleviate such damage. The recommended procedure, based on extensive use by PROVA in recent years, is as follows:

- Fields for chickpea seed production should be designated early in the crop growth cycle and extra precautions taken to maximize their yield (e.g., protection against *Helicoverpa* pod borer). The fields should be of a known improved variety and should be examined for uniformity of plant type, and off-types discarded so as to maintain varietal purity. Chickpea is self-pollinating and so varietal deterioration through cross pollination should not be a concern, only mixing of seed of different genotypes.
- Harvest seed when the crop is fully mature, and dry it as soon as possible after any rain event near maturity.
- Conduct threshing and seed drying on a floor completely devoid of other chickpea seed to avoid mixing seed.
- Dry seed spread out in one layer for at least 8 hours in full sunlight (at ambient shade temperatures of 25–35 ºC). This should lower seed moisture content to an acceptable level (8–9%) and force any bruchids already present in the seed to vacate the seed-drying area.
- Check seed for seed of other species (e.g., weeds) and of other chickpea varieties (if distinguishable), and remove by hand accordingly.
- After sun drying, place seed in shade and allow it to cool to shade temperature, before placing it in a thick plastic bag of 15–50-kg capacity.
- Place one naphthalene ball (1 g) for every kg of seed, evenly distributing the naphthalene as the bag is filled. Dry leaves of the neem tree can be used if naphthalene is not available or there is any chance of the seed being consumed by humans. Another alternative is to thoroughly mix 5 mL of mustard, linseed, or neem oil per kg of seed. However, a prerequisite to ensuring that seed is free of bruchids is thorough sun drying and insect-proof packaging (see above).
- After filling the bag, immediately tie the neck to make an insect-proof seal. Place the plastic bag in a gunny (jute) bag or large drum (plastic or metal) for extra protection.
- Store bags in a cool, dry, sheltered location, on a ramp raised above ground level so that air can circulate around the bags.
- Check bags during the rainy season for any signs of insect (e.g., ant) or rodent damage. If such damage has occurred, the seed will have to be sun-dried again and repacked as described above.
- After opening bags prior to sowing, the seed needs to be checked for viability (percentage germination). Take 50 seeds from representative bags and place them between moist cloth or paper. Inspect seed for germination at 4–5 days. For the degree to which germination is less than 100%, calculate the extra

seed needed to attain the recommended seed rate (e.g., if germination is 80%, then 25% extra seed will be needed to achieve a given seed rate).

Placing sealed bags of chickpea seed in cold storage (5–10 ºC) will better ensure that there is no high temperature or humidity, or insect or rodent damage, but this is considered unnecessary if the mentioned precautions are taken. In any case, cold storage of seed of field crops is generally beyond the reach of resource-poor farmers. The postharvest handling of chickpea seed is usually done by the women and children of the household; therefore, they need to be targeted in any training program on seed preservation.

Village-level chickpea seed production

When PROVA initiated on-farm research on chickpea seed priming in the late 1990s (Musa et al 2001), there was little seed available of improved varieties (e.g., BARI chola 2 and 5) of adequate and uniform quality. It was therefore necessary to begin a seed multiplication program to ensure that enough seed would be available for future on-farm trials, farmer evaluations, and demonstrations. Thus, PROVA undertook two types of seed multiplication and procurement schemes. In one scheme, farmers willing to participate in seed production were identified and seed lots of an improved variety, mainly BARI chola 5 but also BARI chola 2 and some other varieties that had performed well in the HBT, were provided to the farmers. Farmers were also instructed in currently recommended optimum chickpea cultivation practices, but were not provided with any other inputs besides the seed. Participating farmers agreed to return to PROVA, after harvest, one-and-a-half times the amount of seed that they had initially received. However, this scheme would not produce the quantities of good-quality seed required for future programs and so PROVA also purchased seed in addition to the returned seed. The purchased seed was packed as indicated above but stored in cold storage facilities for additional security.

However, in order to initiate a sustainable system of good-quality chickpea seed production in the HBT, irrespective of the seed requirements of PROVA programs, village-level entrepreneurship in meeting local seed requirements was facilitated. First, care was taken in selecting appropriate farmers to be involved in seed production. Farmers among small, medium, and large farming categories in a village were selected on the basis of their interest in participating, possession of a suitable location for seed storage, and having some prior experience in seed preservation. Final selection of which farmers would be assigned which chickpea varieties was made by ballot. Only one variety was assigned for seed production to each farmer to avoid seed mixtures at any step in the process. The selected seed producers were then trained in recommended chickpea cultivation procedures, along with the foundation seed, at the beginning of the season, and trained in seed preservation methods, as outlined above, near harvest. In the first year of training only, they also received the required polythene bags, gunny sacks, and naphthalene. Participating farmers are now also provided with

Table 1. Farmers involved, area of land, seed production, and fate of seed under the chickpea seed multiplication, preservation, and marketing program for the High Barind Tract organized by PROVA over the previous five seasons.

Season	Number of farmers	Land area (ha)	Total seed production (kg)	Seed purchased by PROVA (kg)	Seed preserved by farmers (kg)	Quantity of seed sold (kg)
2000-01	21	4.8	5,365	1,600	2,028	1,134
2001-02	75	24.9	26,000	7,000	4,955	13,899
2002-03	122	51.3	6,485	3,469	2,024	1,035
2003-04	115	44.3	30,958	4,796	n.a.[a]	n.a.
2004-05	330	84.3	45,655	6,880	3,370	35,405

[a]n.a. = data not available.

a register book in which they record details of seed produced, stored, and sold. This allows tracking of dissemination of improved varieties.

The numbers of farmers trained, area sown for seed production, and seed produced over the previous five seasons are shown in Table 1. The amount of seed procured by PROVA, to meet the needs of future programs, the seed preserved by farmers using the recommended methods, and the amounts sold by farmers as seed are also indicated (Table 1). The small amount of seed preserved and sold in the 2002-03 season was the result of frequent rains during the crop reproductive period in that season, causing a severe epidemic of botrytis gray mold (BGM, caused by the foliar disease *Botrytis cinerea*), increased attack by chickpea pod borer (*Helicoverpa armigera*) due to ineffectiveness of insecticide sprays because of frequent rains, water spoilage of seed prior to harvest, and inability to properly dry seed after harvest. This was an unprecedented rainfall experience over this period in the HBT.

Production of chickpea seed in particular is becoming increasingly profitable due to the increasing price of chickpea grain and seed over recent years. Chickpea grain from the 2005-06 harvest was selling in the HBT for Tk 40 kg^{-1} and the current price of chickpea seed, prior to the 2006 sowing period, was Tk 60 kg^{-1}. Assuming costs of preservation, including storage bags, naphthalene, and storage space, to be Tk 5 kg^{-1}, there would be a premium of around Tk 15 kg^{-1} for preserving chickpea seed rather than selling it as grain soon after harvest. However, a disincentive for keeping seed for sale would be the relatively high price of grain at harvest (c.f. previous years), household requirements for chickpea consumption, or an immediate requirement for the proceeds of chickpea grain sale.

Farmers could readily adopt the relatively simple technology steps involved and the inputs required (storage bags and naphthalene) are readily available and inexpensive. However, further follow-up efforts are needed in promoting sustainable small business activities in seed production. Instruction is needed in packaging seed for sale as "truthfully labeled seed." Tamper-proof packaging techniques need to be introduced to permit sale beyond the village boundaries, to customers not otherwise known to the seller. It is suggested that the "Farmseed" model of seed entrepreneurship, as developed by the NGO ASA (Agricultural Advisory Service), be followed (Van Mele 2005). This encourages the development of resource-poor seed producers at the village level who preserve seed themselves and directly sell it onward to fellow farmers. An alternative model, as followed by GKF (Grameen Krishi Foundation), involves the purchase of seed by GKF from contract growers and then packaging and sale of truthfully labeled seed by GKF (Van Mele et al 2005). However, the GKF model involves greater transaction costs due to the extra steps involved. The Farmseed model requires training of farmers in appropriate seed production and preservation techniques and effective packaging, labeling, and marketing techniques applicable at the village level.

Seed production of short-duration rice

One of the constraints to chickpea production in the HBT is the delayed harvest of the T. aman rice crop, causing reduced availability of surface soil moisture for chickpea germination and establishment (see Johansen et al, this volume). A participatory varietal selection (PVS) program involving short-duration rice varieties, which would mature in time for optimum sowing of chickpea, started in 2002 (see Joshi et al, this volume). The test varieties were mainly introduced from Nepal, for which only limited amounts of seed could be brought. PVS methodology necessarily requires large amounts of seed for wide-scale testing in mother and baby trials in farmers' fields (Witcombe et al 2005). There was therefore a requirement to rapidly bulk up large quantities of seed of varieties found promising in first-year mother trials, to allow farmer evaluation in operational-scale plots in baby trials conducted over a wide geographical area.

Production of rice seed is easier than that of chickpea seed for two main reasons. First, in the HBT environment, it is possible to grow rice throughout the year. For example, promising rice varieties could be harvested in November, grown for seed production as irrigated *boro* (winter-spring) rice during December to April, to have seed ready in time for the next T. aman season, for planting in seedbeds in June. Second, rice seed is much easier to preserve than chickpea seed, with fewer precautions required to ensure quality seed. Nevertheless, the following precautions are required:

- Roguing of off-types from the designated seed plots, to ensure varietal purity, and regular monitoring of the plot to ensure minimal infestation of diseases that could be transmitted with the seed.
- In all harvest and postharvest handling procedures, ensure that there is no seed mixing with other varieties; for example, the threshing floor and storage bags should have grains of any other rice varieties completely removed from them.
- Sun drying of rice to a moisture content of <14% prior to storage.
- Storage in airy, dry locations, with regular checking for rodent damage.
- Germination testing prior to sowing, and adjustment of seed rate accordingly.

Table 2. Farmers involved, area of land, seed supplied, and seed production under the short-duration rice seed multiplication and preservation program for the High Barind Tract organized by PROVA.

Year	Season	Number of farmers	Land area (ha)	Seed supplied (kg)	Total seed production (kg)
2003	T. aman	18	2.4	180	5,305
2004	T. aman	159	28.7	2,160	81,500
2004-05	Boro	138	31.5	2,360	170,553
2005	T. aman	40	6.0	450	15,594

Similarly as for chickpea seed production, farmers were selected for rice seed production according to their interest, storage facilities available, and experience in seed production, and each selected farmer was assigned only one variety. The number of farmers involved in seed production of short-duration rice varieties under the PVS program and the quantity of seed produced are indicated in Table 2. For short-duration rice varieties for which a farmer demand eventually develops, it will also be necessary to evolve a village-level seed production scheme. This could follow the procedure as described for chickpea, essentially following the Farmseed model, which was itself originally developed for rice (Van Mele 2005).

Conclusions

Ready availability of good-quality seed of improved chickpea varieties remains a constraint to chickpea production in the HBT, and throughout Bangladesh. Alleviation of this constraint will depend on the proliferation of small-scale seed producers empowered with the necessary technical know-how. Although chickpea seed is particularly sensitive to loss of quality in storage compared with other crop plants, there are established methods of seed preservation well within the reach of resource-poor farmers. Dissemination of this know-how will depend on the conduct of further training programs, directed at all rural household members as women and children play an important role in postharvest operations for chickpea as well as for other crops. Training must not only encompass the technical aspects of seed preservation but also promote skills in small-scale marketing. This will require locally implemented quality control and effective packaging, advertising, and marketing.

Although preservation of rice seed is less problematic than that of chickpea seed, there is also a need to promote village-level production of good-quality rice seed if farmers are to have timely access to new, improved rice varieties. Effective models, such as Farmseed, have been successfully tried elsewhere in Bangladesh and they should also be promoted in the HBT.

Good-quality seed of improved varieties of crop plants can be a vehicle for other components of improved agronomy, such as seed priming, seed treatment with pesticides, inoculation with beneficial microorganisms, appropriate seed rate, etc. It is suggested that improvement of farmers' knowledge of key technical and scientific aspects of the seed will create farmer demand for information on other components of improved agronomy, leading to higher and more stable yields. There is thus a need for more comprehensive training programs, directed toward the entire rural family, on seed technologies of the major crops grown.

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Decision-making for *rabi* cropping in the High Barind Tract of Bangladesh: a farmer perspective

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A farmer perspective on improving agricultural productivity in the High Barind Tract was developed through the analysis of farmer decision-making at both the plot and whole-farm levels. A decision-tree was constructed to model the decision to sow dryland rabi crops. The tree incorporated 11 separate decisions that included a combination of climatic, physical, and socioeconomic variables. A validation exercise showed that the tree correctly predicted 78% of the outcomes. Household survey data were used to analyze socioeconomic factors that influenced rabi cropping. Harvest dates were the same for both long-duration Swarna and short-duration MVs (modern high-yielding varieties), suggesting that farmers minimized transaction costs when hiring harvest labor. The harvest labor contract delayed rabi sowing by one week because of the need for straw to dry. Resource-poor farms were less likely to grow MV T. *aman* rice because they had more highland with poorer soils and because they needed to maximize yields on sharecropped plots. Rabi cropping was also most intensive on resource-poor farms because of the need to make the best use of limited land. Farmers recognized the potential to increase the area under rabi crops if rice was harvested earlier. However, time of harvesting was determined by Swarna, which occupied 80% of the area planted to T. *aman* rice. We conclude that rice-based interventions will have limited impact on agricultural productivity in the rabi season until breeders have developed a variety with a shorter field duration that will be as widely adopted as Swarna.

Recent efforts to increase agricultural productivity in the High Barind Tract (HBT) have focused on increasing cropping intensity by expanding the area planted to *rabi* crops in the dry season. Rabi cropping depends on timely crop establishment after the harvest of the main monsoon rice crop to take advantage of residual soil moisture. Decision-making for rabi is therefore a complex process by which farmers manipulate the time of rice harvest, tillage, and sowing under rainfall and soil conditions that they cannot fully control.

Understanding farmer decision-making is important because the complexity of the rice environment in the HBT limits the value of prescriptive recommendations ("do X") in favor of conditional recommendations ("if Y, do X") that take into account contingencies. A first step in developing recommendations for the HBT is therefore to understand what farmers actually do and the contingencies that they must take into account before deciding on a particular action. This process of decision-making can be formalized in a logical sequence as a decision-tree. Once farmers' decisions are understood in this way, researchers are in a better position to design new technology that will fit the farming system and allow farmers to increase productivity. Decision-trees have been used to model a wide range of decision processes, including the timing and rate of fertilizer application (Gladwin 1976), the adoption of new crop varieties (Franzel 1984), buying fertilizer on credit (Gladwin 1992), and weeding (Orr et al 2002).

Researchers usually test new technology with farmers through on-farm trials (OFTs). One limitation of this approach is that it may fail to capture constraints that operate at the level of the farming system. Consequently, new technology that works well on a single plot may work less well for a whole farm. This makes it essential to complement OFTs with socioeconomic research in which the unit of analysis is not the plot but the farm household. In this paper, we use evidence from household surveys to explore how some socioeconomic factors might influence the acceptability of new technology to increase cropping intensity.

The general objective of this paper is to explore the factors determining farmers' decisions to sow rabi crops in the HBT. Specifically, the paper seeks to answer the following questions:

- How do farmers decide whether or not to sow a rabi crop?
- How important are socioeconomic factors in this decision?
- How much potential actually exists to increase cropping intensity?

The arguments summarized in this paper are based on data collected by the BRRI/IRRI/NRI Project in the HBT over four years of fieldwork. Research results have been reported in a series of Working Papers (Orr and Jabbar 2002a,b, Orr et al 2005). Copies of these Working Papers are available on the compact disc that contains the final project report, which is available on request from the authors.

Data and methods

Data

Information on farmers' decision-making for rabi came from the following sources. Two household surveys were conducted in Rajshahi District in 2002 and 2005. The first surveyed 91 farmers from 12 villages in Godagari, Nachole, and Tanore *thanas* in Rajshahi District (Orr and Jabbar 2002b). The survey was conducted in March 2002 after the harvest of the T. *aman* crop planted in 2001 and the planting of rabi crops harvested in 2002. Originally, it was intended to re-survey households that had participated in an earlier weed management survey conducted for the T. aman crop in 2000 (Orr and Jabbar 2002a) but this was not possible in all cases. Of the 119 farmers from Rajshahi District surveyed in 2000, however, the majority were re-surveyed for the rabi crop in 2001. Hence, both the T. aman 2000 and rabi 2002 surveys cover largely the same farmers. The second household survey sampled 80 farmers from 6 villages from Godagari and Nachole thanas. Of these, 43 (54%) were OFT farmers while 37 (46%) were non-OFT farmers. The survey was conducted in two rounds in 2005, round one in October after the first weeding of the T. aman rice crop and round two in December after the planting of the rabi crop harvested in 2006.

A qualitative study of farmer decision-making was made for a sample of 9 OFT farmers in the 2004 rabi season in order to develop a decision-tree (Orr et al 2005). This decision-tree was tested with a subsample of 29 of the 80 farmers surveyed in 2005. Of these, 21 (72%) were OFT farmers while 8 (28%) were non-OFT farmers.

Methods

Gladwin (1989) has described in detail the methodology of hierarchical decision-trees. A decision-tree can be defined as a sequence of discrete decisions that have to be made before a particular outcome can be chosen. Briefly, a decision-tree contains three elements:

- The choice of alternatives appears at the top of the tree and must represent an either-or choice. In this case, the alternative was posed as "sow rabi*,* don't sow." The set of alternatives must contain all the possible outcomes at the foot of the tree.
- The decision criteria are the set of factors that is actually considered in order to reach the final outcome(s). These may be either mutually exclusive alternatives ordered on a particular feature or aspect of these alternatives, or constraints that must be overcome or "passed" to reach a particular outcome. An example of the latter is the decision criterion "Is seed available for the chosen rabi crop?", which determines whether the farmer has sufficient labor to weed. Decision criteria admit only two outcomes (yes/no).
- Decision outcomes are located at the ends of the paths of the tree and represent the results of a particular decision criterion. Following Gladwin (1989), the term "outcome" is used to mean "action taken" and not the outcome of an action in terms of yield or revenue that might include no action.

Choice *alternatives* are shown in a set at the top of the tree denoted by { }, the *decision criteria* at the branches or nodes of the tree denoted by < >, and the *decision outcomes* denoted by [ ] at the ends of the paths of the tree.

Decision-making for rabi

Decision-tree

A decision-tree developed through discussion with farmers identified 11 discrete decisions that farmers made in deciding whether to leave land fallow or sow a rabi crop (Fig. 1). The decision-tree was tested against the actual decisions made by selected farmers in the 2005 rabi season. Of the 50 plots for which information was collected, the tree successfully predicted 78% of the outcomes. The 11 errors represented plots

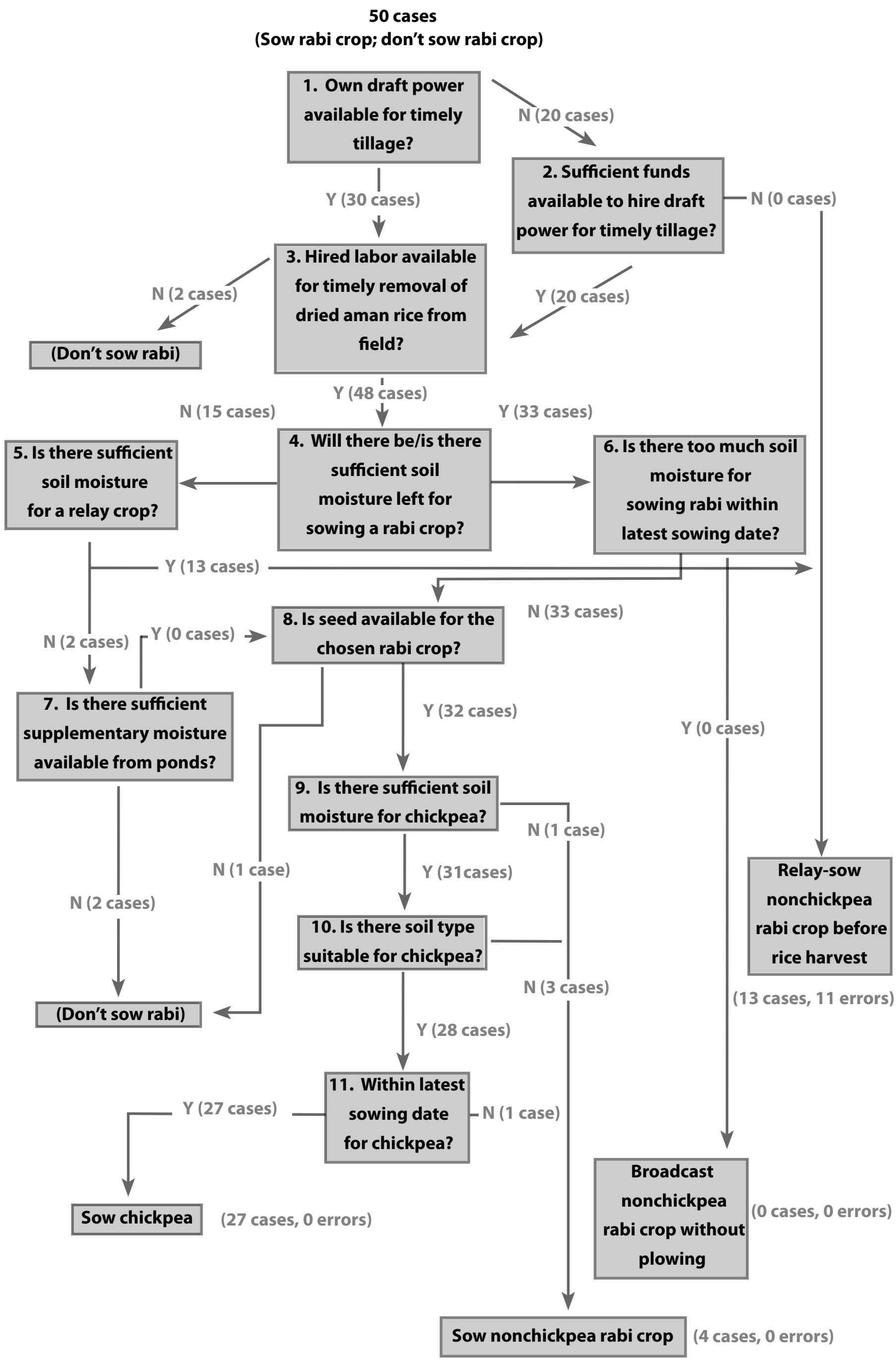

Fig. 1. A decision-tree for sowing of a rabi crop.

where farmers decided not to relay-sow a rabi crop before rice harvest. The reasons farmers gave were that land was high and soil moisture would not last long enough (6 plots), relay-crop yields were too low to justify this practice (4 plots), and inexperience with relay-cropping (1 plot). Thus, the tree represents a reasonably accurate picture of farmers' decision-making process for the rabi crop.

Draft power. Availability of draft power was essential for timely land preparation. Farmers without their own draft power relied on hired draft animals or power tillers. There were mixed opinions about which method was best for rabi crops. Although land preparation with power tillers was faster, some farmers preferred animal draft power because plowing was deeper and this improved the amount of soil moisture available for the crop. Hiring draft animals was sometimes difficult because owners wanted to complete land preparation on their own fields first and because animals were also needed to cart rice from the field after harvest. Farmers who used power tillers nearly always hired draft animals after plowing in order to harrow the soil.

Harvest labor. Rice was usually harvested under a type of contract, known as *zin*. In this contract, a labor gang (*dol*) cut the crop and laid it in the field to dry. After drying, the *dol* returned to the field and helped load the crop into a cart for transport to the homestead for stacking. Transport was the farmer's responsibility; laborers only helped load the crop and build a stack in the homestead. After all the rice was harvested, a *dol* usually rested for a week, then returned to thresh, clean, and help the farmer store the paddy. These people were not responsible for stacking straw once it had been threshed. Payment rates varied but laborers were always paid with a share of the crop (usually 15%).

Soil moisture. Sowing depended on sufficient soil moisture (*batal* or *rosh*) after harvest. Availability of moisture depended on rainfall in the first week of *kartik* (15-21 October) or light rains at harvest; no rain at this time meant the highland dried out before harvesting and had to be left fallow. On lowland, heavy rain might result in too much standing water, which prevented sowing until the soil had dried out. The quality of soil moisture was important, because chickpea needed less moisture than mustard but more moisture than *khesari* (grasspea).

Supplementary irrigation. When soil moisture was inadequate, farmers might irrigate in order to sow rabi crops, but generally fields that could be irrigated from ponds were reserved for wheat rather than for dryland crops. Fields that could be irrigated by tube wells were usually reserved for boro rice but some farmers also sowed mustard between T. aman and boro rice.

Relay-cropping. Farmers who lacked draft power or who feared that soil moisture at harvest would be insufficient had the option of relay-sowing a rabi crop into the rice crop before harvest. Since relay-sowing was not possible with chickpea, this limited the choice of crops to grasspea or linseed. Relay-crops could be sown up to 20 days before harvest but not earlier because they grew tall and interfered with harvesting.

Seed. Farmers preferred to buy seed from villagers they knew and trusted rather than from the local market. Farmers had developed their own methods of testing for seed quality by inserting 20–25 seeds in the stem of the *arum* plant, which was then sealed and opened 1 week later to check the germination rate. If germination was poor, farmers returned the seed to the seller.

Soil type. Farmers distinguished several soil types according to texture and color. Red *chayyai* soils dried out rapidly and were usually left fallow unless irrigated for rice. Another name for these soils was *barendro*. Black *chayyai* soils were described as fertile and could be used for chickpea. Unlike *pali* or *jawai* soils (sandy or sandy-loams), *chayyai* soils were heavier and were not carried down the toposequence by rainwater.

Latest sowing date. On high and medium land, the cut-off date for sowing rabi crops was determined by soil moisture. On lowland where there was standing water, farmers reported that chickpea was not sown after the end of *Agrahayon* (15 November-15 December) because pods were small and there was greater risk of damage from pests.

What does the tree show? Several points can be highlighted from the decision-tree presented in Figure 1.

- Decisions on rabi cropping involved a *combination* of climatic, agronomic, and socioeconomic variables. New technology to increase rabi cropping needs to take all these variables into account, rather than just focusing on one in isolation.
- Socioeconomic variables (labor, draft power) logically take priority because they influence the amount of soil moisture that is actually (as distinct from technically) available for sowing. For example, the inability of farmers to obtain labor to remove straw from the field after drying before the soil moisture dried out might prevent rabi sowing.
- Farmers have a range of options for how and when to sow rabi crops (relay-sowing, broadcasting, zero-tillage). Low yields from relay-crops deter many farmers from rabi cropping.
- Chickpea requires quite specific conditions in terms of soil, soil moisture, and timing of sowing. Even where these conditions are met, farmers might be deterred from sowing chickpea on plots where there is a high risk of theft or damage from livestock (a decision that does not appear in the tree).
- Two important aspects of decision-making that do not appear in the tree are the date of rice harvest, which determined the starting point for the decision-making process, and the very limited time that farmers had for maneuver, which meant that a delay of only a few days might result in land being left fallow.

Socioeconomic factors in decision-making

The decision-tree captured decision-making at the plot level. It did not capture socioeconomic variables that might influence decision-making at the farm level. In this section, we use household survey data to show three ways in which socioeconomic factors influenced decisions about rabi cropping.

Table 1. Mean dates of T. aman transplanting, T. aman harvesting, and rabi planting by variety group, Rajshahi District (2002).

Date	Variety group			Sig. level ($P >$)
	Swarna	MV	Other LV	
Transplanting[a]	19 July (8.52)[b] (n = 175)	19 July (7.98)[b] (n = 66)	Not available	0.893
Harvesting	28 Nov (2.96)[b] (n = 231)	28 Nov (2.61)[b] (n = 44)	28 Nov (2.62)[b] (n = 14)	0.659
Rabi sowing[c]	1 Dec (7.49)[b] (n = 97)	1 Dec (8.33)[b] (n = 33)	1 Dec (9.59)[b] (n = 10)	0.960
Land type[d]				
High	88	12	5	0.341
Medium	101	25	6	
Low	42	7	5	
Total	231	44	16	

[a]From weed management survey (T. aman survey, 2000). [b]Numbers in parentheses are standard deviations. [c]For plots planted to rabi crops (rabi survey, 2002). [d]Plots planted to T. aman rice (rabi survey, 2002).

Aman harvesting

Direct seeding and shorter-duration varieties are, other things being equal, expected to allow earlier harvesting of T. aman rice and so increase the time available for sowing rabi crops using residual soil moisture. Results from OFTs show that DSR can advance the harvest by an average of 10 days. How does this match the reality in farmers' fields?

Table 1 compares mean harvest dates (weighted by plot area) for MV T. aman, Swarna, and local varieties (mostly fine rice). Surprisingly, the results showed no significant difference between the mean harvest date for MV T. aman (28 November) and the other two groups. Consequently, the time of rabi sowing was the same irrespective of rice variety. One explanation is that farmers grew MVs with long field durations. To test this, the area planted to MVs was split into early and late groups based on their reported field durations (Das 2005). Results showed no significant difference in the mean harvest date (14 November) of short-duration MVs such as BR39 and long-duration MVs such as BR11. This suggests that, while it is possible for researchers to harvest MV T. aman varieties early on single OFT plots, farmers harvest all varieties at the same time. Something prevents farmers from harvesting MV T. aman early.

One likely explanation suggests itself. If, like weeding, rice harvesting is done mainly by hired labor, then timing may depend on two factors. The first is labor management. Large farmers have to coordinate harvesting over numerous scattered plots. This may make it more efficient to harvest plots simultaneously, regardless of when rice varieties mature. Since MVs accounted for only 15% of the plots planted to T. aman, farmers may delay harvesting fields planted with MVs until they can be harvested together with Swarna. The need to synchronize harvesting has probably increased because of mechanized land preparation, which allows fields to be transplanted more quickly and means that they are more likely to be ready for harvesting at the same time.

A second factor is the nature of the harvest labor contract. The *zin* harvest contract that separates cutting from removing the straw may delay rabi sowing as farmers wait for straw to dry or wait for laborers to return and remove straw from the field. This delay may be prolonged if the labor gang has contracted with numerous farmers. The prevalence of *zin* contracts in the HBT may reflect the high number of large farms, which grow too much rice for straw to be dried in the homestead compound. In these circumstances, farmers who wanted to harvest MVs before Swarna would have to negotiate separate labor contracts for MVs and might find it difficult to remove the straw without damaging the rice on surrounding fields that were not yet harvested. Farmers who participated in focus group discussions during site characterization reported that "if a farmer had more than 0.13 ha of land distributed over many plots, it would be difficult to get the cattle to the plots for early plowing and early harvesting (removing the rice) through the other fields" (Robinson 2000).

Table 2 tests this explanation by comparing the timeliness of rice harvesting by farm size. To capture differences between farms, the 91 sample households were divided into terciles according to area planted to T. aman rice. There are several points to note from this table:

- Large farms accounted for 65% of the area planted to MV T. aman. The mean area planted to MV T. aman was significantly higher on large farms (0.25 ha) and so was the share of the T. aman area planted to MVs (10%). Hence, the time of harvest for MV T. aman depended primarily on the decisions made by these large farmers.
- There was no significant difference in harvesting dates between large and small farms. This was not due to differences in time of transplanting or land type, which was the same for all three groups.
- Variation in harvesting dates (in days) was lower than for dates of transplanting or sowing rabi crops. The standard deviation for harvesting was about one-third of that for transplanting and sowing rabi crops. Harvesting was also completed more quickly than either of these activities. Both these results are consistent with harvesting by labor gangs employed to harvest the entire crop.
- The fact that the average date for sowing rabi crops was the same for both large and small farms points to the importance of soil moisture in determining how much land was planted to rabi crops. If the average rabi sowing date was earlier on large farms, this would imply that some farmers failed to sow although soil moisture was still available, perhaps because they lacked

Table 2. Mean dates of T. aman harvesting, T. aman transplanting, and rabi planting by farm size, Rajshahi District.

Variable	Tercile 1 (n = 30)	Tercile 2 (n = 30)	Tercile 3 (n = 31)	Sig. level (*P* >)
Area planted to rice (ha)	0.63	1.2	2.7	0.000
Mean aman transplanting date[a]	18 July	19 July	19 July	0.788
	(9.77)[b]	(9.06)[b]	(6.61)[b]	
Mean aman harvest date	27 Nov	28 Nov	28 Nov	0.295
	(2.72)[b]	(3.25)[b]	(2.71)[b]	
Mean rabi sowing date	28 Nov	25 Nov	31 Nov	0.068
	(11.22)[b]	(11.78)[b]	(6.63)[b]	
Mean area planted (ha)				
Swarna	0.50	1.06	2.15	0.000
MVs	0.09	0.07	0.28	0.067
Other LVs	0.01	0.01	0.28	0.076
Total	0.63	1.15	2.72	0.000

[a]From weed management survey (T. aman survey, 2000). [b]Numbers in parentheses are standard deviations. [c]For plots planted to rabi crops (rabi survey, 2002). [d]Plots planted to T. aman rice (rabi survey, 2002).
Source: Rabi survey (2002).

incentives to grow rabi crops. Because they sow at the same time as other farms suggests that cropping intensity on large farms may be limited more by a shortage of labor to sow all plots on time.

A second rabi survey in 2005 provided additional information on harvest labor contracts (Table 3). As with the previous survey in 2002, the results showed no significant difference in average harvesting date by farm size. On average, one full week elapsed between harvesting the rice and cutting the straw. The results also showed no significant difference in the date that straw was finally removed from the field after drying. Rice was harvested mostly under the *zin* system even on small farms, which would have to wait their turn for labor to arrive. Moreover, large farms were more likely to have their own carts for transporting straw whereas small farms had to hire carts or trolleys.

Rice cropping

The influence of socioeconomic factors on rice cropping was investigated by comparing farmers' management practices according to income. As a proxy for income, we used subsistence pressure, measured as the area of effective land cultivated per consumer. This definition of poverty ignores nonfarm income, which a previous survey in the study area showed as about 19% of household income (Orr and Jabbar 2002a).

Table 4 shows that subsistence pressure was highest on resource-poor farms, not because they had larger families but because they owned less land and rented more land on a sharecrop basis, returning half the yield to the landlord. On average, households

Table 3. Harvest labor and timeliness of T. aman rice harvest, by farm size, Rajshahi, 2005.

Variable	Tercile 1 (n = 26)	Tercile 2 (n = 27)	Tercile 3 (n = 26)	Sig. level (*P* >)
Farm size (ha)	0.98	2.29	5.44	0.000
Mean aman transplanting date	17 July	14 July	18 July	0.654
Mean aman harvest date	18 Nov	17 Nov	18 Nov	0.520
	(5.63)[a]	(3.49)[a]	(4.13)[a]	
Mean date that straw was removed from field	24 Nov	24 Nov	25 Nov	0.575
	(5.93)[a]	(4.16)[a]	(4.74)[a]	
Gap between harvesting and removing straw (days)	6.1	6.9	6.9	0.210
	(1.13)[a]	(2.15)[a]	(2.11)[a]	
Rice harvested under *zin* system (%)	87.4	99.4	99.6	0.033
Households owning cart (no.)	5	12	20	0.000

[a]Numbers in parentheses are standard deviations.
Source: Rabi survey (2005).

with the highest subsistence pressure rented almost 60% of the land they cultivated compared with only 35% among households with the lowest subsistence pressure.

Swarna was universal, accounting for more than 80% of the area planted to rice among all three groups. But households with high subsistence pressure were significantly less likely to grow MV T. aman perhaps because rice was grown under less favorable conditions. Households with the highest subsistence pressure had a significantly greater proportion of highland (55%) and a lower proportion of medium land (34%) than others. More than 40% of the rice planted on these farms was on highland with unfavorable Barind soils, and one quarter was planted on land that was high, with Barind soils, and was sharecropped. Alternatively, households with high subsistence pressure might have avoided growing MV T. aman because of the need to maximize yields, particularly on sharecropped plots.

Multivariate regression analysis was used to determine the simultaneous impact of factors determining Swarna cultivation at the plot level. Since the dependent variable for rice cropping was dichotomous (0,1), a binary logistic function was used to obtain maximum likelihood estimates to which tests of significance could be applied. The choice of Swarna was specified to depend on five independent variables (Table 5). Regressions were run separately for small farms and for the sample as a whole. The Chi-square goodness-of-fit statistic showed that the models fitted the data with significance of $P < 0.002$ or better and that the specification explained 80% or more of the variation in the plotwise incidence of Swarna (Table 6). The results showed important differences between small and large farms.

- For the sample as a whole, three independent variables were statistically significant and displayed the expected signs. BARIND soils and rabi cropping (RCROP) were negatively related to cultivation of Swarna, whereas

Table 4. Subsistence pressure and rice cropping (ha), Rajshahi District, 2002.

Variable	Subsistence pressure[a]			Sig. level (*P* >)
	Tercile 1 (n = 30)	Tercile 2 (n = 30)	Tercile 3 (n = 31)	
Effective land per consumer[a]	0.11	0.20	0.54	0.000
Effective land cultivated[b]	0.51	0.95	2.25	0.000
Consumers per household[c]	4.81	4.82	4.41	0.559
Land tenure (ha)				
Owned	0.29	0.67	1.65	0.000
Sharecropped	0.43	0.52	0.66	0.450
Fixed cash rent	0.00	0.01	0.28	0.023
Land tenure (%)				
Rented	58.9	40.9	34.8	0.060
Rice area planted (%):				
Swarna	83.4	82.7	82.6	0.993
MV rice	9.4	15.4	8.6	0.479
Other LVs	7.2	1.9	8.7	0.350
Growing MV T. aman (no.)				
Yes	5	14	11	0.044
No	25	16	20	
Land type (%)				
High	55.3	34.8	20.8	0.000
Medium	33.9	49.1	58.8	0.013
Low	10.8	16.1	20.5	0.190
Soil type (%)				
Barind soil	71.7	74.4	51.6	0.117
% of rice land				
High and Barind soil	42.9	23.9	6.4	0.000
High, Barind soil, and sharecropped	25.6	7.8	0.9	0.001

[a]Effective land cultivated per consumer. [b]Owned land and land on fixed rent, plus half land on sharecrop. [c]Consumer weights = adult male, 0.1; adult female, 0.8; children (age <15), 0.5.
Source: Rabi survey (2002).

Table 5. Definitions of variables used in Table 6.

Variable	Definition
RCROP	Dummy variable for rabi crop (1 = yes, 0 otherwise)
BARIND	Dummy variable for Barind soil type (1 = yes, 0 otherwise)
SHARED	Dummy variable for sharecropped plot (1 = yes, 0 otherwise)
HARVDATE	Code for T. aman harvest date (1 = 15 Nov, 35 = 5 Dec)
SWARNA	Dummy variable for Swarna (1 = yes, 0 otherwise)
LANDTYPE	Categorical variable for toposequence (H = high, M = medium, L = low)
PRESSURE	Effective land cultivated[a] per consumers in household[b]

[a]Owned land and land on fixed rent plus half land sharecropped. [b]Consumer weights: adult males, 1.0; adult females, 0.8; children (age <15), 0.5.

Table 6. Regression estimates of determinants of Swarna cultivation, Rajshahi District.

Variable[a]	Swarna (SWARNA)			
	Small farms[b]		All farms	
	Coefficient	Sig.	Coefficient	Sig.
BARIND	+ 0.526	0.296	+ 0.923	0.007
RCROP	+ 0.403	0.382	–1.194	0.000
SHARED	+ 1.315	0.016	+ 0.872	0.022
LANDTYPE (HIGH)	+ 1.165	0.091	+ 0.261	0.560
LANDTYPE (MEDIUM)	– 0.106	0.858	– 0.290	0.489
PRESSURE	+ 3.347	0.028	+ 0.319	0.223
– 2 Log likelihood	130.504		265.185	
Model Chi-square	20.546	$P = 0.002$	30.971	$P = 0.000$
Predicted correctly (%)	81.8		79.7	

[a]For definitions, see Table 5. [b]Terciles 1 and 2 (n = 60).

sharecropping (SHARED) was positively related to Swarna cultivation. However, LANDTYPE and PRESSURE (an index of consumption pressure) were not statistically significant.

- For small farms, in contrast, BARIND and RCROP were not statistically significant, whereas PRESSURE was statistically significant and displayed the expected positive sign. The coefficient for sharecropping (SHARED) showed the expected positive sign and was also statistically significant.

These findings suggest that Swarna is well adapted for conditions in the HBT, particularly on resource-poor farms. Swarna's long field duration is an advantage when grown on highland and poor soils because it allows more time for the crop to recover from drought stress and shortages of nutrients. Swarna is also advantageous on sharecropped plots because yields from long-duration varieties are higher than from shorter-duration MVs, and this is beneficial to sharecroppers who must give half the yield to their landlord.

Rabi cropping

We used the same approach to explore the influence of socioeconomic factors on rabi cropping. Table 7 shows that the most intensive rabi cropping was found on farms with the highest subsistence pressure. Households in this category planted 43% of their farm to rabi crops compared with just 25% on farms with the lowest subsistence pressure.

Intensive rabi cropping on resource-poor farms cannot be attributed to earlier harvesting of T. aman rice or earlier sowing of rabi crops because the mean dates for these operations did not differ significantly between the three groups. Resource-poor

Table 7. Subsistence pressure and rabi cropping, Rajshahi District, 2002.

Variable	Subsistence pressure[a]			Sig. level ($P >$)
	Tercile 1 (n = 30)	Tercile 2 (n = 30)	Tercile 3 (n = 31)	
Effective land per consumer[a]	0.26	0.49	1.34	0.000
Area planted to rabi crops				
Mean area (ha)	0.66	0.93	1.43	0.001
% of rice area	43.3	26.2	24.7	0.007
% of total area	21.6	30.3	44.3	
Mean T. aman harvest date	27 Nov	28 Nov	28 Nov	0.862
Mean rabi sowing date	27 Nov	26 Nov	31 Nov	0.137
% rabi crops planted on				
Highland	48.2	23.4	30.0	0.288
Medium land	38.8	33.8	39.2	0.854
Lowland	20.7	24.5	27.6	0.797
% rabi crops planted on				
Barind soils	77.7	66.9	51.6	0.320
% rabi crops planted on rented land	61.1	22.0	28.0	0.044
% rabi planted after				
Swarna	88.5	54.5	70.0	0.113
MVs	9.3	20.7	19.1	0.318
Cropping pattern (%)				
Swarna-rabi	37.7	22.8	23.1	0.066
Swarna-fallow	52.3	70.5	73.7	0.021
MV-rabi	9.3	29.7	22.5	0.084
MV-fallow	7.4	17.0	13.0	0.403

[a]Effective land cultivated per consumer.
Source: Rabi survey (2002).

farms grew rabi crops under slightly less favorable conditions than other farms. Nearly half the rabi crops on resource-poor farms were planted on highland and almost 80% were planted on Barind soils. These differences were not statistically significant, however. But rabi crops on resource-poor farms were more likely to be grown on sharecropped plots. The normal practice in this case was for one-third of the yield to be shared with the landlord. As we have seen, households with high subsistence pressure planted the same share of their rice land to Swarna as other farms. Despite this, and because they harvested at the same time as other farms, they were more likely to follow Swarna with a rabi crop.

The potential for rabi cropping

The potential increase in cropping intensity was explored by asking farmers about their perceptions on how to expand the area planted to chickpea. To capture differences between farms, households were divided into terciles according to the share of cultivated land planted to rabi crops.

Table 8. Potential for increase in area planted to chickpea, by intensity of rabi cropping, Rajshahi District, 2002.

Variable	Cultivated area planted to rabi crops (%)				Sig.level (*P* >)
	Tercile 1 (n = 30)	Tercile 2 (n = 30)	Tercile 3 (n = 31)	Total (n = 91)	
Area planted to rabi (%)	10.4	26.5	59.1	32.3	0.000
Area planted to T. aman (ha)	1.74	1.78	1.04	1.51	0.004
Is farmer growing chickpea?					
Yes	11	16	11	38	
No	19	14	20	53	0.290
Area planted to chickpea (ha)	0.06	0.15	0.11	0.12	0.037
Factors helping planting of chickpea (mean rank):					
Good soil moisture	2.00	2.06	1.91	2.00	0.955
Suitable soils	2.18	1.94	1.45	1.87	0.670
Early harvest of T. aman	1.18	2.13	2.09	1.84	0.101
Irrigation available	3.00	2.00	1.73	2.21	0.125
No rent paid to landlord	1.73	1.06	0.00	0.95	0.040
Can chickpea area be increased if T. aman is harvested earlier?					
Yes	20	20	16	56	0.376
No	10	10	15	35	
If increase not possible, why?					
Land not suitable	4	4	9	17	0.252
No irrigation	2	4	1	7	
Poor yield	4	2	3	9	
Low harvest prices	0	0	2	2	
Weeks earlier required to increase area planted to chickpea					
One week	19	20	12	51	0.070
Two weeks	1	0	3	4	
Potential change in chickpea area following earlier harvest of T. aman (ha):					
Additional chickpea area	0.75	0.72	0.24	0.55	0.056
Existing rabi area	0.17	0.45	0.55	0.40	0.000
Additional + existing rabi area	2.35	2.88	2.10	2.44	0.455
Potential rabi cropping (%)	55.5	61.3	86.2	67.8	0.021

Source: Rabi survey (2002).

As expected, farmers with a high share of land planted to rabi crops had significantly smaller farms and significantly greater consumption pressure (Table 8). Forty-two percent of the farmers grew chickpea, with no significant difference between the three groups. Among the reasons farmers gave as helping the cultivation of chickpea, availability of irrigation was ranked first, followed by good soil moisture and suitable soils. Early harvest of T. aman was ranked fourth. Interestingly, small farmers did not cite the absence of rent as a factor promoting chickpea, suggesting that they normally paid rent; this was the only significant difference in ranking between the groups. Since chickpea can be grown without irrigation, the importance farmers gave to the availability of irrigation is puzzling. Farmers may regard irrigation as insurance against failure in dry years, or as necessary for acceptable yields. Alternatively, farmers may genuinely not know that chickpea can be grown without irrigation.

Fifty-six farmers (62%) believed that the area planted to chickpea could be increased if T. aman was harvested earlier. For those farmers who believed that no increase was possible, the main reasons given were that their land was not suitable or that they expected low yields. Among those who reported that an increase was possible, most thought that this was achievable if T. aman was harvested just 1 week earlier. With an earlier harvest, farmers reported that an additional 0.6 ha might be cultivated in the rabi season. This would increase the average area planted to rabi crops from 0.4 to 1.0 ha, equivalent to raising the share of land cropped from 32% to 68%. On smaller farms facing consumption pressure, the share planted to rabi crops would increase from 59% to 86%.

These figures represent the additional area that farmers regard as *feasible* for rabi crops, not the area they might actually plant. Given the importance farmers gave to soil type and to irrigation (although chickpea is a dryland crop), it seems doubtful that earlier T. aman harvesting would *on its own* result in such a large increase in rabi cropping. Nevertheless, the figures demonstrate both that farmers believe they can expand the area planted to rabi and that the earlier harvest of T. aman has an important role to play in this process.

Fitting the puzzle together

The interactions among rice harvest date, rice variety, rabi cropping, and subsistence pressure make a complicated story. How do the various elements of this puzzle fit together?

Subsistence pressure forces small farmers to plant Swarna under more unfavorable conditions, namely, on high plots with poor soils where there is greater risk of crop failure and on rented land where they usually must share half the yield with the landlord. These conditions in turn reinforce the subsistence pressure faced by small farms. Because households in the HBT have few opportunities to earn income from outside agriculture, rice yields are critical for livelihoods. The preference for Swarna on these resource-poor farms is explained partly by the unfavorable conditions that make land unsuitable for MVs and partly by the imperative to maximize the take-home yield on sharecropped plots.

Subsistence pressure also explains why rabi cropping is most intensive on the poorest farms. Just as this pressure forces small farmers to grow rice under unfavorable conditions, so they are forced to maximize the area planted to rabi crops. They manage this although they have no advantage in timeliness, harvesting rice, and sowing rabi crops at the same time as other farms. Small farmers had to plant rabi crops on marginal plots where soils were less favorable for rabi, and after cultivation of Swarna, which might be grown on less fertile plots than MVs.

In contrast, large farms with lower subsistence pressure were able to pick and choose the plots they used for different rice varieties and rabi crops. Because they were not obliged by land type or soil type or share contracts to grow Swarna, a higher proportion of large farmers grew MV T. aman. Similarly, they had a greater choice of where to sow rabi crops. Because their farms were bigger, however, they had less time available after rice harvesting to complete sowing rabi crops on all their plots. Big farmers could sow more rabi crops if they harvested MV T. aman earlier. But, although MVs were grown predominantly by bigger farmers, this did not lead to any advantage in the timing of the rice harvest. Both short-duration MVs and long-duration Swarna were harvested at the same time. We suggested that this was because where harvesting depends on contract labor it was easier for farmers to harvest plots simultaneously. An additional risk was that earlier harvesting of MVs might damage rice on surrounding plots that were not yet ready for harvest.

This analysis suggests that interventions to increase cropping intensity can be targeted at two broad target groups:

- Large farms where cropping intensity is low and with some fallow on which additional rabi crops can be grown under reasonably favorable soil conditions.
- Small farms where cropping intensity is higher and with little or no fallow on which rabi crops can be grown under reasonably favorable soil conditions.

The first group may be more interested in technology that extends the area planted to rabi while the second group may be more interested in technology that improves existing rabi yields.

Farmers believe that the area planted to rabi can be expanded significantly if rice is harvested 1 week earlier. This is possible with MVs or with direct seeding. But what is possible on an OFT plot may not always be possible on the whole farm. If farmers delay harvesting until all plots can be harvested simultaneously, reducing the field duration of T. aman through DSR or early-maturing MVs will not result in earlier harvesting. This is because the timing of harvest is determined by the harvesting of Swarna, which occupies 80% of the area planted to T. aman rice. To expand the potential for rabi cropping by bringing forward the harvest date, farmers would have to replace Swarna with a new variety that had a shorter field duration but gave equal or better yield under similar conditions.

Rice-based interventions have demonstrated their potential to improve agricultural productivity in the T. aman season by reducing costs, improving profitability, and helping farmers overcome irregular rainfall that prevents timely transplanting. But as long as TPR Swarna remains the dominant aman variety, these interventions may not improve agricultural productivity in the rabi season because farmers will continue to harvest rice simultaneously, irrespective of when particular fields are ready for harvesting. This is because farmers have an economic incentive to minimize their transaction costs when hiring harvest labor. Consequently, the potential to increase rabi cropping in the HBT through earlier harvesting of rice depends on the success of breeders in developing a new variety with a shorter field duration that will be as widely adopted as Swarna.

Conclusions

A farmer perspective on increasing agricultural productivity in the rabi season was developed by identifying the factors that determined farmers' decisions at the plot level and by analyzing some socioeconomic factors that might influence decision-making at the whole-farm level.

A decision-tree showed that the decision to sow a rabi crop on any given plot involved 11 separate decisions and was determined by a combination of physical, climatic, and socioeconomic variables. Overall, the decisive factor was the availability of residual soil moisture. However, farmers' ability to take advantage of soil moisture might be limited by socioeconomic factors such as shortages of labor and draft power. Even when these resources were available, farmers might be unable to sow chickpea because of a lack of seed, or unsuitable soils, or because they had exceeded what they perceived as the optimum sowing date. When sufficient soil moisture was not available after harvest, farmers had the option of relay-sowing a rabi crop into standing rice before harvest. Farmers' decision to relay-crop depended on their expectation of yield.

Several socioeconomic factors were found to determine the scope for rabi cropping at the whole-farm level. Rice varieties were harvested at the same time irrespective of field duration. This probably reflected the high transaction costs of hiring harvest labor on large farms. The *zin* harvest contract, where straw was left in the field to dry after cutting, delayed rabi sowing by 1 week. Resource-poor farms were more likely to cultivate highland with poorer soils than other farms. They were also less likely to grow MV T. aman, perhaps because land was less suitable but more likely because, as sharecroppers with limited land, they needed to maximize rice yields to feed their families after sharing half the crop with the landlord. Despite these disadvantages, the intensity of rabi cropping was highest on resource-poor farms. Again, this reflected the need to make the most of limited land even when yields were poor.

Farmers recognized that they could increase the area planted to chickpea if rice was harvested earlier. They estimated that it was possible to double the area planted to rabi crops if rice harvesting could be advanced by 1 week. While this estimate need not be taken literally, it demonstrates the potential within the system for improving productivity through rabi cropping.

If the key to unlock this potential is earlier harvesting, how can this be best achieved? Is it through DSR or short-duration varieties or both? The socioeconomic findings suggest that these interventions will not necessarily lead to earlier harvesting if most of the area planted to rice continues to be dominated by long-duration varieties such as Swarna. The key to unlocking agricultural productivity in the HBT is therefore to develop a rice variety that can match the performance of Swarna and yet be harvested 2 weeks earlier.

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Formulation and dissemination of improved cropping system packages for the High Barind Tract

M.A. Salam, A.M. Musa, and C. Johansen

Prospects for increasing irrigation in the High Barind Tract (HBT) of Bangladesh are limited and thus improvement of rainfed cropping systems is necessary to increase agricultural production and improve the well-being of rural households of the region. Rainfed rainy-season rice (T. aman) is the major crop of the region and chickpea has proven to be the most viable postrice rainfed crop. Efforts supported by recent projects funded by the Department for International Development (DFID) of the UK have improved various components of chickpea cultivation, building on earlier efforts of the Bangladesh Agricultural Research Institute (BARI) in collaboration with the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). However, despite the development of improved production packages, chickpea remains a risky crop. Attempts to demonstrate improved packages of chickpea cultivation have usually fallen short of expectations due mainly to rainfall-related constraints—excess rainfall exacerbating pest and disease incidence and low rainfall inducing drought stress.

The complex nature of the constraints affecting transplanted aman rice–chickpea rotations has necessitated a collaborative approach in attempting to solve the problems. Effective collaboration among researchers, extension personnel, and farmers has been developed to evaluate and demonstrate improved technology in farmers' fields. Effective means of ensuring early harvest of rice, to permit sowing of chickpea and other rabi crops before surface soil moisture dries out, have been developed. This includes the use of short-duration varieties and direct seeding of rice, which allow earlier sowing of rabi crops without sacrificing rice yields. Other technologies for reducing the risk of chickpea cultivation such as seed priming, alleviating nutrient deficiencies, and management of pests and diseases have been successfully evaluated by farmers, but further farmer training and widespread demonstration are required if significant adoption leading to favorable impact on rural livelihoods is to occur.

The High Barind Tract (HBT) of Bangladesh is an uplifted region of alluvial soil that has undergone weathering in a subtropical climate as it is not subject to annual flooding by the major river systems. The surface soil (0–15 cm) is acidic to neutral (whereas deeper soil is alkaline to neutral), has low base saturation and soil organic matter levels, and the soil has high bulk density and sets hard on drying. The soil is particularly suitable for cultivation of rainy-season T. aman rice (transplanted rice grown in the monsoon season) because rain water is readily retained in bunded fields. On the other hand, cultivation of postrice crops is made difficult by these particular soil conditions and opportunities for post-rainy-season irrigation are limited. The traditional cropping system in the HBT has been, simply, T. aman rice, with most fields remaining fallow during the remainder of the year. Over the last two decades, deep tube-well irrigation has expanded in the southern HBT, thereby permitting a greater degree of rabi (winter) season cropping. However, prospects for further expansion of irrigation are limited, and even decreases in irrigated area are envisaged, due to declining water tables and increasing difficulties of pumping water (increasing fuel costs and scarcity of electricity). Increased and sustainable agricultural production in the HBT depends on increasing the cropping intensity in rainfed situations and generally increasing cropping system water-use efficiency (crop production per unit of water applied from rainfall and irrigation) of the HBT system. This paper describes attempts to improve rainfed rabi cropping in the HBT, to best integrate with rainfed rice cropping, to increase agricultural productivity and production in the region.

Collaboration to develop packages

Historical perspective

Concerted efforts to improve the cropping system in the HBT began in the late 1970s when the Bangladesh Agricultural Research Institute (BARI) first placed scientists in the region. These scientists later became part of the On-Farm Research Division (OFRD) of BARI. It was shown that rabi crops could be sown after the harvest of rainfed rice, if the rapid drying of surface soil after the harvest of rice could be managed (Islam et al 1994). This involved careful land selection, to ensure sufficient soil moisture at sowing time, minimum tillage prior to sowing to minimize evaporative loss from the seedbed, and effective burying of seed immediately after sowing. If the seeds could germinate and seedlings establish before the surface soil dried out, the roots could then penetrate into deeper soil layers where water was present to support crop growth (Ali et al 2005). The researchers also noted that the declining water status through the rabi season required the use of shorter-duration varieties than those normally adapted to the floodplain soils, so that grain maturity could occur before the soil moisture was exhausted and the air temperatures rose in March. Rabi crops that could be successfully cultivated after T. aman rice in the HBT included chickpea, linseed, and barley.

Chickpea proved to be the most successful postrice crop species in the HBT, in terms of reliability of crop establishment after rice and yield (Kumar et al 1994). This attracted collaboration from the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), which had a global mandate for chickpea improvement in the semi-arid tropics. ICRISAT researchers noted that the short growing season of the HBT, terminated by drought and heat stress, resembled seasons found at lower latitudes in India, for which shorter-duration chickpea genotypes had been developed. During the 1980s, therefore, this short-duration material was introduced into Bangladesh and tested under HBT conditions. Varieties were evaluated and eventually released by the Pulses Research Centre (PRC) of BARI, some of which proved to be well suited to the HBT, such as Nabin, initially, and then BARI chola 5.

During the 1980s, the OFRD researchers also undertook adaptive research on watershed management in the HBT, introduction of tree species, development of ponds for fisheries, homestead vegetable cultivation and fruit trees, and green manuring. They evolved a recommended rainfed cropping system for the HBT of green manure (*Sesbania* spp.)–T. aman–chickpea (Islam et al 1994). All of this adaptive research and extension were done in farmers' fields or within their homestead areas, as there was no research station specifically established for the HBT. The absence of a research station, in hindsight, proved to be much more of an advantage than a disadvantage. It allowed the OFRD researchers to develop methodologies of on-farm research, which would eventually prove to be of value well beyond the confines of the HBT. From the beginning of the OFRD efforts, farmers were directly involved in the research process and could give their feedback directly to the researchers. The OFRD researchers also linked closely with other development agencies in the region, such as the Department of Agricultural Extension (DAE), so that research efforts would more directly flow on to extension activities, and feedback loops would be maintained.

The Bangladesh Rice Research Institute (BRRI) also undertook research activities in the HBT starting in the early 1980s (Mazid et al 1998). They realized that shorter-duration T. aman varieties were necessary for successful rainfed rabi crop production. Such varieties should mature well within November to avoid terminal drought stress themselves and be harvested while soil moisture was sufficient for the establishment of rabi crops. Varieties such as BRRI dhan 32 and BRRI dhan 39 were eventually identified as suitable for this purpose. BRRI researchers also explored management options for ensuring an earlier harvest of T. aman rice, such as direct seeding of rice. BRRI researchers in the HBT also took a "cropping systems" approach, promoting the green manure–short-duration T. aman–chickpea cropping system.

During the 1990s, both commodity priorities (rice and chickpea) and "cropping system" and "participatory on-farm research" approaches in the HBT attracted increasing interest from ICRISAT, the International Rice Research Institute (IRRI), and associated international organizations, working with BARI and BRRI. Various collaborative initiatives focused on the HBT, as it was a distinct rainfed environment threatened by environmental degradation and with a high degree of rural poverty. It was considered that there was ample scope to build upon the advances made in rainfed agriculture in the HBT during the 1980s and 1990s through a focused project approach.

Two initiatives developed in the late 1990s received funding support from the Science Programmes of the UK's Department for International Development (DFID). One was a project on "promotion of chickpea in the High Barind Tract" (R7540) supported by the Plant Sciences Programme (PSP) based at the University of Wales. This project involved collaboration among researchers in the Centre for Arid Zone Studies

(CAZS) of the University of Wales, ICRISAT, BARI, DAE, and PROVA, a newly formed (1998) NGO specializing in agricultural R&D for the HBT. PROVA was the main implementing agency and site coordinator for the project.

At about the same time, in late 1999, another DFID project that included the HBT as a target area started. This was a project on "weed management in rice" (R7471) under the Crop Protection Programme managed from the Natural Resources Institute (NRI), University of Greenwich, UK. Collaborators in this project were NRI, IRRI, and BRRI.

Mode of farmer collaboration

Most of the research to improve cropping systems in the HBT has been conducted in an "on-farm research and development" (OFR&D) mode. This comprised the following activities, all carried out in farmers' fields:

- Problem diagnosis, including farmer surveys and diagnostic trials.
- On-farm trials (OFTs), whereby several factors are experimentally compared. A randomized block experimental design can be used with dispersed replication in different fields.
- On-farm evaluations (OFEs), which are farmer-implemented comparisons of different factors or of an improved package with a traditional package. Farmer training and guidance is provided primarily by researchers but extension personnel are also involved. The evaluations are conducted in operational-scale plots with test plots side-by-side, replicated in different farmers' fields across a target region, and can be statistically analyzed as a paired "t" test or randomized block design (if >2 treatments).
- On-farm demonstrations of optimum agronomic packages, after successful evaluation against prevailing practice. These are implemented by farmers in operational-scale plots and replicated many times across a target region, with training and guidance given by extension personnel. The plots are displayed to other farmers through signboards and the conduct of farmer walks and field days.
- Measurement of adoption and impact of introduced technologies.

Figure 1 illustrates the research-to-adoption continuum and the roles of the various participating organizations in relation to the continuum, at least in projects undertaken by PROVA. On-farm research most likely to result in technology adoption by resource-poor farmers within a reasonable time period requires that there be both feedback as well as feed-forward across the continuum. This in turn requires considerable overlap between participating organizations in terms of working together on particular activities. In coordinating project activities, PROVA has been involved across the entire spectrum, along with the project management organizations in the UK. Even though their prime role is extension, DAE has participated in the adaptive on-farm research aspects, by assisting implementation and providing feedback on technology constraints. Farmers have also been directly involved across the entire spectrum, including applied research studies conducted on their land. This encourages feedback from farmers at

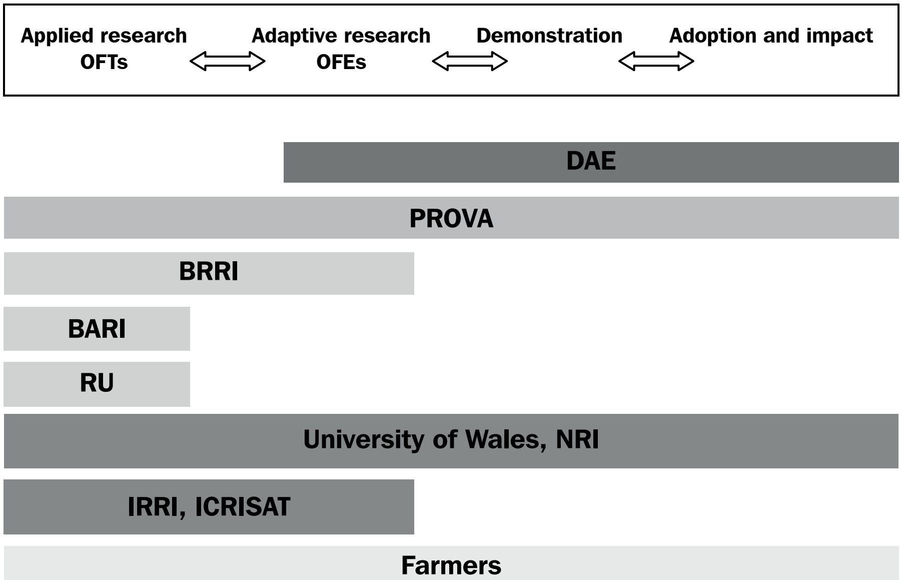

Fig. 1. Participation of the different groups collaborating in R&D for rainfed agriculture in the HBT in relation to the research-to-adoption continuum. RU = Rajshahi University; other abbreviations are defined in the text.

developmental stages of the technology and gives them a feeling of ownership of the technology should it eventually prove worthwhile.

The approach outlined above is consistent with the New Agricultural Extension Policy (NAEP) for Bangladesh, introduced in 1996 (Ministry of Agriculture 1996). The goal of the NAEP is to "encourage the various partners and agencies within the national agricultural extension system to provide efficient and effective services which complement and reinforce each other, in an effort to increase the efficiency and productivity of agriculture in Bangladesh." The key components of NEAP are

- Extension support to all categories of farmers,
- Efficient and appropriate extension services to be ensured,
- Decentralization,
- Demand-led extension,
- Working with groups of all kinds,
- Strengthened extension-research linkage,
- Training of extension personnel,
- Appropriate extension methodology,
- Integrated extension support to farmers,
- Coordinated extension activities, and
- Integrated environmental support.

Improving the chickpea component

In Bangladesh, chickpea has been traditionally cultivated on recent alluvial soils in the western districts of Bangladesh (e.g., Jessore, Faridpur, Pabna, etc.). These soils have better soil moisture-holding characteristics and fertility levels than those of the HBT. Thus, optimum agronomic practices developed for traditional chickpea-growing areas would need modification for the HBT, particularly with respect to coping with soil characteristics. The DFID-funded projects managed by PSP, University of Wales—R7540, and its successor project "Improvement of rainfed cropping systems in the High Barind Tract of Bangladesh" (R8269) implemented during 2002-06—addressed limitations to chickpea caused by soil moisture deficit and nutrient deficiencies, as well as major biotic stress factors. The results of these efforts have been reported in this volume by Harris et al and Johansen et al. The recommended agronomic package for chickpea in the HBT, as applicable up to 2003, was summarized by Musa and Johansen (2003), but since then recommendations on applying molybdenum (Mo) and *Rhizobium* in the priming water for acid soil locations have been included (see Harris et al, this volume). Table 1 summarizes the current recommendations for growing chickpea in the HBT, and compares them with those applicable to the traditional chickpea-growing areas of the country (Kumar et al 1995). Recommendations differ for many of the components.

It needs to be emphasized that the recommended package of practices for chickpea in the HBT is dynamic, evolving from year to year. For example, studies are under way to determine whether phosphorus can also be applied in the seed-priming process and whether biological antagonists such as *Trichoderma* spp. can inhibit collar rot. Work is also attempting to identify chickpea varieties for the HBT superior to BARI chola 5. Attempts are also being made to commercialize the production and distribution of *Helicoverpa* nuclear polyhedrosis virus (HNPV) and Mo + *Rhizobium* sachets for adding to priming water.

Integrating chickpea with the rainfed rice component

To establish a viable rainfed rice–rabi crop cropping system, it must be ensured that the two crops blend effectively. A particular problem in the HBT is the late harvest of rice, resulting in depleted soil moisture conditions for the following crop, as discussed by Johansen et al (this volume). There are two main avenues for ensuring earlier harvest of T. aman rice: decreasing the duration of rice through techniques such as direct seeding of rice (DSR) (Mazid et al, this volume) or using shorter-duration rice varieties (Joshi et al, this volume). The use of short-duration T. aman varieties can increase cropping options (see Figure 2 of Johansen et al, this volume).

It is also necessary to reduce the turnaround time between the rice harvest and chickpea planting. One problem is that, traditionally, after rice sheaves are cut, they are laid out on the same field to dry, thus delaying entry to the field to sow a following crop. This practice can be overcome by requesting farmers to place cut sheaves along bunds or on other off-field areas or other fields not intended for rabi cropping. Another

Table 1. Recommended package of practices for chickpea cultivation in the High Barind Tract (see Musa and Johansen 2003), as compared with recommendations for traditional chickpea-growing areas (recent alluvial soils) (after Kumar et al 1995).

Practice	Recommendation for HBT	Recommendation for traditional growing areas
Variety	BARI chola 2 or 5	Mostly BARI chola 5
Sowing time	15-30 Nov	22 Nov to 7 Dec
Land preparation	Sow seed and add soil-applied fertilizer before any tillage, then 1 or 2 plowings and laddering	Plow twice before sowing and fertilizer application, and plow and ladder afterward
Seed rate	40–45 kg ha^{-1}	35–40 kg ha^{-1}
Seed priming	Required	Mostly not required
Collar rot protection	Avoid continuous cultivation of chickpea	Avoid continuous cultivation of chickpea and treat seed with Vitavax-200®
Rhizobium	Apply in seed-priming process at 4 g peat L^{-1}	Generally not needed
Phosphorus	Broadcast 100 kg ha^{-1} triple superphosphate	Same
Boron	Generally not needed	Site-specific needs, 1 kg ha^{-1}
Molybdenum	Apply in seed priming process at 2 g sodium molybdate L^{-1}, if soil pH$<$5.5	Not required
Weeding	Weeding usually not required	Hand weeding usually necessary
Botrytis gray mold protection	Required only if there are humid conditions in late Feb-early Mar	Always required; maintain plant population at $<$20 plants m^{-2}, spray Bavistin® as required (Johansen and Musa 2004a)
Helicoverpa pod borer protection	Practice IPM of scouting, placing bird perches, and need-based spraying of HNPV or chemical insecticide (Johansen and Musa 2004b)	Same
Seed/grain preservation	Sun drying, sealed plastic bags, use of naphthalene or neem leaves, store in elevated, airy location	Same

problem is the shortage of labor at the time of the rice harvest, with an increased labor requirement to manage the rice harvest and a labor requirement for sowing of the rabi crop superimposed. This is an increasing cause of delay in sowing of the rabi crop. At least partial mechanization of both rice harvesting and sowing operations for the following crop seems the only option to overcome this problem. The recent increased availability of power tillers to facilitate timely sowing of rabi crops provides some respite in this regard but this type of tillage is often not effective for rainfed rabi crops, due to the inducement of soil moisture evaporation and shallow burial of seeds.

Evaluating and demonstrating improved rainfed rice-chickpea systems

The 2002-03 season

The University of Wales DFID Project R8269 and the NRI DFID Project R8234 ("Weed Management in Rice in the High Barind Tract") collaborated from the end of 2002 to evaluate and demonstrate improved rainfed rice–chickpea cropping systems in the HBT. This collaboration started with the chickpea component in the 2002-03 season, as the previous rice crop was grown before the start of these particular projects. The DAE and PROVA collaborated to widely demonstrate, in farmer-managed plots, the best available technology for rainfed production of chickpea in the HBT. Some 585 demonstrations of 0.13-ha plot size were established in nine *upazilas* of Rajshahi, Chapai Nawabganj, and Naogaon districts in the rabi season of 2002-03.

Before the demonstrations, training was given to participating DAE personnel and farmers. At these training sessions, the "best-bet" chickpea cultivation technology was described and details of layout, operations, and data requirements of the demonstrations given. A field book with all such details was provided to all DAE personnel. A laminated sheet describing recommended chickpea cultivation practices was provided to all participating farmers and DAE personnel. BARI chola 5 was the variety demonstrated and seed priming was given universally. Participating farmers were given 6 kg of seed (BARI chola 5) and 13 kg of TSP (enough for 0.13 ha). Sowing of demonstration plots occurred mainly in late November to mid-December and harvesting was done from late March to early May. Block supervisors (BSs, but currently designated sub-assistant agricultural officers) of DAE compiled farmer estimates of grain yield harvested from each plot.

Table 2 summarizes the grain yields obtained in each block of the three HBT districts covered. Unfortunately, the yields were extraordinarily low, usually well below the average chickpea yields normally achieved in the HBT. This was due to the frequent and heavy rainfall received from the end of February, throughout March, and into early April (100–150 mm). This rainfall induced unprecedented high incidence of botrytis gray mold (BGM), a disease caused by the fungus *Botrytis cinerea* (Pers. ex Fr.). This disease occurs regularly on chickpea growing in the traditional chickpea-growing areas of Bangladesh, the recent alluvial soils of central-western Bangladesh (e.g., the districts of Jessore, Jehnaidah, Kushtia, Rajbari, Magura, Faridpur, etc.). It is indeed the major constraint to chickpea production in these areas and has been a major reason for the gradual decline in chickpea production in Bangladesh from the 1980s. However, previously, BGM occurred only to a minor extent in the HBT, presumably because of the warmer, less humid conditions at canopy level during February-March in the HBT compared with the traditional growing areas. The frequent rain and overcast conditions of this season in the HBT created conditions in the canopy of chickpea crops suitable for development of the disease. Remedial action could not be taken because of insufficient time to procure fungicidal spray (e.g., Bavistin®) and train DAE personnel and farmers in its appropriate use.

The continuing moist conditions also favored the buildup of *Helicoverpa armigera* pod borer, which severely attacked any pods that could form during March. Thus, the

Table 2. Grain yields (kg ha^{-1}) of chickpea cultivar BARI chola 5 in on-farm demonstration plots averaged for each upazilla, rabi season, 2002-03.

District	Upazilla	No. of plots	Mean yield (kg ha^{-1})	Yield range (kg ha^{-1})
Rajshahi	Tanor	60	103	0–240
	Godagari	60	107	0–1,200
Chapai Nawabganj	Nawabganj Sadar	105	181	11–600
	Nachole	45	157	30–300
	Gomostapur	75	281	113–353
Naogaon	Niamatpur	60	94	0–338
	Patnitala	60	98	45–375
	Shapahar	60	291	0–915
	Porsha	60	131	0–488

proportion of damaged pods was high, giving the appearance that pod borer was the main yield reducer, whereas it was primarily BGM in limiting pod formation in the first place. Further damage to any pods that could form was also caused by heavy rains in some places during the harvesting period in early April. This also prevented and delayed drying and threshing of crops already harvested, causing damage to harvested seed (e.g., seed of high moisture content and with postharvest fungal infection).

Nevertheless, there were some isolated cases of respectable yields being obtained. At Rajabari, in Godagari upazilla, yields of 0.6, 0.9, and 1.2 t ha^{-1} were obtained (Table 2). At Jamalpur/Tilna, in Shapahar upazilla, yields of >0.8 t ha^{-1} were recorded (Table 2). This gives an indication that reasonable yields are possible even when environmental conditions, and consequent biotic stresses, are so adverse.

At field days organized and conducted by DAE and PROVA, detailed discussions were held on BGM and pod borer and possible measures to manage them in the future. Training was given in the preservation of chickpea seeds and large polythene bags for this purpose were given to farmers.

The 2003-04 season

In the 2003-04 season, operational-scale on-farm evaluations (OFEs) of optimum cultivation technology for the rainfed cropping system of T. aman rice followed by chickpea were conducted at 100 locations across the HBT. The OFEs were implemented by farmers with the guidance of DAE BSs, PROVA trial monitors, and BRRI staff. The effect of using a short-duration rice variety (BRRI dhan 32) was compared with the commonly grown Swarna, with and without the use of a granular herbicide, Machete® (butachlor).

During 25-29 May 2003, familiarization and training programs were held for DAE officers (42), BSs (16), and participating farmers (92). PROVA and BRRI staff were

Table 3. Summary of rice grain yield (t ha^{-1}) results for rice variety × herbicide on-farm evaluations in the HBT, 2003-04 season.

District	Rice		
	Swarna	BBRI dhan 32	Significance
Naogaon	4.21	3.94	$P < 0.05$ for variety × district interaction
Rajshahi	4.14	3.47	
Chapai Nawabganj	4.08	3.67	
All districts	4.14	3.68	$P < 0.001$
	$P < 0.001$ for upazilla within district and variety × upazila within district interactions		

the faculty. The OFEs were established in ten upazillas of the three HBT districts, spanning the HBT. At transplanting, during July and August, 0.13-ha plots were divided into quarters, with one half planted to Swarna and the other half to BRRI dhan 32, and these plots were then subdivided between normal weeding practice (two hand weedings) and the use of herbicide (Machete + one hand weeding). Optimum agronomic practices under farmer management were followed. Chickpea variety BARI chola 5 was sown in each subplot after the harvest of rice.

Rainfall was well below normal during July-August, causing drought stress, particularly in the northern and southern extremities of the HBT (e.g., Porsha, Shapahar, and Godagari upazillas). However, adequate rains in September and October allowed good crop recovery. Farmer field days and informal field visits were held during the course of the season, and farmers' opinions on the treatments applied were solicited. Training programs on chickpea cultivation were conducted in November for DAE personnel and farmers participating in this program.

The use of Machete resulted in slightly, but significantly, higher rice yields (3.84 t ha^{-1} with hand weeding only and 3.98 t ha^{-1} with Machete; $P < 0.030$) and lower production costs as less labor was required for hand weeding when Machete was used. Swarna generally outyielded BRRI dhan 32 and there was a significant variety × district interaction (Table 3). Data for Porsha upazilla were discarded from the analysis due to poor establishment of the crops there, mainly because of drought. Swarna demonstrated broad adaptability but BRRI dhan 32 performed poorly in Rajshahi.

Chickpea yields were not affected by the weeding treatments, indicating no adverse residual effect of the herbicide on chickpea. However, chickpea yields were generally significantly higher in plots where BRRI dhan 32 was grown as compared with Swarna (Table 4). This can be attributed to the earlier maturity of BRRI dhan 32 and hence earlier sowing of chickpea. However, earlier sowing of chickpea in rice plots harvested earlier could not always be achieved for field management reasons. Some farmers preferred to sow the whole field to chickpea only after all plots had been cleared of rice, for logistical reasons.

Table 4. Grain yields (t ha^{-1}) of chickpea sown after rice in the rice variety × herbicide on-farm evaluations in the HBT, 2003-04 season.

District	Upazilla	Chickpea yield (t ha^{-1}) after		Significance[a]
		Swarna	BRRI dhan 32	
Naogaon	Niamatpur	0.815	0.900	$P<0.01$
	Shapahar	0.575	0.633	$P<0.001$
	Patnitala	0.479	0.503	ns
Rajshahi	Godagari	0.384	0.452	$P<0.001$
	Tanor	0.268	0.272	ns
Chapai Nawabganj	Nawabganj Sadar	0.803	0.848	$P<0.01$
	Nachole	0.909	0.953	$P<0.05$
	Gomostapur	0.646	0.785	$P<0.001$

[a]ns = not significant.

The 2004-05 season

In this season, the intent was to conduct 72 farmer comparisons of direct seeding of rainy-season rice (DSR) with the usual practice of transplantation (TPR), followed by chickpea. It was hypothesized that rice would mature earlier under DSR, thus allowing earlier planting of chickpea, and consequently higher yields of chickpea. DAE personnel and farmers were trained in the procedures and farmers provided with the required inputs as in the previous season. Direct seeding was to be done by one of three techniques depending on soil conditions: use of a *lithao* if the soil was near field capacity but not saturated, use of a drum seeder if the soil was saturated, and hand broadcasting if these implements were not available. The time of direct seeding was similar to time of sowing of seed in seedbeds for transplanting. Fields of 1,333 m^2 were divided in two and DSR imposed in one half and TPR in the other. Different rice varieties were used at different locations—they included Swarna, BR-11, BRRI dhan 31, and BRRI dhan 32—but each treatment comparison involved only one variety. Herbicides were used for weed control in both treatments and otherwise optimum agronomic practices were followed. Chickpea variety BARI chola 5 was sown as soon as possible after the harvesting of rice, using the recommended package of practices.

Unusually heavy rains in June 2004 resulted in failure to sow, or loss of, many DSR plots and OFEs could be successfully conducted at only 26 locations. In viable comparisons, rice in DSR plots matured 7–10 days earlier than in TPR plots, and grain yields were slightly more in DSR plots, reaching significance for the OFEs conducted in Rajshahi District (Table 5). Yields of subsequent chickpea were also higher in DSR plots, which can be attributed to the time of sowing effect (Table 5).

Staff of DAE and PROVA conducted surveys to obtain farmers' opinions on the use of DSR as compared with the traditional TPR practice. The advantages of DSR as expressed by farmers were

Table 5. Grain yields (t ha^{-1}) of rice and following chickpea in on-farm evaluations comparing direct-seeded rice (DSR) with transplanted rice (TPR) in the HBT during the 2004-05 rainfed rice–chickpea season.

District	Number of comparisons	Rice			Chickpea		
		DSR	TPR	Signif.[a]	DSR	TPR	Signif.[a]
Rajshahi	11	5.46	5.02	$P<0.01$	0.86	0.78	$P<0.001$
Chapai Nawabganj	13	4.56	4.38	ns	0.65	0.52	$P<0.001$
Naogaon	2	5.47	5.20	–	0.64	0.38	–

[a]Significance of difference; not applicable for Naogaon as only two comparisons were successfully completed; ns = not significant.

- Less time required for sowing, with no labor-intensive transplanting required.
- Earlier maturity, to the extent of 7–10 days.
- BR 11 and Swarna are better suited to DSR than other rice varieties.
- DSR is best done within June.
- DSR involves less labor cost.
- There is a lower crop water requirement for DSR.
- Tillering begins earlier in DSR plots.
- Liquid herbicide is more effective than granular herbicide.
- Herbicide is more effective in TPR plots than in DSR plots.
- Ronstar® is an effective herbicide for DSR.

The disadvantages of DSR were perceived by farmers as follows:

- Heavy rain just after sowing damages seeds.
- Germination of seeds and establishment of seedlings are less than expected in a normal seedbed (to be used for transplanting).
- For drum-seeder-sown and hand-broadcast plots, seed removal by pigeons, ducks, and other birds is very high unless elaborate protection (bird scaring) is given.
- Herbicide is costly.
- Ronstar can sometimes damage seedlings, causing chlorosis and retarding growth.
- Some major weeds cannot be controlled by Ronstar (e.g., *Cynodon dactylon* and *Cyperus* spp.).
- Weed infestation of DSR plots is very high and further hand weeding is required after 25–30 days.
- Weed infestation is greater if soil moisture is less, due to increased difficulty of weeding drying soil.

Table 6. Mean grain yields (t ha^{-1}) of chickpea in demonstrations of the optimum chickpea package in upazillas of the HBT conducted in 2005-06.

District	Upazilla[a]	Number of demonstrations	Mean yield (t ha^{-1})
Chapai Nawabganj	Nawabganj Sadar	30	0.22
	Nachole*	30	0.41
	Gomostapur*	30	0.16
	Bholahat*	30	0.19
Naogaon	Porsha*	20	0.57
	Sapahar*	20	0.38
	Niamatpur*	20	0.29
	Patnitala*	20	0.33
	Dhamoirhat*	20	0.25
	Mohadebpur*	20	0.15
Rajshahi	Godagari	60	0.49
	Tanore*	50	0.30
Joypurhat	Panchbibi*	50	1.35

[a]* indicates locations with acid surface soils where Mo + *Rhizobium* was applied.

- DSR is at the mercy of excessive, low, or untimely rainfall (such as the exceptionally high rainfall in the 2004-05 season), whereas TPR is buffered against this; sowing by a lithao and drum seeder requires the soil to have suitable moisture.
- DSR is not suitable for lowland conditions or for heavy soils (where chickpea is most suitable).
- Most farmers are unwilling to attempt DSR, particularly by using the hand-pulled lithao.
- Even if DSR matures earlier than TPR, labor shortage and logistical problems prevent an earlier harvest of rice.

The 2005-06 season

Four hundred demonstration plots of 0.13 ha of the optimum recommended chickpea cultivation practice were implemented across 13 upazillas of the HBT in the 2005-06 season (Table 6). DAE and PROVA provided preseason training and supplied the required inputs (but only inputs not normally used by the farmers) to the participating farmers. In this season, priming with Mo and *Rhizobium* was included in the package, for acid soil locations. Mid-season in-the-field training was also given to farmers in management of BGM and pod borer and postharvest training was given in seed preservation.

There was no rainfall during the entire cropping season and moisture stress is considered the main reason for the generally low mean yields obtained (Table 6). An exception to the low yields was Panchbibi in Joypurhat. Pod borer damage was also a major constraint in some areas. A major manifestation of moisture stress was in the seedbed, despite seed priming, causing poor plant stand and stunted seedling growth. It appears that this situation was exacerbated by the increased use of power tillers in land preparation for chickpea. This procedure allows only shallow tillage and the rotovating action maximizes moisture evaporation from the soil surface. This contrasts with the effect of the traditional animal-drawn moldboard plow in effectively burying the chickpea seed while minimizing soil evaporation, but this procedure is slow and limits area coverage. Some form of minimum tillage with burial of seed to about 10 cm would seem necessary to overcome this limitation. The lack of any rain during the growing season prevented recovery of plants initially affected by moisture stress.

Conclusions

Although progress has been made in being able to alleviate some of the major constraints to chickpea in the harsh environment of the HBT, the crop is still prone to high risk beyond the control of farmers. Further training is required if farmers are to reliably manage the major biotic constraints of *Helicoverpa* pod borer and, even if it occurs only occasionally, BGM. However, the persistent overriding constraint to chickpea is moisture limitation. Irrigation is not an answer for chickpea as this crop is very susceptible to even temporary flooding. The key is in the establishment of seedlings strong enough to develop an effective tap-root system that will access abundant supplies of stored soil moisture through the growing season (Ali et al 2005). Although seed priming assists in this regard, it is suggested that a more effective soil tillage and seed placement system is required to adequately overcome the soil moisture limitation.

Earlier sowing increases the probability of higher surface soil moisture, and thus earlier harvest of rainy-season rice is a means of reducing moisture stress to chickpea. The projects under discussion have demonstrated two viable means of achieving earlier harvest of rice, without a yield loss to rice—the use of short-duration varieties and DSR. Although there are various constraints to the adoption of these options, farmers generally appear more willing to adopt short-duration varieties than DSR. Earlier harvest of rainy-season rice is beneficial not only to chickpea but also to any other rainfed or irrigated crop that can be grown in the HBT.

The DFID-funded Project R8269 has effectively addressed the limitations to chickpea caused by acid soil conditions—Mo deficiency and low nitrogen fixation. However, the key to improving soil fertility in the HBT, a prerequisite for improved and sustainable crop production, is substantially increasing soil organic matter levels from their current meager levels. This is only likely to be achieved by inclusion of a vigorously growing green manure crop in the rotation. *Sesbania* spp. have proved effective in this regard in the HBT environment, as demonstrated long ago by OFRD researchers (Islam et al 1994) but adoption of this vital technology has been negligible. Constraints to the adoption of green manuring need further study and increased promotional efforts are needed to improve soil organic matter status in the HBT.

The actual and potential cropping systems of the HBT, with or without irrigation, involve many complexities. Diverse technologies are required to tackle the range of constraints present. This in itself requires interaction of researchers across a wide range of disciplines. However, to convert possible technological solutions into forms manageable by resource-poor farmers requires close and continuing interaction among researchers, extension specialists, social workers, and the target farming families. The projects discussed here present an example of how this could be achieved, even if there is still a long way to go in using technology for poverty alleviation in the HBT.

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Notes

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Experiences from the region

Extending rabi cropping in rice fallows of eastern India

J.V.D.K. Kumar Rao, D. Harris, M. Kankal, and B. Gupta

Southern Asia is one of the major rice-producing regions of the world, where about 50 million hectares are grown. Using satellite imagery and GIS, it was estimated that about 30% of *kharif* (rainy season) rice area (14.3 million ha) remains fallow in the *rabi* (postrainy) season. The spatial distribution of these "rice fallows" in southern Asia was documented. In India, rice area was estimated at 40.2 million ha during the 1999 kharif season and the total rice fallow area during the 1999-2000 rabi season was 11.7 million ha. Chattisgarh, Jharkhand, Orissa, West Bengal, eastern Madhya Pradesh, and Assam states account for most of the rice fallows in India. These rice fallows represent an enormous underused resource for crop diversification and increasing cropping intensity and production.

In India, after preliminary surveys during 2001-02 had identified several reasons why farmers do not sow a second crop after harvesting rice, exploratory farmer participatory trials of technology previously developed in Bangladesh, with chickpea as a test crop, generated enormous enthusiasm among farmers for rainfed rabi cropping (RRC).

Subsequent research with many more farmers (2002-05) refined the technology to include the use of short-duration chickpea varieties, block planting so as to protect the crop from grazing animals, sowing using rapid minimum tillage as soon as possible after harvesting rice, seed priming for 4–6 hours with the addition of sodium molybdate to the priming water at 0.5 g L^{-1} (kg^{-1} seed) and *Rhizobium* inoculum at 5 g L^{-1} (kg^{-1} seed), and the application of manure and single superphosphate. Chickpea yield following kharif rice ranged from about 0.4 to about 3.0 t ha^{-1} across various rice fallow areas in eastern India. Although yields were invariably low for the first year that farmers tested the package, making their own mistakes proved to be a valuable learning experience and farmers were always enthusiastic about growing chickpea in subsequent years. The various biotic and abiotic constraints of rainfed rabi cropping of chickpea in rice fallows of eastern India will be discussed along with possible avenues to overcome some of those constraints. More than 10,000 farmers who have been exposed to this technology are now convinced that a second crop can be grown without irrigation in rice fallows. An effective approach to dissemination of the RRC technology to new villages includes the identification of farmers who

must agree to plant in a block to facilitate protection from grazing by free-ranging livestock; the provision of training on crop production technology; the provision of seed of short-duration chickpea; starter packs of sodium molybdate, *Rhizobium* inoculum, and P fertilizer; and technical backstopping.

South Asia is one of the major rice-producing regions of the world, where about 50 million hectares are grown. Much of this area has a single crop per year, usually rainy-season rice, and no crop is grown after the rains mainly due to a lack of irrigation. Despite growing demand for food production because of increasing population in South Asia, there is little scope for expanding cropping into new areas. Therefore, an increase in cropping intensity along with raising of yields needs to take place on existing agricultural lands. Rice fallows (land kept fallow after the harvest of rainfed rice) present considerable scope for crop intensification and diversification if the appropriate technology is applied. Using satellite imagery and GIS, it was estimated that about 30% of *kharif* (rainy-season) rice area amounting to 14.3 million ha remains fallow in the *rabi* (postrainy) season in South Asia (Table 1) and its spatial distribution was documented (Subbarao et al 2001). Our study also attempted to relate the spatial and temporal distribution of rice fallows with the various climatic and edaphic variables and socioeconomic information to assess the possibility of legume intensification for specified rice fallow situations. Accordingly, recommendations for better use of rice fallows through legume cultivation have been made. Crop diversification through the addition of new regenerative components such as legumes, and the adoption of minimum-tillage methods, seed priming, and crop rotations can be particularly successful approaches to sustainable intensification (CSD 2000, Harris et al 1999, 2000).

In India, the rice area was estimated as 40.2 million ha during the 1999 kharif season and the total rice fallow area during the 1999-2000 rabi season was 11.7 million ha (Subbarao et al 2001). Chattisgarh, Jharkhand, Orissa, West Bengal, eastern Madhya Pradesh, and Assam account for most of the rice fallows in India. These rice fallows represent an enormous underused resource for crop diversification and increasing cropping intensity and production. We report salient fndings of our participatory approach to promote rainfed rabi cropping (RRC) of chickpea (as a case study) in rice fallows of eastern India during 2001-05. The main objective is to improve the livelihoods of the farmers in the study areas by making better use of their land by growing short-duration crops with minimal inputs in the rabi season on residual moisture after kharif rice has been harvested.

Reasons for not growing a second crop and preliminary evaluation of rainfed rabi-cropping technology

The reasons why farmers do not sow a second crop after harvesting rice were explored in a combined survey (Joshi et al 2002) and trials during the 2001-02 season. The survey covering about 320 farmers in 18 villages in five Indian states (Chattisgarh, Jharkhand, Orissa, West Bengal, and eastern Madhya Pradesh) indicated that farmers

Table 1. Estimates of rice area during 1999 kharif season and rice fallows during rabi season of 1999-2000 based on satellite image analysis.

Country	Kharif rice area (million ha)	Rabi fallow (million ha)	Rabi-fallow as % of rice area	% total rice fallows in South Asia
Nepal	1.45	0.39	26.9	2.7
Bangladesh	6.36	2.11	33.2	14.8
Pakistan	2.45	0.14	5.7	1.0
India	40.18	11.65	29.0	81.5
Total	50.44	14.29	28.3	–

are generally not aware of, or do not pursue opportunities for, rainfed rabi cropping. The other main constraints were a lack of protection from unsupervised grazing animals; a lack of information on rabi cropping; various physical soil- and water-related issues, predominantly drought and the high cost and poor availability of inputs; in particular the nonavailability of seeds of short-duration chickpea varieties as tested in the preliminary trials; poor market opportunities; and limited access to institutional credit.

The rainfed rabi-cropping technology

Rainfall during the kharif season in these areas is usually more than enough to grow rice. However, rainfall in the rabi season is much less, sporadic, and highly unpredictable, but the soil profile remains well charged after the rice harvest with residual moisture that could sustain a short-duration crop such as chickpea. Unfortunately, the surface layers of the soil dry out rapidly so crop establishment is a key objective. Two things are essential to achieve this: (1) rapid tillage to cover the seeds while causing minimal disturbance to the soil and minimal loss of moisture, and (2) soaking the seeds for 4–6 hours in water before surface-drying them to facilitate handling, then sowing ("on-farm" seed priming). This combination has proved to be outstandingly effective in growing chickpea in the rice fallow areas of the Barind region of Bangladesh (Musa et al 2001).

Farmers who had implemented preliminary trials based on the above RRC technology were almost unanimous in wishing to grow chickpea again, despite getting low yields of chickpea in some cases, and were convinced of the main elements of the preliminary package. Both the survey and feedback from the preliminary trials with farmers revealed that (1) many farmers were unaware that a short-duration crop could be grown successfully after rice, and (2) the preliminary trials demonstrated convincingly the potential for such additional cropping and exposure generated enormous enthusiasm among farmers.

Improved rainfed rabi-cropping technology of chickpea in rice fallows

Subsequent research in both India and Bangladesh (Harris et al 2005, Johansen et al 2004, Kumar Rao et al 2004) has refined the technology. In summary, the RRC

Table 2. Comparison of returns from short-duration chickpea variety ICCV 2 and a local variety (data from CRS, Satna, Madhya Pradesh, India).[a]

Variety	Cost of seed (Rs kg^{-1} estimated)	Sale price (Rs kg^{-1})	Net returns (Rs ha^{-1})
ICCV 2	45	25	21,330
Local	22	15	9,530

[a]US$1 = Rs 45.5 approximately.

technology tested and approved by east Indian farmers (Harris and Kumar Rao 2004) consists of

- Well-adapted short-duration chickpea varieties, currently ICCV 2, KAK 2, and JGK 1.
- Sowing under rapid minimum tillage as soon as possible after harvesting rice.
- Seed priming for 4–6 hours with the addition of sodium molybdate to the priming water at 0.5 g L^{-1} (kg^{-1} seed) and *Rhizobium* inoculum at 5 g L^{-1} (kg^{-1} seed). *Rhizobium* inoculum should have about 10^9 viable rhizobia g^{-1} inoculum.
- Application of manure and single superphosphate to impoverished soils.
- Block planting to protect the crop from animal grazing.

More than 10,000 farmers who have been exposed to this technology are now convinced that a second crop can be grown without irrigation in rice fallows.

Performance of RRC

The yield of chickpea following kharif rice ranged from about 0.4 to about 3 t ha^{-1} across various rice fallow areas in eastern India. Although yields were invariably low for the first year that farmers tested the package, making their own mistakes proved to be a valuable learning experience and farmers were always enthusiastic about growing chickpea in subsequent years. The preliminary benefit:cost analyses are very promising (Table 2). The mean yield of chickpea following kharif rice in different major rice fallow states of eastern India during 2003-04 is presented in Figure 1. The mean chickpea yield following kharif rice was highest in Orissa (1.1 t ha^{-1}), followed by Jharkhand (0.96 t ha^{-1}) and Madhya Pradesh and Chattisgarh (0.83 t ha^{-1}) and was lowest in West Bengal (0.37 t ha^{-1}). The mean yield of chickpea was calculated from on-farm trials and bulk chickpea plots representing many farmers/villages/districts in each state. Yield varied significantly across farmers depending on soil type, planting time, and biotic and abiotic constraints. The biotic constraints include collar rot—a seedling disease caused by *Sclerotium rolfsii* affecting plant stand in the early stages—up to about a month after sowing, and pod borer (*Helicoverpa armigera*) affecting grain yield. The abiotic constraints include low soil fertility (most of the rice fallow soils examined [approx. 1,000] since 2002 were generally deficient in N, available P, S, B, and Mo), and drought—early-season drought caused by early cessation of monsoon

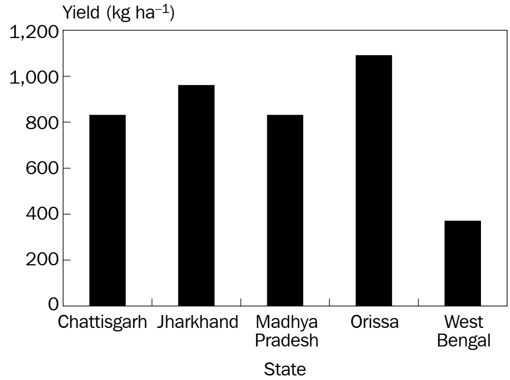

Fig. 1. Mean chickpea grain yield after kharif rice in eastern India, rabi 2003-04.

rains and/or late harvesting of paddy, and late-season drought caused by either delayed sowing of chickpea following kharif paddy or traditional chickpea varieties that are generally late maturing. Most of the rice fallow soils, examined using the most-probable number plant-infection method (Toomsan et al 1984), indicated either a lack of native chickpea rhizobia or rhizobia present in low numbers, at about 100 rhizobia g^{-1} dry soil (data not presented).

A simple method of inoculating chickpea seed with *Rhizobium* through seed priming was found to be as good as the traditional and sometimes cumbersome method of seed inoculation using an adhesive to ensure good nodulation and nitrogen fixation (Harris et al 2005). Our on-farm research since 2002 has suggested that molybdenum (Mo), a micronutrient, was relatively unavailable in these rice fallow soils and that nodulation, growth, and yield could be improved by providing small amounts of Mo. A low-cost technology within the scope of resource-poor farmers has been developed to overcome Mo deficiency (Kumar Rao et al 2004). This involves applying sodium molybdate at 0.5 g kg^{-1} seed L^{-1} of water through seed priming. The response of chickpea to Mo, either applied through seed priming or broadcast on the soil surface, and with inoculation of *Rhizobium* through priming, was evaluated in on-farm trials conducted on rice fallow lands with acid soils in eastern India in 2003-04. In 29 trials (spread over Orissa, Chattisgarh, eastern Madhya Pradesh, Jharkhand, and West Bengal states) with chickpea cultivar ICCV 2, the mean yield increase over a control without Mo (for which mean yield was 869 kg ha^{-1}) was 21.6% when Mo was applied through seed-priming water and 20.3% when Mo was applied to soil (Table 3). In 19 trials with chickpea cultivar KAK 2, the mean yield increase over a control without Mo (for which mean yield was 784 kg ha^{-1}) was 16.8% when Mo was applied through seed-priming water and 24.6% when Mo was applied to soil (Table 3). Therefore, it is imperative to recommend *Rhizobium* inoculation and application of Mo for an effective symbiosis and nitrogen fixation of chickpea, particularly in the rice fallows of eastern India. We also need to know the extent of the limitation of chickpea growth

Table 3. Effect of Mo application through seed priming and soil application on grain and stover yields of chickpea cultivars ICCV 2 and KAK 2 in farmers' fields of eastern India following rice, postrainy season, 2003-04.

Treatment	Chickpea cultivar			
	ICCV 2[a]		KAK 2[b]	
	Grain yield ($t\ ha^{-1}$)	Stover yield ($t\ ha^{-1}$)	Grain yield ($t\ ha^{-1}$)	Stover yield ($t\ ha^{-1}$)
Control (no Mo)	0.87	1.71	0.78	1.57
Mo applied by seed priming	1.06	1.97	0.92	1.89
Mo applied to soil	1.05	1.96	0.98	2.02
SE (±)[c]	0.036	0.069	0.050	0.129
Significance	$P<0.01$	$P<0.01$	$P<0.01$	$P<0.01$

[a]Mean of 29 on-farm trials spread over Orissa, West Bengal, Jharkhand, Madhya Pradesh, and Chattisgarh states of India. [b]Mean of 19 on-farm trials spread over Madhya Pradesh, Orissa, and Chattisgarh. [c]Standard error of difference between two sample means.

and yield as a result of other nutrient deficiencies such as B, S, etc. If they play a critical role in legume growth, then we need to consider ways of supplementing those specific nutrients as well.

There is a need to explore simple avenues of alleviating nutrient deficiencies such as P as most of the rice fallows are deficient in available P. Phosphatic fertilizers are expensive, their efficiency is low, and hence they are seldom used. Therefore, crop growth is often constrained by low phosphate. Preliminary trials in Pakistan have shown that priming maize seeds with dilute solutions of phosphate increases growth and yield by about 30%, perhaps by stimulating vigorous early root growth and thus enabling the uptake of extra phosphorus from the soil (D. Harris, personal communication). Work is continuing to confirm this effect in maize and chickpea for South Asia.

The effect of drought can perhaps be minimized by using a short-duration paddy variety that facilitates the early harvest of paddy and early sowing of chickpea while there is soil moisture in the upper soil layer. The effect of end-of-season drought can probably be minimized by using short-duration chickpea cultivars such as ICCV 2 or KAK 2 that could escape end-of-season drought.

Integrated pest management practices for the control of pod borer are available (Visalakshmi et al 2005), but the problem lies in technology transfer to farmers and ensuring the availability of good-quality pesticides and nucleopolyhedro virus in the market. There is a need to develop effective control methods for collar rot disease of chickpea. It is desirable to develop a simple, low-cost fungicide treatment that is compatible with chickpea *Rhizobium* and sodium molybdate that are applied to seed through seed priming.

Future dissemination

Through dialogue and experimentation with farmers, a consensus has evolved:

- Thousands of farmers (>10,000) who have been exposed to this technology are now convinced that a second crop, for example, chickpea (other rabi crops such as lentil, lintel, mustard, wheat, etc., need to be tested) after rice, can be grown without irrigation.
- An effective approach to dissemination has emerged. For new villages, this includes
  - Identification of interested and committed farmers and the formation of growers' groups. The groups must agree to plant in a block to facilitate crop protection.
  - Provision of training on crop production technology (as given above) to group representatives and village-level extension staff.
  - Provision of 200–300 kg of seed of short-duration chickpea varieties. Currently, only ICCV 2, KAK 2, and JGK 1 are available, but additional varieties are being developed using farmer participatory breeding approaches.
  - Provision of "starter packs" (enough *Rhizobium* inoculum, sodium molybdate, and single superphosphate for 200–300 kg of seeds, i.e., about 2–3 ha). Assembly and distribution of packs of *Rhizobium* and sodium molybdate represent an opportunity for small-scale business development in resource-poor communities.
  - Technical backstopping where necessary.

Conclusions

Rainfed rabi cropping in rice fallow areas increases income and improves food security and human nutrition. In many instances, it also improves social organization, agricultural skills, general empowerment, and commitment to the land. According to Singh (2002), "Rainfed areas have the highest concentration of poor and malnourished people as these areas are characterized by low agricultural productivity, high natural resource degradation, limited access to infrastructure and markets, and other socioeconomic constraints…. There is evidence to suggest that investment in less-favored areas can yield relatively high rates of economic returns and significantly reduce poverty and environmental and natural resource degradation." We believe that investment in promoting rainfed rabi cropping in these five states of India is a sound and productive avenue for poverty reduction and rural development and should be pursued more widely.

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Notes

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Direct seeding of rice and opportunities for improving productivity in Asia

D.E. Johnson, S.M. Haefele, A.L. Rathore, P. Romyen, and H. Pane

Direct seeding of rice with dry seed is thought to be the oldest method of establishing the crop, but this gave way to transplanting in many areas to reduce losses to weeds and raise yields. Traditional dry-seeding methods prevail in many areas, however, and opportunities exist to raise productivity through improved management. In other areas, direct seeding allows earlier rice establishment and increases the probability that farmers will be able to grow a second crop. Rising labor costs have led farmers to return to direct seeding and, in other areas, farmers are likely to change in the near future. Varietal development could contribute to improving the productivity of the direct-seeding systems. Rapid rice seedling growth is one characteristic that may help crop establishment and reduce losses to weeds. Weed management, however, is critical to successful direct seeding and options are required to manage the likely changes in weed species. Problem species include weedy rice and *Echinochloa* spp. Rainfed lowland areas may be characterized by the substantial variability that occurs, particularly in relation to rainfall. To allow farmers to respond to such conditions, flexible management options are required to allow them to exploit prevailing conditions more fully.

Rice production has been transformed over much of Asia in recent decades, with rice yields rising by 2.4% per annum from 1968 to 1999 (IRRI 2004). The greatest improvements have been in irrigated areas, where yields have risen from 3.0 to 5.8 t ha^{-1} over the three decades compared with a rise of 1.4 to 2.1 t ha^{-1} in rainfed areas. These increases have been achieved through the introduction of improved germplasm, agronomy, pest management, and, in many cases, mechanization. The yield growth in irrigated rice areas has slowed in recent years, however, as the achievable yields with current technologies in farmers' fields have been approached. Further, production increases from expanding irrigated areas are unlikely as investments in irrigation projects in Asia are declining after having reached a peak in 1975-85 (Rosegrant 1991). There are also increasing concerns over supplies of irrigation water in existing schemes and farmers in many rice-growing areas are likely to have only limited irrigation water available and, in the future, most of the 22 million ha of dry-season rice in South and

Southeast Asia will fall into an "economic water scarcity zone" (Bouman and Tuong 2003). Given these constraints to increasing rice production in irrigated areas, it is therefore likely that the rainfed lowlands will have an increasingly important role in meeting the demand for rice from the expected increases in population (Zeigler and Puckridge 1995).

Crop establishment issues

Dry seeding is probably the oldest rice establishment method (Pandey and Velasco 2002) but it gave way to transplanting and more intensive cropping in the favorable lowlands long ago. By the 1950s, transplanting had become the dominant rice establishment system in the majority of Asia as it had the major advantages of higher and more stable yield. Transplanting gives farmers a substantial advantage in terms of controlling weeds as rice seedlings have a considerable size advantage over the germinating weeds and fields can be immediately flooded, which suppresses the majority of weed species. Another advantage is the higher indigenous N supply in flooded fields because of the comparatively high biological N fixation compared with dryland fields. Transplanting also improves the chances of good crop establishment, compared with direct seeding, providing rainfall has been sufficient for land preparation.

Dry direct seeding (DS) of rice has remained the preferred establishment practice in areas where labor is in short supply, human population density is low, or climatic/hydrological constraints prevented intensification of the land. Apart from lower labor requirements, a limited and unstable water supply is a major factor favoring direct-seeded systems. Direct seeding allows earlier crop establishment than transplanting, thus reducing percolation and evaporation losses from early-season rains. Roots of direct-seeded rice tend to be deeper, finer, and more extensive and, as a result, these crops consistently perform better under drought conditions (Ingram et al 1994, Singh et al 1995, Castillo et al 1998, Fukai et al 1998). In addition, direct-seeded rice matures earlier than transplanted rice, which reduces total crop water consumption and the risk of late-season drought (Cabangon et al 2002, Rathore and Sahu 2002, Sharma et al 2005). In drought-prone environments, frequently also characterized by limited nutrient availability, weed competition for water and nutrients may contribute greatly to crop losses. Thus, although direct seeding offers advantages and opportunities, direct-seeded systems tend not to be as robust as transplanted systems and management tends to be more critical to successful crop establishment, effective weed control, and high and stable yields.

The preferred establishment method largely reflects the degree of water control farmers have, the available labor, the availability of chemical weed control methods, and the need and opportunities to intensify/diversify production. A change in these factors can convince farmers to change their preferred establishment method, and such changes occur today in rainfed systems as well as in intensive irrigated systems. We discuss below some issues related to DS in the lowlands with examples of opportunities to improve productivity in (1) traditional or established DS systems and (2) where

Table 1. Time of establishment and cumulative rainfall with different rice establishment methods, 1995-2000, Raipur, India.

Establishment method	Event	Day of year	Cumulative rainfall (mm)
Dry-seeded rice	Sowing	159	0
	Establishment	177	131 ± 51
Broadcast, biasi rice (moist soil)[a]	Sowing	174	112 ± 52
	Establishment	193	255 ± 60
	Biasi (plowing)	219	532 ± 106
Transplanted rice	Transplanting	219	496 ± 112

[a]1998-2000 only
Source: Rathore and Sahu (2002).

DS is an alternative to transplanting. Changes in the weed flora caused by the shift to direct seeding and related issues are treated in the third part of this document, and lastly we look at the possibilities and options of more flexible crop establishment and management systems.

Improving productivity in the existing DS systems

In the rainfed lowland rice areas of eastern India (approx. 12.8 million ha) that are subject to shallow and intermediate flooding depth, *biasi* (also referred to as *beushening* or *beusani*) is a traditional rice establishment method, popular among farmers in 50% to 80% of the area (Koshta et al 1991, Nayak and Lenka 1988, Tomar 2002). In the biasi system, with the first rains, dry rice seed is broadcast on fields followed by wet plowing in order to control weeds at 20–35 days after emergence and when there is 5–10 cm of water on the fields (Fujisaka et al 1993). Rice is able to recover after the plowing, provided there is sufficient water in the fields, whereas many of the weeds do not. Farmers may also undertake some supplementary hand weeding to control subsequent weed growth.

Studies in the 1990s showed that different practices for dry seeding could lead to improved crop growth and increase the chances of growing a second crop. Dry sowing could be undertaken before the monsoon has started, whereas sowing in moist soil, as practiced with the biasi system, requires 112 mm on average while transplanting requires almost 500 mm of rainfall (Table 1). DS rice suffered less from water deficit, resulted in better rainfall-use efficiency (Rathore and Sahu 2002), and gave the best yields over the three years of study (Table 2). Further, DS rice could be established 16 days before sufficient rainfall to moisten the seedbed for biasi and 42 days ahead of transplanting. Advancing the rice crop increased the chances of a subsequent crop; in 1998, DS rice and earlier planting of chickpea gave the best yield and in the following year only dry seeding of rice permitted a second crop (Table 2). No second crop was possible in 2000, a drought year.

Table 2. Effects of rice establishment method on rice and chickpea grain yield (t ha^{-1}) in an on-station experiment at Raipur, India, 1998-2000.

Crop	Establishment method[a]	Year		
		1998[b]	1999[c]	2000[d]
Rice	DSR dry	4.61	4.22	3.12
	DSR moist	4.21	3.61	0.82
	DSR biasi	3.55	2.72	0.68
	TPR	3.25	1.69	0.39
Chickpea	DSR dry	1.10	0.62	NE
	DSR moist	0.96	0	NE
	DSR biasi	0.88	0	NE
	TPR	0.69	0	NE

[a]DSR = dry-seeded rice in dry or moist soil, or in the biasi system. TPR = transplanted rice. NE = not established. [b]Normal year. [c]Moderate drought year. [d]Severe drought year.
Source: Rathore and Sahu (2002).

Similar amounts of cumulative rainfall were required for biasi plowing as for transplanting (Table 1) and this is related to one of the constraints in the system. Poor rainfall can lead to delayed wet plowing and high crop losses because of weed competition. Improved weed management options based on row seeding, interrow cultivation, and herbicides could eliminate the need for wet plowing (biasi) of the rice at the tillering stage and provide a pathway to improving crop productivity. Line sowing rather than broadcasting permits interrow cultivation and easier hand weeding, and the application of either preemergence (pendimethalin) or postemergence herbicide (fenoxaprop + chlorimuron ethyl + metsulfuron) provides further options. Weed biomass was greatest at 20 DAE where rice had been sown into dry soil; at 35 DAE, across the weed management treatments, weed density and biomass were greatest in the broadcast biasi (Table 3). Weed biomass at 20 DAE was least, across establishment methods, with preemergence herbicide and at 35 DAE with the postemergence herbicide treatment. Across weed management treatments and three sites, DS rice, line sown in moist soil, gave the best yield compared with line sowing in dry soil or the traditional biasi system (4.05, 3.62, and 2.96 t ha^{-1}, respectively, LSD 5% = 0.182).

Farmers in Java also practice dry seeding, though within different systems than those of eastern India. In Central Java, two rice crops and often a vegetable crop are harvested from fields in one year in areas with a total rainfall of about 1,500 mm and without supplementary irrigation (Pane et al 2005). In this system, dry-seeded rice (*gogorancah*) is grown at the beginning of the rainy season, followed by a transplanted rice crop (*walik jerami*). Both rice crops may be subject to flooding of varying periods, with duration and depth depending on the toposequence. In this labor-intensive system, dry seeding of rice helps farmers make maximum use of the potential growing season. Studies on yield constraints in farmers' fields examined losses to weeds to determine the specific scope to increase productivity through improved weed management. Ad-

Table 3. Weed density and biomass as influenced by methods of establishment and weed and fertilizer management in 2005, Kotanpali, Raipur, India.

Treatment	Weed density[a] (plants m^{-2})		Weed biomass (g m^{-2})	
	20 DAE	35 DAE	20 DAE	35 DAE
Establishment method				
Line seeding, dry soil	8.1	3.5	18.6	10.1
Line seeding, moist soil	8.2	3.5	13.3	10.2
Broadcast biasi	8.2	3.8	13.9	12.3
LSD (5%)	ns[c]	0.2	3.0	1.4
Weed management				
Preemergence herbicide[b]	7.0	3.6	13.3	11.6
Postemergence herbicide[b]	8.8	3.3	16.6	9.8
Interculture/biasi	8.7	3.9	15.8	11.2
LSD (5%)	0.2	0.2	2.2	1.3

[a]Log transformed. [b]See text for details. [c]ns = nonsignificant.

ditional weeding and fertilizer led to higher yields across the toposequence (Fig. 1). Yield gains by the farmers' weeding practice were least on the lower portion of the toposequence and, on average, in excess of 1 t ha^{-1} elsewhere (Table 4). The yield gains by additional weeding were relatively minor compared with those of the farmers' weeding practice, indicating that farmers were achieving effective weed control. The yield gains by the farmers' fertilizer practice were broadly similar to those of the farmers' weeding practice, and there was opportunity for yield gains with additional fertilizer applications, particularly on the upper positions. Although weed species were similar across the catena, the weed densities were lower at the lower positions than at the higher positions (38, 78, and 91 plants m^{-2}, respectively). Sixty-seven weed species were recorded in the direct-seeded crops, of which approximately half also occurred in transplanted crops.

In northeast Thailand, farmers also dry direct seed rice though they may interchange this with transplanting depending on the rainfall pattern. Competition from weeds in direct-seeded crops causes serious yield losses and it was shown that, with farmers' practices, 23% of the yields were being lost to weed competition (clean weeded versus farmers' weeding, 2.67 versus 2.04 t ha^{-1}, S.E. = 0.114). In this study, farmers were applying postemergence herbicides at 70 DAS, long past the interval when effective control could be expected. The effects of weeds were compounded by other factors in that farmers reported greater losses in drier years and, further, with greater levels of weed infestation, farmers applied less fertilizer. The degree of losses may be affected by position in the toposequence and Nantasomsaran and Moody (1995) reported that weed density and weed biomass were greatest in the upper positions on the slope. Further, weed biomass in direct-seeded rice was more than three times that in transplanted areas. Farmers use less labor in northeast Thailand for hand weeding

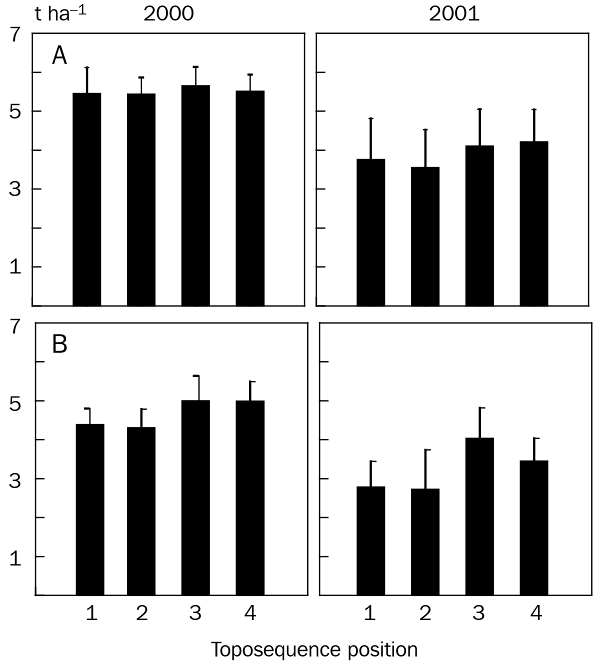

Fig. 1. Rice grain yield (mean ± S.E., t ha^{-1}) in relation to toposequence position and cropping season: (A) yield with intensive weeding and fertilizer; (B) yield under conventional farmers' practices. Toposequence position: 1 = high, 2 = upper mid, 3 = low mid, 4 = low (adapted from Pane et al 2005).

Table 4. Yield gains (kg ha^{-1}, means over sites) in relation to treatments. Toposequence position: 1 = high, 2 = upper mid, 3 = low mid, 4 = low (adapted from Pane et al 2005).

Year and season	Toposequence position	Gain by farmers' weeding	Gain by additional weeding	Gain by farmers' fertilizer	Gain by additional fertilizer	Gain by additional fertilizer and weeding
2000 *Gogorancah*	1	1,653	80	778	782	278
	2	1,059	–	1,345	980	154
	3	1,147	188	630	460	192
	4	712	294	1,001	112	416
	Overall S.E. 522					
2001 *Gogorancah*	1	1,368	2	962	540	431
	2	819	220	845	410	413
	3	1,529	130	1,006	132	–
	4	772	266	779	487	268
	Overall S.E. 354					

than in Central Java and many farmers seek alternative employment in urban areas during the cropping season.

Varietal improvement will remain an important element to improve productivity across the systems described above. Farmers may, however, gain greater benefit from these developments if these were linked more closely to typical crop management practices and production constraints, especially in the drought-prone systems. Characteristics not related to yield under "favorable" conditions may, however, be important in the target environment and under conditions of stress. An often overlooked important varietal characteristic in direct-seeded, water-limited environments is early vigor. Quick canopy development helps to reduce unproductive evaporation losses, enables faster access to water and nutrient resources below the soil surface layer, and increases the weed competitiveness of the rice crop (Tuong 1999, Zhao et al 2006a). Recently, Zhao et al (2006b) showed that weed-suppressive ability and weed competitiveness under upland conditions are strongly associated with rapid seedling growth in the first 4 weeks after sowing, a trait for which substantial variability exists within and among the major rice germplasm groups (Zhao et al 2006c). A study of Atlin et al (2006) showed that cultivars with medium height, medium duration, high early vigor, some drought tolerance, and good fertilizer-N response were the best performing cultivars in aerobic rice environments. As in many rainfed lowlands, aerobic rice is established by direct seeding and is often constrained by water limitations and high weed pressure. As a consequence, screening for seedling biomass accumulation has been incorporated as a routine screening step in the IRRI rainfed and aerobic rice breeding programs (Atlin, unpublished). Varieties with increased drought tolerance and high early vigor therefore could be an important step to making direct-seeded rice in rainfed lowlands less risky, more viable, and more productive in the near future.

Direct seeding as an alternative to transplanting

The decreased availability of labor and increasing labor costs in many areas of Asia have led farmers to adopt direct seeding in place of transplanting of rice (Pandey and Velasco 2005). Malaysia was one of the first countries in Asia where this transition occurred. The Green Revolution started to have impact in Malaysia in the 1960s, in the 1970s rice production in irrigated schemes was changing to double cropping, and in the 1980s there was a shift from transplanting to direct seeding (Ho 1998). As farmers elsewhere face increasing labor costs and the need for improvements in labor productivity, the transition to direct seeding continues.

Rainfed rice is grown over 0.1 million ha of the High Barind Tract in Bangladesh and 80% of this land lies fallow in the postrice season (Mazid et al 2003). Farmers traditionally transplant the crop but direct seeding is feasible and it can increase the chance that a subsequent cash crop such as chickpea can be grown (Mazid et al, this volume). A challenge in rainfed rice systems, however, is to improve reliability at the same time as improving overall system productivity. To achieve this in the Barind of Bangladesh, direct seeding was proposed as an alternative to transplanting to enable an earlier harvest and to increase the opportunities for a rabi crop (e.g., chickpea or mustard) to be grown on the residual moisture (Mazid et al 2002). Direct seeding allows earlier establishment as the land can be prepared after only 150 mm of rainfall have fallen compared with a total of 400 mm for transplanting in Bangladesh (Saleh et al 2000). The greater cumulative rainfall required for transplanting results in delayed transplanting by up to 1 month in two years out of ten. A similar study in the Philippines (Saleh and Bhuiyan 1995) showed that land preparation for transplanting can require 600 mm of cumulative rainfall, which can lead to delays in transplanting by up to 2 weeks in two years out of ten.

Direct seeding as an alternative to transplanting and as an approach to reduce costs and improve flexibility has also been demonstrated in the rice-wheat system of the Indo-Gangetic Plains (Singh et al 2005). A significant portion of the rice-wheat areas is irrigated but many of the constraints, particularly with regard to weed management, are common to the rainfed areas. In the rice-wheat system, the yield potential of direct-seeding options is similar to that of transplanting but the potential losses to weeds and need for effective weed management are much greater (Singh et al 2005). In the Indo-Gangetic Plains, rice can be either direct-seeded with pregerminated seed sown on puddled soil or dry-sown, either after conventional dry tillage or with zero-tillage, using the tractor-mounted seed-drills used for the wheat crop. The application of pendimethalin, a preemergence herbicide, followed by one hand weeding, has been shown to be an effective way of controlling the majority of weeds in studies over five seasons.

Relation between establishment method and weed species

Changes in weed populations that result from changing from transplanting to direct seeding were recorded in Malaysia, one of the first areas in Southeast Asia to revert to direct seeding (Fig. 2). Broadleaf weeds, including *Sagittaria* and *Monochoria* species, were dominant weeds in transplanted rice in the late 1980s but, with a change to direct seeding, grass weeds became of increased importance. *Echinochloa* spp., having been relatively minor weeds previously, became the dominant weeds in direct-seeded rice. The annual grass *Ischaemum rugosum* and the perennial grasses *Leersia hexandra* and *Panicum repens* also presented threats, having not previously been recorded. Substantial changes in the composition of weed flora with a change to direct seeding have also been recorded in the irrigated systems of India (Singh et al 2005) and in the rainfed systems in Bangladesh (Mazid et al, this volume). Compilation of this information forms a substantial knowledge base that can be used for weed management in some of the most important rice production areas in Asia. Many of the weed species present are common to these systems and the transition from transplanting to direct seeding is reflected in shifts in the composition of weed populations. These shifts tend to be toward competitive grasses, including *Echinochloa* species, *Leptochloa chinensis*, and *Ischaemum rugosum* in irrigated wet-seeded rice and the perennial sedge *Cyperus rotundus* in dry-seeded rice. In the rainfed systems, *Cynodon dactylon*, *Fimbristylis miliacea,* and *Echinochloa crus-galli* all increased under dry direct-seeded rice compared with transplanted rice. Management of such

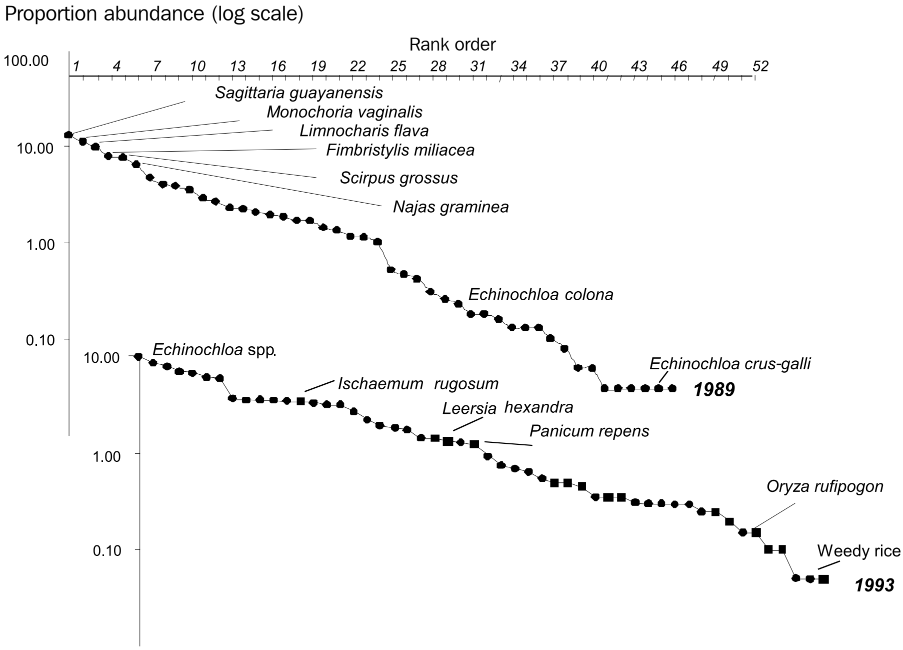

Fig. 2. Changes in weed species composition in farmers' fields in Kemuba, Malaysia, resulting from the change from transplanting (1989) to direct seeding (1993) of rice. Species ranked in terms of their proportional abundance based on area coverage. Species not present in 1989 are indicated by squares in 1993 abundance curve (modified after Mortimer and Hill 1999).

weeds is challenging and it requires farmers to anticipate changes in weed populations and exploit integrated strategies comprising tillage, water, and crop management to complement herbicide application. In Malaysia, by 1993, *Oryza rufipogon* (a wild rice) and "weedy" rice (*O. sativa*) were widespread in the weed flora having not been recorded in 1989 (Fig. 2). Weedy rice, characterized by high grain shattering, has become a serious problem in Malaysia and Vietnam, and has subsequently been reported elsewhere in Asia (Azmi et al 2005). The vigorous growth of this weed results in serious yield losses, and its rapid spread threatens the sustainability of direct-seeded rice production. Control of weedy rice is particularly difficult because of its close relation to the crop, though strategies combining preventive and cultural measures have been shown to be partially effective. A further outcome of the shift to direct seeding, and the concomitant increased reliance on herbicides, has been that certain weed species, including *Sphenoclea zeylanica* and *Fimbristylis miliacea*, have developed resistance to 2,4-D herbicide (Watanabe et al 1997). More recently, possible ALS (acetolactate-synthase) inhibitor-resistant biotypes of *Bacopa rotundifolia* and *Limnophila erecta* have been reported (Azmi and Baki 2003). This is likely to be an increasing concern as the intensity of herbicide use increases.

Fewer studies have been conducted on the effects of changes in traditional direct-seeded systems on weed species composition. However, similar problems, with an increase in the pernicious grass weeds in particular, will probably emerge as in the cases described above. Indications of this were apparent in the first year of experiments in eastern India where line seeding of rice was compared with the traditional biasi (Rathore and Sahu 2002) and where the principal weeds occurring were *Echinochloa colona*, *Eclipta prostrata*, and *Ischaemum rugosum.* These species also occurred, in both direct-seeded and transplanted systems, in Java and Thailand along with the troublesome perennial weeds *Cyperus rotundus* and *Cynodon dactylon* (Pane et al 2005, Moody 1989).

Management options for rainfed systems for improving productivity

Rainfed lowlands are characterized by considerable spatial variability in soil characteristics and hydrological conditions, often related to the undulating topography. Considerable temporal variability within the season and between years is added by variations in seasonal rainfall patterns, the onset of the monsoon, and seasonal rainfall quantity. These factors, together with farmers' available resources, varietal preference, and cropping practices, will greatly affect the feasibility of options for direct seeding. Further, because of changing rainfall patterns, feasible options in one year might not be possible in a subsequent year. In some regions, farmers react to these conditions with great flexibility. In eastern India, for example, farmers that usually dry-seed may transplant if the monsoon rains come early (Fujisaka et al 1993). Further, in northeast Thailand, farmers may shift between transplanting and direct seeding depending on the monsoon rainfall and topography. However, such adaptive crop management strategies are not common in many other rainfed lowlands and current research as well as existing recommendations often overlook a range of crop management options that could help farmers achieve more flexibility yet cater to local variability. The example for this approach given in Figure 3 gives farmers the opportunity to combine general advice on establishment and weed management with their own field experiences and observations. Given the conditions in many rainfed environments, flexible solutions should be better suited to helping farmers respond to their highly variable environment and to securing their livelihoods.

Although these options may increase the potential productivity of rice-based systems, changes in crop establishment must be reflected in changes in weed management. The farmers' practice that provides reasonable weed control in transplanted systems or the traditional biasi system is unlikely to be adequate in dry drill-seeded rice. The introduction of weed management interventions, involving interrow cultivation and herbicides, could provide an alternative to biasi. As farmers move from transplanting to direct seeding or from the biasi systems, however, they will need more information on the management of weeds and how farmers can limit undesirable shifts in weed populations (Johnson and Mortimer 2005). The commonality in weed populations in direct-seeded rice, across a range of environments, offers scope to develop means

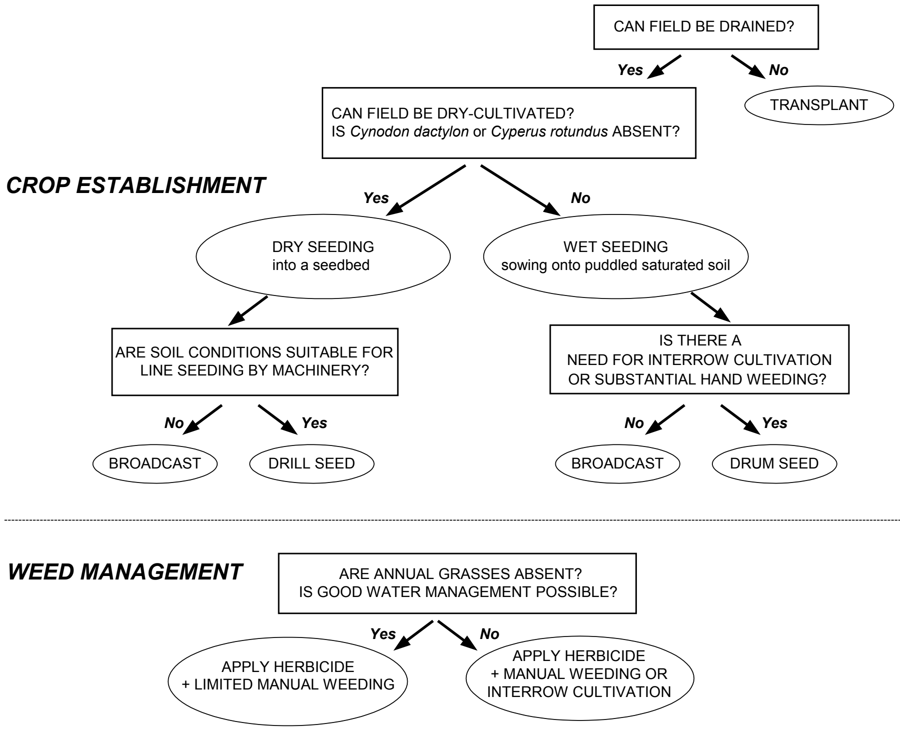

Fig. 3. Illustrative decision-tree for adoption of direct seeding with respect to favorable rainfed lowland rice (Johnson and Mortimer 2005).

of assisting farmers in their decision making. The studies in India on direct seeding have shown that *E. colona*, *C. rotundus,* and *Commelina diffusa* are discouraged by wet seeding, while this has the opposite effect on *Ischaemum rugosum*, *Leptochloa chinensis,* and *Fimbristylis miliacea* (Singh et al 2005). Further gains in the development of such knowledge, which predicts undesirable shifts in weed populations, will help develop and refine the means to help farmers prevent these from occurring.

As production systems evolve, farmers will need considerable support to enable them to exploit the potential of many of the various options. This is particularly true of herbicide use, with which farmers may have little experience and poor access to information. Farmers will need substantial information and continuing guidance to enable them to use products safely and effectively. In many locations, this is likely to be achieved only with substantial effort and partnership among the official, commercial, and informal sectors in rural areas.

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Notes

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Acknowledgments: The research in eastern India and in northeast Thailand was partly funded by the Consortium for Unfavorable Rice Environments (CURE).