Australian Government

Australian Centre for
International Agricultural Research

Sustainable intensification of Rabi cropping in southern Bangladesh using wheat and mungbean

ACIAR TECHNICAL REPORTS

78

Research that works for developing countries and Australia

Sustainable intensification of Rabi cropping in southern Bangladesh using wheat and mungbean

Editor: H.M. Rawson

ACIAR
Research that works for developing countries and Australia

aciar.gov.au

2011

The Australian Centre for International Agricultural Research (ACIAR) was established in June 1982 by an Act of the Australian Parliament. ACIAR operates as part of Australia's international development cooperation program, with a mission to achieve more productive and sustainable agricultural systems, for the benefit of developing countries and Australia. It commissions collaborative research between Australian and developing-country researchers in areas where Australia has special research competence. It also administers Australia's contribution to the International Agricultural Research Centres.

ACIAR TECHNICAL REPORTS SERIES

This series of publications contains technical information resulting from ACIAR-supported programs, projects and workshops (for which proceedings are not published), reports on Centre-supported fact-finding studies, or reports on other topics resulting from ACIAR activities. Publications in the series are distributed internationally to selected individuals and scientific institutions, and are also available from ACIAR's website at <aciar.gov.au>.

Rawson H.M. (ed) 2011. Sustainable intensification of Rabi cropping in southern Bangladesh using wheat and mungbean. ACIAR Technical Reports No. 78. Australian Centre for International Agricultural Research: Canberra. 256 pp.

ISBN 978 1 921738 87 6 (print)
ISBN 978 1 921738 88 3 (online)

Technical editing by Mary Webb, Canberra
Design by Clarus Design, Canberra
Printing by CanPrint Communications

Cover: Threshing wheat quickly in Bangladesh using a locally modified, rotating squirrel cage fan (Photo: H.M. Rawson)

Foreword

The Australian Centre for International Agricultural Research (ACIAR) supports an active program of research for development in South Asia. In 2006, ACIAR commenced an initiative in the southern coastal region of Bangladesh that aimed to lift agricultural productivity in the region and address the large and growing wheat deficit of the country. Significant areas of land lying underutilised between sequential plantings of rice provide an opportunity to grow a short-duration dry-season crop. The challenge was to determine whether wheat or other crops, including mungbean, could be grown profitably under the hot, humid and sometimes saline conditions of this region.

ACIAR supported a project led by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) to research this opportunity and its challenges. Research partners included the Bangladesh Agricultural Research Institute (BARI) through its Wheat Research Centre (WRC) and On-Farm Research Division (OFRD), and the Bangladesh Department of Agricultural Extension (DAE). The non-government organisations, PROSHIKA, and later the Forum for Regenerative Agricultural Movement (FoRAM) and the Socio-Economic Research and Development Initiative (SERDI), were important contributors to the agronomic and socioeconomic research and the scaling out of project results.

This publication summarises the findings from the project, which ran from 2006 to 2011. It reports that about 800,000 ha of land are being underutilised in southern Bangladesh. Interviews with farmers in the region indicated their willingness to intensify cropping during the Rabi (dry) season. Wheat varieties were tested and selected in the southern region and, depending on salinity levels, yielded between 2.0 and 4.5 t/ha from over 200 on-farm sites. A key finding was that watertables throughout the southern coastal region supplemented water supply to wheat through direct root access to the shallow watertable and its capillary fringe. It was also found that a single supplementary irrigation using water from ponds and canals could be sufficient for wheat cropping.

The ACIAR project verified the technical feasibility of wheat production in southern Bangladesh. Yet the question remains on whether the findings can be adopted by the local farmers, who clearly expressed the need for training in wheat production, which is not a traditional crop of the region. The report will serve as a source document for local researchers, policymakers, government extension organisations and local non-government organisations to support training of farmers, encourage the supply of improved seed and access to credit for inputs, and ensure future development avoids risks to communities and the environment.

Nick Austin
Chief Executive Officer
ACIAR

Contents

Dedication

This report is dedicated to the memory of Dr Mirko Stauffacher who died in January 2011.

Dr Stauffacher was ACIAR's Research Program Manager for Land and Water Resources who managed this project. Most importantly, from the point of view of the many researchers, support staff and farmers who contributed in some way to the contents of this report, Mirko was an easygoing, highly approachable and constructive manager; a person whose door was always open whether in the Canberra office or in the field with local staff in Bangladesh. His contribution to the project was as much in his personality as in his ideas and management attributes. The report contributors thank him and remember him as a big man with a big heart.

Mirko Stauffacher in Bangladesh (Photo: H.M. Rawson)

Author details

M. Abu Zaman Sarker (Chapters 3.1, 3.4), Senior Scientific Officer, Wheat Research Centre, BARI (Bangladesh Agricultural Research Institute), Nashipur, Dinajpur, Bangladesh. Email: <zaman1965@yahoo.com>

Sharmin Afroz (Chapters 1.2, 5.1, 5.2), Coordinator (Sustainable Rural Livelihoods) SERDI (Socio-Economic Research and Development Initiative), Block # B, Section # 06, Mirpur, Dhaka-1216, Bangladesh. Email: <linksaji@hotmail.com>

M.M. Akhter (Chapter 3.1), Scientific Officer, Wheat Research Centre, BARI, Nashipur, Dinajpur, Bangladesh. Email: <masuma_73@yahoo.com>

M. Amin (Chapters 3.2, 3.4, 3.5), Principal Scientific Officer, On-Farm Research Division, BARI, Noakhali, Bangladesh. Email: <psoofrd@ymail.com>

Abul Awlad Khan (Chapter 3.1), Scientific Officer, Regional Agricultural Research Station, Ishurdi, Pabna, Bangladesh.

Himu Bain (Chapter 1.2), Researcher (Sustainable Rural Livelihoods) SERDI (Socio-Economic Research and Development Initiative) Block # B, Section # 06, Mirpur, Dhaka-1216, Bangladesh.

N.C.D. Barma (Chapters 3.2, 3.3, 3.6), Principal Scientific Officer, Regional Wheat Research Centre, BARI, Gazipur 1701, Bangladesh. Email: <ncdbarma@gmail.com>

Peter S. Carberry (Chapters 1.1, 4.1, 4.2, 6), Deputy Director, CSIRO (Commonwealth Scientific and Industrial Research Organisation) Sustainable Agriculture Flagship, PO Box 102, Toowoomba, Queensland 4350, Australia. Email: <Peter.Carberry@csiro.au>

Neal P. Dalgliesh (Chapters 2.2, 4.1, 4.2, 4.3), Leader and farming systems researcher, ACIAR Project SMCN (LWR)/2005/146, CSIRO Ecosystem Sciences, PO Box 102, Toowoomba, Queensland 4350, Australia. Email: <Neal.Dalgiesh@csiro.au>

M. Enamul Haque (Chapters 3.3, 3.5) Scientific Officer, ACIAR Project SMCN (LWR)/2005/146, Bangladesh. Email: <ehaquekhdkbd@yahoo.com>

M. Farhad (Chapters 3.3, 3.4, 3.5), Assistant Plant Breeder, Plant & R&D Farm, Lal Tir Seed Ltd, Bason Road, Gazipur, Bangladesh. Email: <farhadnabin@gmail.com>

M. Farhad Hossain (Chapters 3.4, 3.5), Scientific Officer, ACIAR Project SMCN (LWR)/2005/146, Bangladesh. Email: <mdfarhadbd@gmail.com>

M. Helal Uddin (Chapters 3.3, 3.5), Scientific Officer, ACIAR Project SMCN (LWR)/2005/146, Bangladesh. Email: <helaluddin81@yahoo.com>

A.B.S. Hossain (Chapters 1.1, 3.2, 3.3, 3.4, 3.6), In-country Coordinator, ACIAR Project SMCN (LWR)/2005/146, Bangladesh. Email: <abshossain@gmail.com>

M. Ilias Hossain (Chapter 3.1), Senior Scientific Officer, Regional Wheat Research Centre, BARI, Shyampur, Rajshahi, Bangladesh. Email: <iliaswrc@yahoo.com>

A. Hossain (Chapter 3.1), Scientific Officer, Wheat Research Centre, BARI, Nashipur, Dinajpur, Bangladesh. Email: <tanjimar2003@yahoo.com>

M. Ihsanul Huq (Chapter 3.3), Director (S&S) BARI, Gazipur-1701, Bangladesh. Email: huqrars@gmail.com>

Md Jahangir Kabir (Chapters 4.1, 4.4), Senior Scientific Officer, Agricultural Economics Division, Bangladesh Rice Research Institute, Gazipur-1701, Bangladesh. Email: skabir1974@yahoo.com

M. Abdul Khaleque (Chapter 3.1), Principal Scientific Officer, Regional Agricultural Research Station, Ishurdi, Pabna, Bangladesh. Email: <mkhaleque2000@yahoo.com>

Iqbal Alam Khan (Chapters 1.2, 4.1, 5.1, 5.2), Team Leader (Sustainable Rural Livelihoods), SERDI (Socio-Economic Research and Development Initiative), Block # B, Section # 06, Mirpur, Dhaka-1216, Bangladesh. Email: <swapnapurno@hotmail.com>

M. Mustafa Khan (Chapter 3.1), Scientific Officer, Regional Wheat Research Centre, BARI, Gazipur-1701, Bangladesh. Email: <mmkhanwrc@yahoo.com>

Nibir Kumar Saha (Chapter 3.6), BRAC Agricultural Research and Development Centre, Jogotola, Gazipur-1701, Bangladesh. Email: <nibirsau@gmail.com>

M. Mahbubur Rahman (Chapter 3.6) Scientific Officer, Regional Wheat Research Centre, BARI, Gazipur-1701, Bangladesh.

M. Manirul Islam (Chapter 3.3), Senior Scientific Officer, Biotechnology Division, Bangladesh Rice Research Institute, Gazipur-1701, Bangladesh. Email: <mislambrri73@gmail.com>

Rohan Nelson (Chapter 4.1), Director, Agriculture, Department of Climate Change, Australian Government, Australia. Email: <rohan.nelson@climatechange.gov.au>

Perry L. Poulton (Chapters 2.1, 2.2, 2.3, 4.1, 4.2, 4.3), APSIM (Agricultural Production Systems Simulator) and farming systems researcher, CSIRO Ecosystem Sciences, PO Box 102, Toowoomba, Queensland 4350, Australia. Email: <Perry.Poulton@csiro.au>

Howard M. Rawson (Chapters 1.1, 2.1, 3.1, 3.3, 3.4, 3.5, 3.6, 4.4)**,** Consultant, ACIAR Project SMCN (LWR)/2005/146, Wombalano, Creewah, Nimmitabel, New South Wales 2631, Australia. Email: <Howard.Rawson@gmail.com>

Kakali Roy (Chapter 3.4), Scientific Officer, Agronomy Division, BARI, Gazipur-1701, Bangladesh. Email: <kakalisau@yahoo.com>

M. Saifuzzaman (Chapters 1.1, 3.1,.3.2, 3.3, 3.4, 3.5, 3.6), Ex-Principal Scientific Officer, Consultant ACIAR Project, SMCN (LWR)/2005/146, Regional Wheat Research Centre, BARI, Gazipur-1701, Bangladesh. Email: <szamanwrc@gmail.com>

Nasrin Sultana (Chapter 1.3), PhD student, School of Agriculture and Food Sciences, The University of Queensland, St Lucia Campus, Queensland 4072, Australia. Email: <nasrin.sultana@uqconnect.edu.au>

M. Sydur Rahman (Chapters 3.3, 3.5), Scientific Officer, ACIAR Project SMCN (LWR)/2005/146, Bangladesh.

M.H. Ullah (Chapter 3.4), Chief Scientific Officer, Regional Agricultural Research Station, Rahmatpur, BARI, Barisal, Bangladesh.

Summary

The Australian Centre for International Agricultural Research (ACIAR) project (LWR/2005/146, 'Expanding the area for Rabi-season cropping in southern Bangladesh') began in 2006 with the primary aim of intensifying crop production in southern Bangladesh during the Rabi (dry) season. The target crops were wheat, which is declining in production and rising in consumption, and mungbean, which is a high-value crop that yields poorly. The factors that made the project timely were: new potentially high-yielding varieties of wheat becoming available from the Wheat Research Centre (WRC) of the Bangladesh Agricultural Research Institute (BARI) and of short-duration mungbean from BARI Pulse Research Centre; and reports of substantial areas of land lying fallow or underutilised in the region that perhaps could suit wheat and mungbean. The land was fallow between sequential rice crops. The challenge from the research viewpoint was that little wheat was grown in the region, in part because the climate was considered too hot, the soil was often too saline, and irrigation water was not available in sufficient quantities for the supposed requisite three applications. Where irrigation infrastructure was available, the water was used for growing boro rice. Furthermore, the window for growing the crop between sequential rice crops was too short for older wheat varieties.

The project did two things in parallel: collated existing data and collected new data on the climate, soils and water resources of the region (Chapters 2.1, 2.2 and 2.3); and, through cooperating farmers, tested the suite of new varieties and the feasibility of intensified Rabi cropping on farms across southern Bangladesh (Chapters 3.2 and 3.3). The participating farmers could test the suitability of the varieties and along the way be trained in how to grow the material optimally, and become a seed grower and supplier of their preferred varieties for their locality. Their farms would also be the laboratory for collecting cropping and environmental data and selected local villages the sites for collecting sociological data (Chapters 1.2, 1.3, 5.1 and 5.2).

Bangladesh Government data on land use, analysed in various ways and supplemented using satellite imagery, indicated that around 800,000 ha of land in the medium–high and medium–low land classes and suitable for wheat were indeed fallow or underutilised during Rabi (Chapter 2.3). The climate, although 2–3 °C hotter than the traditional wheat-growing centres farther north in Bangladesh (Chapters 2.1 and 3.1), could potentially support 3 t/ha crops of wheat. Equally, the soils and water resources of the region were adequate, particularly since watertables there are generally shallow and accessible by roots, either directly or by capillarity (Chapter 2.2). Intensification could therefore proceed sustainably without a need to develop irrigation infrastructure and run the common risk of overexploiting the resource.

The cropping data collected on-farm demonstrated that with a single irrigation, available from ponds or canals early in Rabi, and applied 20 days after sowing with a top-dressing of nitrogen (Chapter 3.4), the new wheat varieties could realise 3–4 t/ha potential. This was as expected from the research and modelling of the climate, soil and water data, in the absence of salinity. The new varieties could also complete their life cycles within the 90 days available after harvesting transplanted aman rice in mid to late December, and before rainfall occurred to allow planting of following crops (Chapter 3.3). Continuing selection of wheat throughout 4 years of the project, using procedures to accentuate heat and late-planting tolerance and lower salinity susceptibility, resulted in the release of a further two new varieties for the southern regions (Chapter 3.6). Wheat crops planted at the end of December in marginally saline conditions yielded 2–3 t/ha. This is one month later than the time considered suitable in traditional wheat-growing areas for acceptable yields (Chapters 1.1 and 3.1).

It was expected there would be benefits, particularly in the more saline areas, from planting wheat crops on raised beds and more generally from using row-planting techniques rather than broadcasting

(Chapter 3.5). The research data showed no significant benefits from either practice, although farmers were more likely to control weeds in row-planted rather than broadcast crops; crops overrun by weeds yielded as low as 0.5 t/ha.

Farmers were always concerned about the high price of fertilisers and suggested ways they might supplement inorganic fertilisers with some of the organic materials that were available to them. Experimentally, and over the short term of two seasons, good yields could not be achieved without some chemical fertilisers. While farmyard manure was a beneficial supplement, there was no apparent positive effect on yield of using the readily available water hyacinth composts (Chapter 3.4).

Mungbean supplied to farmers for sowing after wheat (Chapter 4.3) produced acceptable yields when sown before late March and if there was sufficient rain or irrigation water available to establish the crop. Mungbean sown after late March was invariably severely damaged by heavy rain or by tidal surges flooding the land. Regardless of sowing time, potential yield exceeding 1 t/ha was reduced where diseases, insects and weeds were not controlled. However, mungbean grown instead of wheat and planted by mid January and well managed would yield 1.1–1.6 t/ha according to collected data and model predictions. This high likelihood of success was due to water being available in the soil profile with little risk from destructive climatic events. The crop realised good economic returns because of minimal inputs and high market value (Chapter 4.4).

Rice is the preferred core food for Bangladesh people (Chapter 1.2). In recent years, the rice varieties produced during the monsoon have been significantly overhauled in national production by Rabi-season boro rice, which is dependent for good yield on between 20 and 30 irrigations from deep or shallow tube wells (Chapter 1.1). Farmers grow boro rice during Rabi if they have access to irrigation with its associated infrastructure. Most farmers in the south have no such access (Chapter 2.2). Boro rice is a preferred crop choice for farmers, primarily because it provides food security for the family (Chapter 5.1). However, economically it lags behind wheat-based rotations in climatically good and average seasons (Chapter 4.1), although it is better in poor seasons because of its use of irrigation water.

Boro rice requires more effort to grow than wheat; it occupies the land for longer and requires more inputs, although these are spread across the season rather than close to planting as is the case for wheat. So, logically, farmers should prefer to grow wheat over rice. But wheat is not a traditional crop in the south, so premier seed for planting is not available in local markets. Most importantly, farmers say they do not know how to grow wheat to achieve good yields. Hence, wheat is currently generally regarded as a risky crop that should not be grown until several major changes in society have occurred (Chapter 5.1).

The farmers' list (Chapter 5.2) of requirements is long, but central is the need for widespread training in how to grow wheat, and that must target particularly the poor tenant farmers who make up 50% of farmers, and should include women who handle the crops postharvest and make many of the management decisions within the household. Any training must include problem-solving advice throughout the Rabi season from the Bangladesh Department of Agricultural Extension (DAE). Farmers specify regular farm visits by DAE technical staff. Easy-repayment government loans would assist in the purchase of fertiliser and other essentials that must be available at the local markets before land preparation in December. And capital equipment, such as threshers, must be available at the community level, with the government or non-government organisations providing them as a service.

Although the opportunity is now present to increase food security and livelihoods sustainably throughout the south of Bangladesh through the more intensive use of fallow land and rice/wheat-based crop sequences, the road required to achieve this is still hard without considerable government initiative, coordination and leadership (Chapter 6). Furthermore, with the issue of climate change threatening (Chapter 2.1), there is pressure to act now.

The map below shows the major administrative districts of Bangladesh. Wheat cultivation areas (red dots) for the 2007–08 Rabi season demonstrate regional differences between the traditional northern wheat-growing regions and the southern regions, which concern this report, bordering the Bay of Bengal. The map is reproduced from the United Nations' World Food Programme via the website link below. The site gives a good overview of agriculture and people in Bangladesh.

<http://www.foodsecurityatlas.org/bgd/country/availability/agricultural-production>.

Distribution of wheat

Year 2007–08

Source: Bangladesh Bureau of Statistics (BBS), 2008

Section 1

Background to wheat in southern Bangladesh

1.1 The challenge to increasing wheat production

H.M. Rawson, P.S. Carberry, A.B.S. Hossain and M. Saifuzzaman

Abstract

Wheat has never been more than a minor crop in the coastal south of Bangladesh. The south has historically been classified as less than 20% suitable for wheat. Temperatures are regarded as too high for this temperate crop, soils are often considered too saline and irrigation infrastructure is lacking for the three irrigations assumed to be required by wheat. Perhaps most importantly, sowing has to be delayed well beyond its perceived optimum period in November because transplanted (T.) aman rice is harvested late and soils are slow to dry sufficiently for pre-sowing cultivations. So, perceptions have been that the season is too late and too short and consequently that yield potential is very low.

A small study funded by the Food and Agriculture Organization of the United Nations (FAO) showed in 2003–05 that on the 60 farms tested in Noakhali and Barisal the situation for wheat was not as dire as expected, as some farmers achieved yields approaching 4 t/ha. Even with sowings delayed well beyond the optimum time for the north, and after T. aman rice had been harvested, 3 t/ha yields were possible. An Australian Centre for International Agricultural Research (ACIAR)-funded scoping study in 2005–06 confirmed these findings, but again on a very small scale, and raised the possibility that with the recognised shallow watertables in the south, maybe wheat could grow well without irrigation or with a single early establishment irrigation around 20 days after sowing. The question was whether those positive results and positive ideas could be realised to make wheat an economic option for farmers throughout the south. And by extension, make the south a major contributor to reducing the deficit in Bangladesh wheat production by cropping its large tracts of underutilised lands during the Rabi (dry) season.

In 2006–10 a large ACIAR project tested the potential of the south for wheat production by interacting with farmers throughout the region, training them to grow the suite of new wheat cultivars and concomitantly collecting data on the environment, the soils and the availability of water, as well as on the performance of on-farm crops with and without irrigation. Research questions have been asked and answered both on-farm and on research stations.

This chapter is an introduction to the perceived challenges associated with growing wheat in the region, but later chapters cover where and how the crop-management challenges have been met, the potential for wheat production in the region and the viewpoints of the farmers.

Introduction

Bangladesh, when it was called East Bengal, had two main crops; rice, grown primarily during the monsoon, and jute. From the late 1800s, jute was a vital export commodity to Europe, the United States of America (USA) and Australia, where it was used to make bags or gunny sacks for holding agricultural products. Some of the jute bags returned to East Bengal filled with Australian wheat. Following World War II, East Bengal was separated from India and in 1947 became East Pakistan. This also separated the main areas for growing jute from Calcutta, now in India, where the jute had been manufactured into bags. Nevertheless, annual jute production remained at the previous levels of around 6 million bales/year (Bharadwaj and Fenske 2009) grown on 0.7 million hectares (ha) (van der Steen 2005). The jute–rice cycle continued largely unchanged.

It was still another decade before wheat was grown in the country and well into the 1970s, when East Pakistan had become Bangladesh, before wheat could be considered a crop that farmers in the cooler north could realistically include as a crop choice. Wheat was not a farmer option in the hot and humid south. There, the British-founded Barisal Coconut Research Station (Figure 1) reflected the general view of what was an appropriate crop for the climate. The late 1960s and early 1970s were the green revolution for India, and Bangladesh as a neighbouring country eventually benefited from the new wheat germplasm that was coming through the Ford/Rockefeller Foundation and the associated International Maize and Wheat Improvement Center (CIMMYT) breeding initiatives. The stage was then set for wheat to become an established crop in Bangladesh (Ahmed and Meisner 1996).

As wheat is grown during the dry or winter Rabi season in Bangladesh, it does not compete for land with the wet-season transplanted (T.) aman rice crop that farmers needed for their food security. This temporal synergy provided the opportunity for introduction of wheat in northern Bangladesh.

However, even in the north, wheat did not become the prime Rabi crop. From the mid 1970s, high-yielding varieties (HYV) of boro rice, sometimes referred to as winter rice, started to become available and rapidly became the Rabi crop of choice. Boro needs 20–30 irrigations and high rates of fertiliser, insecticides and weeding to produce a good crop, taking around 120–130 days from planting to harvest (Hossain et al. 2005). The number of irrigations is dependent on the permeability of the soil profile, with sandy loams needing the most water. As Bangladesh had high watertables, this water was readily extracted using shallow tube wells (STWs, Figure 2). Starting with a contribution of foreign aid from the United Nations International Children's Emergency Fund (UNICEF), initially aimed at providing clean drinking water across Bangladesh, STWs were progressively sunk throughout the northern and central regions in an unplanned way so that by 2000 there were around 4 million throughout the country (Asad uz Zaman 2004). The boro area expanded in concert with the sinking of the tube wells. Boro's contribution to Bangladesh rice production has exceeded 12 million metric tonnes (t), more now than the contribution from wet-season T. aman rice (Sattar 2000). On the negative side, watertables have fallen through over-exploitation for cropping and a large number of the STWs have some arsenic pollution (Meharg and Rahman 2003). Nevertheless, the boro story in Bangladesh has been one of great success.

By 2000, many farmers had food security both from wet- and dry-season rice production and

Figure 1. Coconut Research Station at Barisal (Photo: HMR)

sufficient resources to mechanise their farms with at least a hand-tractor with rotavator/chisel tiller (Hobbs and Gupta 2004). This in turn meant that the time between sequential crops had reduced to a few days, being no longer dependent on the bullock-drawn country plough (Figure 3) that required 1–2 weeks for the three to five ploughings and several laddering passes to prepare the soil before sowing. This preparation period could not start until the soil was dry enough for the animals to work in the field. Hand-tractors could start the process earlier. This chain of events gave progressive Bangladesh farmers the opportunity to grow a wet-season rice crop (T. aman) harvested in November–December, followed by a short-duration Rabi crop before a late January (trans) planting of boro (Figure 4). One crop per year had now potentially increased to three.

Throughout the past 40 years of political and agricultural change, wheat has continued to be grown largely in the northern regions and has provided the country with around 1 million t of grain each year after 1985 (Figure 5c). Output rose to almost 2 million t in the 1999 season before reducing thereafter. Wheat remained secondary to boro rice as it was commonly grown where irrigation was not available, with the consequence that wheat yields were under 2 t/ha compared with 2.5 t/ha for boro (Figure 5b). Wheat does not provide the same food security for farmers as rice and so it has generally been treated as an opportunity crop with lower than recommended levels of inputs.

Figure 2. Sinking a shallow tube well (Photo: HMR)

Figure 3. First ploughing pass (Photo: HMR)

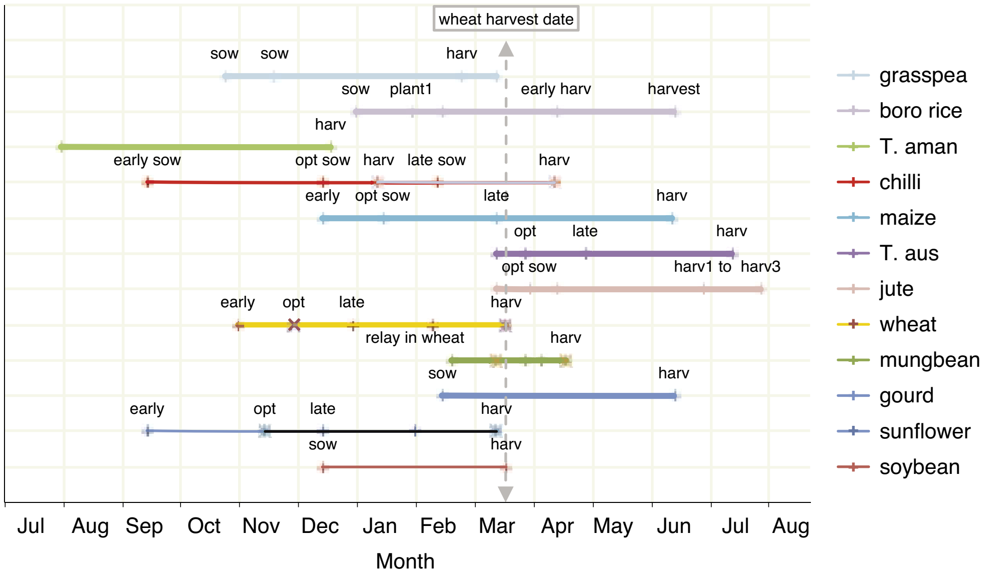


Figure 4. Dates for sowing and harvest of important crops such as rice, wheat, jute and mungbean

Most of the Bangladesh wheat crop has historically been produced in the cool north and central zones. The coastal southern regions have contributed little. For example, in the 1999 season for wheat, the whole of Barisal division, including the large island of Bhola, contributed only 0.5% or 10,000 t to the country total of almost 2 million t.

FAO: initiative on wheat productivity

In 2002, the Bangladesh Government asked the Food and Agriculture Organization of the United Nations (FAO) to support an initiative to increase wheat production in the country through the 'Sustainable intensification of rice–wheat systems'. The rationale was that wheat food aid from countries such as Australia had stopped, after being 1.8 million t in the early 1990s, while at the same time the Bangladesh crop had declined since 1999 due to reduced areas being planted with wheat (Figure 5a). Concomitantly, consumption was rising at 3% per year, approaching 4 million t, equivalent to 28–30 g/person/day. Then, imports of wheat cost around US$230 million/year, which strained scarce foreign currency reserves. If Bangladesh were to increase production to meet internal demands, an extra 1.5 million t (rising toward 2 million t) was needed annually to make it self-sufficient.

The thrust of the FAO project built on the spread of hand-tractors (power tillers) throughout the country, with an estimated 60–70% of agricultural land being tilled by these machines in 2002. Using these tillers, fallow time between sequential crops could be reduced, theoretically allowing a full wheat cycle to be squeezed between rice crops in more cropping regions and, equally importantly, allowing it to be planted at the best time to produce high yield; so often wheat was planted late, because it took too long for the preceding rice crop to mature and dry and too long to cultivate the soil after rice. Introduction of zero-till systems—minimum-till, direct-planting systems (called power-tiller-operated seeders, PTOSs, Figure 6) and bed planters—were suggested.

The proposed project was aimed primarily at increasing yields in areas that already grew wheat, but included a southern coastal area (Noakhali) which might have some potential, despite salinity concerns (Figure 7, locations 10 and 11). There was apparently much underutilised land in these southern regions during the Rabi season; this land being available because it lacked the irrigation infrastructure needed to grow boro rice. Noakhali, as an example, had produced only 86 t of wheat from 47 ha in 2002. The question was whether there was potential for wheat expansion in Noakhali and other parts of this southern region. The new technology, which included developing, building

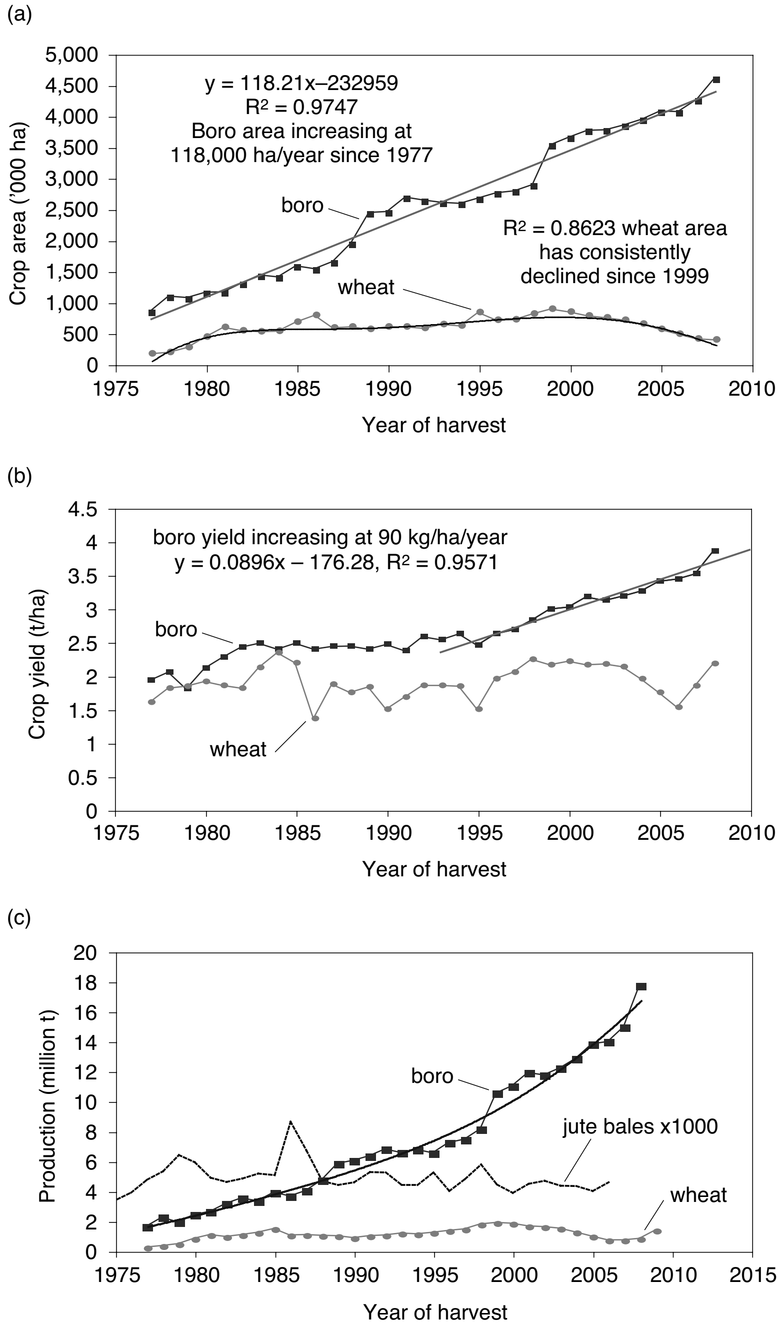


Figure 5. Wheat and boro rice in Bangladesh over time: (a) land area occupied; (b) yield per hectare; (c) total production

Figure 6. Tilling and line sowing in one pass using a power-tiller-operated seeder (PTOS) (Photo: E.M. Haque, CIMMYT Bangladesh)

and testing the cultivation and seeding machinery, was to be tried here as well as in the traditional wheat lands to the north. The integrated-management package of new machinery, new varieties, timing of seeding, and timing and amounts of irrigation and fertiliser applications linked to crop phenology, was expected to differ in the south with its later T. aman harvest and higher temperatures.

The FAO project was run from the Wheat Research Centre (WRC, Figure 7), sited near the northern town of Dinajpur. WRC is a division of the Bangladesh Agricultural Research Institute (BARI) and so had access to Regional Agricultural Research Stations (RARSs) throughout the country with resident wheat scientists. The project also employed local staff of the Department of Agricultural Extension (DAE) to manage trials at chosen on-farm sites. Consequently, technologies were tested widely, both as research projects on research stations and as extension projects in farmers' fields. Around 200 farmers tested recommended systems on their land over the 2 years of the study. Figure 7 shows the numbered locations of the cooperating farmer blocks, each of 15 farms, of which locations 1–9 were in areas proven over many years to be suitable for wheat. Shaded areas on Figure 7 were classed as unsuitable for wheat.

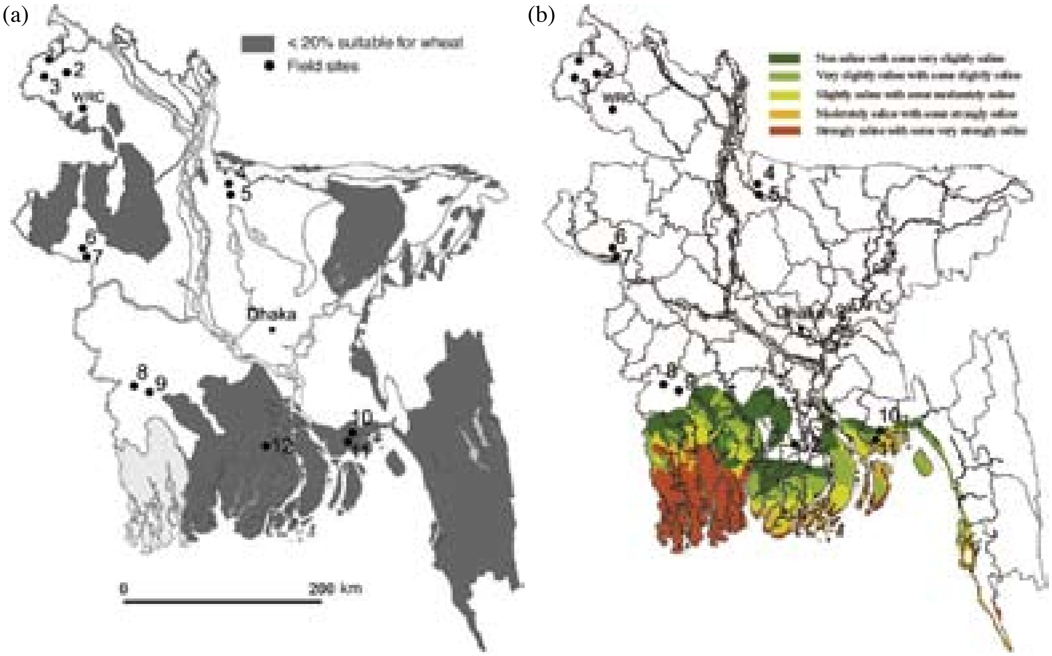
Just before the FAO-funded study, yields in the traditional rice–wheat-growing areas of Bangladesh had been estimated overall as 2.2 t/ha (Timsina and Connor 2001), with 2.9 t/ha as the average of research experiments, 3.5 t/ha from research experiments with high fertiliser inputs, 2.6 t/ha as yields from farmer surveys and 3.1 t/ha as controlled experiments on farmers' lands. These estimates set the benchmark for the FAO study at between 2.6 and 3.1 t/ha that must be exceeded to prove the new technology package was superior to current practice.

Some results from the FAO-funded study

Detailed results of the study are in Rawson et al. (2007).

The tillage systems compared in traditional and new southern wheat areas

To put the new tillage systems in context, the systems were always compared against a modern



Note: FAO = Food and Agriculture Organization of the United Nations; CIMMYT = International Maize and Wheat Improvement Center; WRC = Wheat Research Centre; location 12 (Kashipur in Barisal) is salt free whereas 10 and 11 (in Noakhali, including Hazirhat) are within a salt-affected area

Figure 7. Map of Bangladesh showing: (a) locations of farmer blocks in the FAO-funded studies—the shaded areas were classed as less than 20% suitable for wheat in CIMMYT (2006); (b) saline areas

version of the 'conventional' buffalo-powered country plough method that had been used for decades. The modern version used a power tiller instead of the buffalo but the farmer was required to broadcast the seed and fertiliser rather than placing them in rows. For many reasons, broadcasting is considered inferior to row planting (Anderson 2003) so it was expected that the so-called 'New Conventional' method would give poor yields. Table 1 summarises the results from the 200 farms.

The expectation from the FAO project, that PTOSs would result in better yields than other seeding and cultivation approaches, was confirmed, but the effects were not significant. Immediately after harvest of the T. aman rice and under optimal field moisture, this method completes a shallow light cultivation over rice stubble or weedy fallow and drills seeds in rows in a single pass. It is quick and, after emergence of the crop, weeds between the rows can be easily seen and removed, usually by hand or hand hoe. Zero tillage has a potential problem with weeds but in these studies that was negated by use of herbicides. New Conventional needs two to three passes with a power tiller to cultivate and cover the seed and fertilisers and, given that seeds are broadcast, is hard to weed, especially if the work is postponed until crop and weeds are intermingled. The real surprises from the study were that the New Conventional method ranked first or second, and that differences in yield between that and PTOS were relatively small. The rationale for the success of New Conventional was that Bangladesh farmers are familiar with, and very good at, broadcasting and, in theory, plants that are spread uniformly in space should initially grow faster than those that are mutually shaded in rows; that trend was in fact measured in some studies. Zero till was the most variable practice, being excellent in the light soils of Rajshahi but poor in Noakhali when it was used on soils that were too wet.

Table 1. Grain yields (g/m²) over two seasons from on-farm blocks, each of 15 farms, using different tillage and sowing methods, in traditional wheat-growing areas (locations 1–9 in Figure 7) and new areas (10–12 in Figure 7)

Method	Traditional wheat areas		New southern sites	
	2003–04	2004–05	2003–04	2004–05
New Conventional	369	380	204	301
PTOS[a]	374	389	217	287
Strip tillage	368	382	201	Not used
Zero tillage	339	366	154	262
Bed formed	351	360	170	233
Average	360	375	189	271
Average	368		230	

[a] PTOS = power-tiller-operated seeder

Note: numbers of farms used for each method are different between columns; 369 g/m² is the same as 3.69 t/ha and 3,690 kg/ha

The FAO-funded project yields in context

Yields of 3.68 t/ha achieved by farmers in the traditional wheat zones 1–9 matched those estimated by Timsina and Connor (2001) for research station yields using high fertiliser inputs, thus indicating the FAO-funded methodology had closed the yield gap between on-farm and on-research-station agriculture.

Yields in the non-traditional southern sites of Noakhali in 2003–04 and Noakhali and Barisal in 2004–05 were much better than expected, considering that the Noakhali sites were saline (Figure 8) and that the 60 farmers involved had no experience of growing wheat before the project. Indeed, the better than 2.5 t/ha average of 2004–05 compared favourably with previous estimated wheat yields from the traditional zones. Clearly, based on this restricted trial, the southern zone had potential to produce acceptable crops of wheat (see Figure 9 for an example).

What must be stressed is that the project aimed to optimise management of these crops; something that farmers rarely achieve because of time or money constraints. First, all crops were planted within the time window for wheat recognised as optimal in traditional zones. This window was assessed to be late November with a decline in yield at 1.5% per day's delay after late-November sowing (44 kg/ha for each day's delay after 30 November; Ahmed and Meisner (1996), quoted by Timsina et al. (2001)). This variable was removed because it was argued that all tillage technologies used allowed farmers to cultivate and plant early, although PTOS, strip till and zero till might save 2 days over New Conventional and 3 days over the bed planter. Second, irrigations and fertilisers were applied in the optimal amounts and at optimal crop-development stages in accord with the training that all farmers received under the project. And third, it had been decided to use a new variety of wheat called Shatabdi, not yet generally released to farmers, which replaced the 30-year-old Kanchan (derived from the Indian variety C306), which had become susceptible to leaf diseases. So, these farmers were growing their crops in a coordinated, balanced management package much as would be used on a research station. Nevertheless, the project yields set the achievable farmer standard for the future.

What did cooperating farmers think about the cultivation and sowing technologies?

Because the project was designed so that all the cultivation and sowing plots were located within a neighbourhood or village—within sight of each other—farmers could see the results and to some extent compete, particularly with their equivalent-treatment neighbours. The general pattern was that farmers liked the method they were using, be it PTOS, zero till, strip till or beds. They had no costs to bear, apart from fuel for the machines. Farmers were critical of the New Conventional method because it was not new technology and they had to do the steps of broadcasting fertiliser and seed manually. Also, weeding was difficult. On balance, PTOS was most popular. The farmers enjoyed the ease and speed of using the machine. However, if they had to buy a PTOS to do the job, it would cost them the profits from growing wheat over several years, whereas the New Conventional method would cost nothing, assuming they already had access to a power tiller. The New Conventional method was clearly the practical option for new wheat farmers and once they had

Figure 8. Salt on the soil surface in Noakhali (Photo: HMR)

Figure 9. Farmer block from the Food and Agriculture Organization of the United Nations (FAO)-funded trial in Noakhali 2004–05. Best and poorest farm yields were 4.29 and 2.64 t/ha, and the 15-farm average 3.35 t/ha. This was a saline site with salt crystals on the soil surface at harvest. (Photo: HMR)

proved to themselves over a few years that wheat was a viable crop, they could then work towards buying a PTOS. Farmers in the traditional wheat-growing areas might move towards a PTOS more quickly (Figure 10 shows a group of farmers discussing their preferences and problems in the FAO project).

In Noakhali and Barisal, the rice farmers, now also wheat growers, raised bigger problems.

- Where would they get the new varieties of wheat not available locally?
- Who would support them in using the technology?
- Threshing was difficult, done manually, so what were the solutions?
- Who would provide and service the wheat machinery they might buy?
- Fertiliser costs were high and they couldn't afford to apply the recommended amounts, particularly at sowing when there was no cash flow from sale of the preceding rice crop.
- In the absence of irrigation from tube wells, how could they apply the late irrigation needed to fill the grain when all surface water left over from the wet season had dried up?
- What price would they get for their wheat at market?
- Growing wheat would be risky. If they worked as labourers and left their land fallow they would make more money than realised from the wheat and there would be no risk.

It was all about managing risk. Some basic cost–benefit analyses were done for growing wheat in the south using recommended management and with the wheat price at taka (Tk)12/kg; farmers would need to produce more than 500 kg/ha to begin making money. This break-even point is very dependent on the price of wheat in Bangladesh which can fluctuate significantly. Farmers would be more prepared to grow the crop if the price was higher than Tk12/kg, as this would reduce the risk.

What were the reservations to southern wheat cropping voiced by project researchers?

These fell into seven categories:

1. Late harvesting of T. aman rice would delay planting of wheat well beyond the date required for high yields. The expectation was that the optimal planting date for wheat would be around the end of November but no studies had been done in the south to prove this. It was also pointed out that some farmers left their cut T. aman crop lying on the stubble to dry in the sun for 1–2 weeks, causing further delays.
2. After the monsoon, the land in some regions would not dry down sufficiently for wheat planting until January—far too late for profitable yields.
3. There was very minimal irrigation infrastructure in the south, either as shallow or deep tube wells, so yields would be poor because the necessary three irrigations for good yield, as needed in the traditional wheat-growing zones, would not be available.
4. Cyclones could destroy young crops as optimal planting should be during the cyclone season of November; cyclones are relatively frequent in the southern coastal regions.

Figure 10. Cooperating farmers and neighbours expressing their views in their village in 2004 (Photo: HMR)

5. Temperatures in the south were too high for growing the temperate-crop wheat. Even in the north with its less extreme conditions, yields could be constrained by high temperatures.
6. Dense fogs and heavy dews can blanket the region for days. Leaf diseases could result and the low radiation levels would constrain photosynthesis and thereby biomass production and yield.
7. The last warning was about salt. The coastal regions by virtue of their recent marine history have localities where salt during the Rabi season prevents cropping of salt-susceptible species. In the wet season when growing rice, salt is generally not a problem as the soil is flushed with rain water and some areas are flooded with this fresh water to a depth of 0.4 m.

All these comments were salient and helpful warnings, and demanded answers.

In the FAO-funded work, data loggers recording temperature had been placed at sites in Dinajpur (north, close to WRC on Figure 7) and Noakhali (south locations 10–11, Figure 7). The data showed Noakhali was some 3 °C hotter than Dinajpur throughout the 2004–05 wheat season. Mean full-season temperatures were respectively 23 °C and 20 °C and mean maximums were around 30 °C and 27 °C (Figure 11). These Noakhali values are very high temperatures for wheat but with latitude of 22° for the far south compared with 26° for the north, their potential yields should still be respectively 4 t/ha in the south and more than 5 t/ha in the north, assuming equivalent soil conditions and based on a simple photothermal quotient analysis (Rawson 1988; and see the latitude axis on Figure 12).

The optimal temperature for wheat actually changes as the crop develops, and differs a little between varieties (Rawson 1985; Slafer and Rawson 1995), as well as being altered by other components of the environment like prevailing sunshine hours (Rawson 1993). But such details do not deny the broad premise that yields fall at high temperature because the crop grows for fewer days which means fewer days for radiation to be intercepted, and fewer days for grains to fill (e.g. Rawson 1988).

The perceived constraint of dense fogs reducing yield is logical too. Additional to the effects on photosynthesis, large reductions in radiation, especially if associated with high humidity, can reduce or stop the transpiration stream through the plant. Severely reduced transpiration rates, whether due to high humidity or stomatal closure, can reduce boron uptake from the soil to levels that are insufficient to make developing pollen grains fertile (Rawson 1996). Indeed, anything that stops the transpiration stream, including water stress and waterlogging, during the 10 or so days of pollen meiosis, which is just before ear emergence, can lead to boron-deficient sterility and devastate yield (Rawson and Noppakoonwong 1996). This warning is particularly pertinent in Bangladesh, which has boron-deficient soils. The Australian Centre for International Agricultural Research (ACIAR) Proceedings No. 72 (Rawson and Subedi 1996) covers this topic in detail.

Salinity can reduce biomass production linearly at 0.24% for each mol/m^3 sodium chloride (NaCl) as concentration increases between 0 and 250 mol/m^3 (250 mol/m^3 is around 22 dS/m). At 22 dS/m, biomass at heading stage was reduced to less than one-quarter compared with no salt, as reported in Rawson et al. (1988). Soil electrical conductivity (EC) measurements at the Char Jublee (2004–05) site (Figure 9) in Noakhali averaged 1.8 dS/m for the bulk soil to 1.5 m depth. Soil EC values at wheat crop maturity ranged up to 12 dS/m at different Hazirhat (Noakhali) farms, sufficient to reduce wheat yields to uneconomic levels.

Conclusions about wheat in the south from the FAO-funded study

Achievable yields

For the traditional rice–wheat-producing areas of Bangladesh, it was concluded that by using the proposed technology, which allowed farmers to plant on time, and by using the new varieties and proposed fertiliser and irrigation regimes to suit the varieties, yields would be raised to 3.5 t/ha, potentially providing an extra 800,000 t to the national wheat harvest.

For the new zones of the south, where fallow land during Rabi was estimated at more than 400,000 ha in 2005 (Figure 13), the potential contribution to Bangladesh wheat production could be 1 million t. This was the potential, but, realistically, adoption by farmers could be quite slow due to wheat being a little-used crop in the zone and fallow being a risk-free use of the land.

Together, if realised, these contributions from the traditional zones and the coastal south would significantly reduce the deficit in wheat production in Bangladesh. However, to realise these agricultural changes would require widespread training of farmers and significant government activity to support and promote extension.

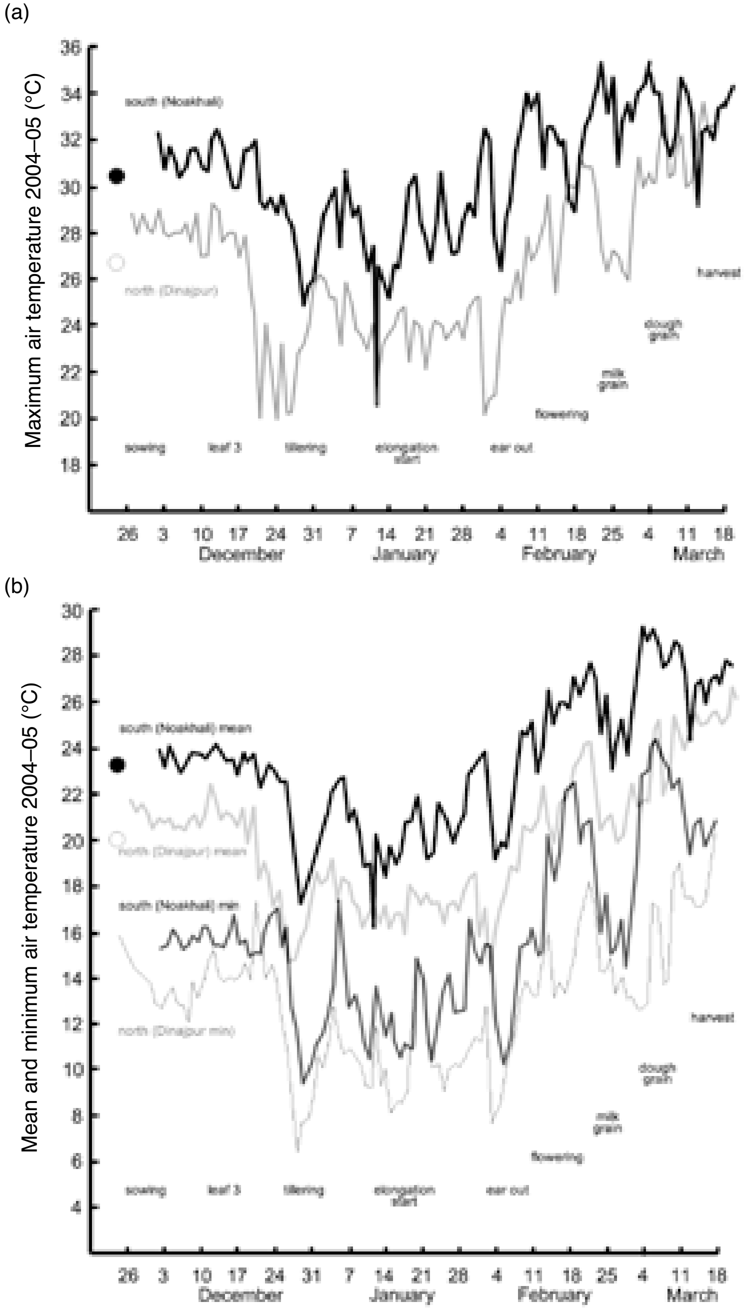


Figure 11. Maximum (a) and mean and minimum (b) air temperatures for Dinajpur (north) and Noakhali (south) during the Rabi (dry) season, 2004–05—round symbols denote averages; crop stages are as occur in Jessore

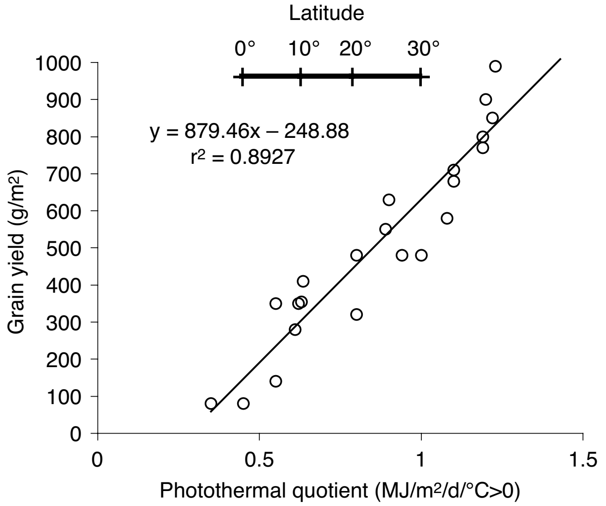


Figure 12. Grain yield of wheat as related to photothermal quotient (accumulated radiation divided by accumulated thermal time in the 3 weeks before anthesis) and latitude at sea level (Source: Rawson 1988)

The ACIAR scoping study: could the earlier findings be substantiated?

In essence, the ACIAR scoping study conducted wheat trials aimed at checking the yield claims from the FAO-funded work by using a control site at Joydebpur, the head office of BARI near Dhaka, and 12 farms at each of five locations—one in Jessore (Monirampur, a traditional wheat-farming area, location 9 in Figure 7), two in Noakhali (Hazirhat and Char Jublee, near locations 10, 11) and two in Barisal (Khanjapur and Kashipur, near location 12) and the 60 farmers followed essentially the same crop management as in the FAO studies. A variant was that the number of irrigations ranged from zero to three to see whether wheat could be grown on limited water in the region as scarcity of water had been raised in the previous studies as a reason that wheat may fail. Importantly, measurements were made of soil and water use, which had previously been ignored. These were in part to allow the system to be modelled by the Agricultural Production Systems Simulator (APSIM) (Keating et al. 2003) using Bangladesh long-term meteorological data to see whether the previous studies reflected likely yields over years.

This is how the aims of the scoping study appeared in the ACIAR proposal:

1. to collect field crop–soil–climate datasets attuned to modelling from on-farm trials on wheat production in southern Bangladesh during the 2005–06 dry season
2. to collate the long-term minimum dataset required to quantitatively describe the climate, biophysical environment, irrigation resources, management systems and production performance for current and proposed rice/wheat systems of southern Bangladesh
3. to set up APSIM to simulate the current and proposed rice/wheat production systems of southern Bangladesh and test performance against available datasets
4. to evaluate the technical and economic feasibility and the risk profile of rice/wheat production systems in southern Bangladesh benchmarked against current production systems
5. to provide recommendations on the research priorities and investment required to progress development of rice/wheat systems of southern Bangladesh.

Findings generally supported those from 2003–05. One real surprise and very positive finding was that a single irrigation was all that was needed to optimise yield; additional irrigation could be water wasted and at one site a third irrigation normally required in the traditional wheat-growing regions actually appeared to reduce yield.

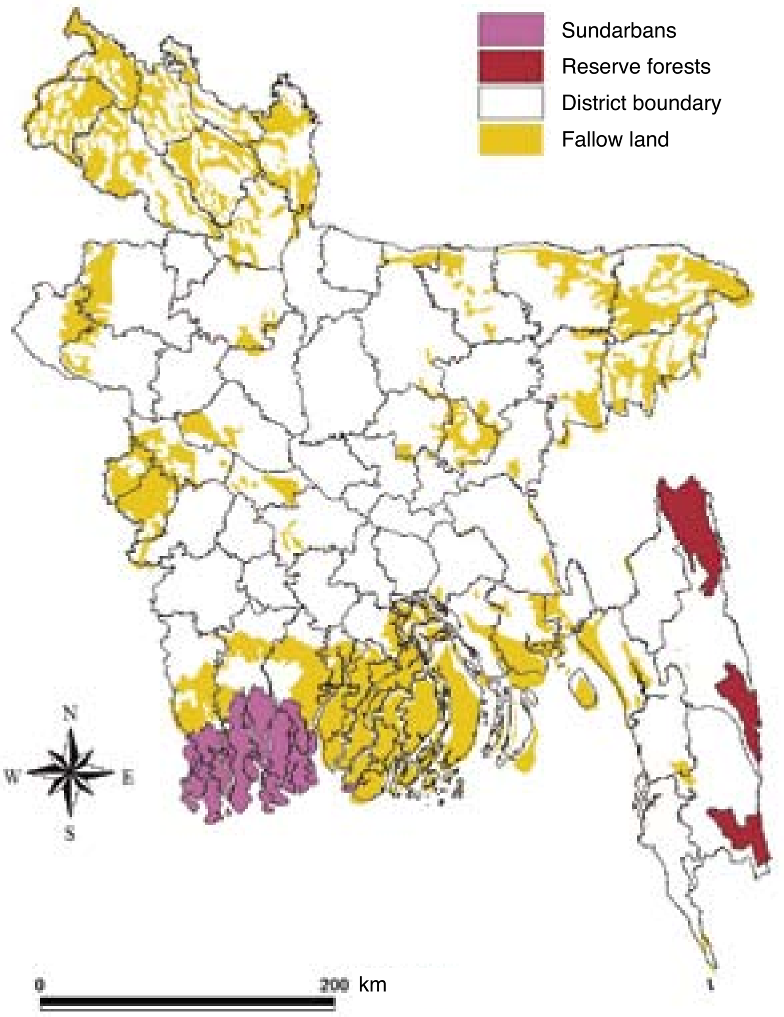


Figure 13. Estimated Rabi fallow land distribution in Bangladesh (Source: CIMMYT 2006)

Another surprise was the effect of that one irrigation on yield. In the traditional wheat-growing regions represented by Monirampur and Joydebpur, that irrigation almost doubled yield but in Kashipur, Khanjapur (Figure 14) and the two Noakhali locations, the yield improvement over the unirrigated control was only 20%.

This led to speculation that high watertables in the south might be providing much of the water needed by the crops. But what was not known was the possible extent of high watertables. Were they only at the chosen sites and only in that year?

The results were promising enough for ACIAR to agree to support a 4-year study in the south but, importantly, this study must determine why farmers were not already growing wheat, so must include a socioeconomic component.

The ACIAR 4-year project: finding, characterising and overcoming the problems

Below is how the main aims were summarised in the ACIAR project proposal.

The aim of this project is to improve the livelihoods of farmers in southern Bangladesh by introducing crops, such as wheat, onto currently fallow lands during the post-rice Rabi season. Specific objectives are to:

1. delineate and characterise the areas where Rabi-season cropping is feasible on currently fallow lands with or without supplementary irrigation
2. finetune agronomic practices specific to each potential region and socioeconomic grouping, especially in the efficient utilisation of limited water resources and fertilisers
3. encourage farmer uptake of emergent cropping practices through training and support of the regional change agents who have ongoing commitment to supporting smallholder farmers.

Figure 14. Height of the watertable in relation to a wheat crop at Khanjapur, Barisal (ACIAR scoping study)—the non-irrigated crop at this site yielded 3.3 t/ha while those with three irrigations yielded 3.6 t/ha. It was surmised that non-irrigated crops were using water from the watertable. (Photo: HMR)

To expand wheat production through the southern fallow lands, the current proposed study will build on the established collaboration with WRC/BARI, CIMMYT, DAE and OFRD (On Farm Research Division of BARI) and add a new non-government organisation (NGO) partner, PROSHIKA. This team will work together to progress through the four steps of:

1. constraint characterisation
2. development and demonstration of farm-management packages to handle local constraints
3. training extension personnel in the use of packages, who then
4. train farmers in an outreach program. The pattern will proceed concomitantly in several regions starting with Noakhali, Barisal and Bhola, with a control site in the traditional wheat-growing area of Jessore.

Where in the current report the project aims are answered

The ups and downs of the 4-year ACIAR-funded project and the extent to which the aims were realised are the story of this technical report.

The following chapters (1.2, 1.3) recount the views of farmers as to why they are reluctant or unable to consider wheat as a crop they can grow. They are based on personal and group interviews conducted over two seasons in villages in Noakhali and Bhola. They present some gender issues.

Section 2 reassesses the suitability of the climate of the south for growing wheat and particularly, considering the release of new more heat-tolerant varieties, it reassesses the water and soil resource and the likely availability of land suitable for wheat production. It concludes that over 800,000 ha are potentially available that have sufficient water in shallow watertables accessible to crop roots to produce wheat yields averaging around 2.5 t/ha.

Section 3 presents the agronomic methods developed during the project to ensure that economic wheat crops can be grown in the coastal south without disrupting farmers' traditional crop rotations and demonstrates, on-farm, that good crops can be grown throughout the whole southern region.

Section 4 looks to the economics of different crop choices and, by using computer modelling, explores the most appropriate choices of individual crops and cropping sequences. Specifically, it assesses the future of mungbean in the region.

Section 5 describes the current livelihoods of farmers in different socioeconomic situations and presents their views on what support they will need to help them take a step towards intensifying their cropping patterns and potentially increasing livelihoods in the whole southern region.

Section 6 assesses what has been learnt overall from the project.

References

Ahmed S.M. and Meisner C.A. 1996. Wheat research and development in Bangladesh. Australian Agency for International Development (AusAID)/International Maize and Wheat Improvement Center (CIMMYT)-Bangladesh: Dhaka, Bangladesh.

Anderson W.K. 2003. Optimizing plant population, crop emergence and establishment. Pp. 39–48 in 'Explore on farm: on-farm trials for adapting and adopting good agricultural practices', ed. by H.M. Rawson. Food and Agriculture Organization: Rome.

Asad uz Zaman M. 2004. Databank: groundwater and surface water resources, Bangladesh. Barind Multipurpose Development Authority, Ministry of Agriculture: Dhaka.

Bharadwaj P. and Fenske J.E. 2009. Partition, migration, and jute cultivation in India. Social Science Research Network. At <http://ssrn.com/abstract=1358620>, accessed 6 April 2011.

CIMMYT (International Maize and Wheat Improvement Center) 2006. Bangladesh country almanac version 3.0 (CD). CIMMYT: Dhaka.

Hobbs P.R. and Gupta R.K. 2004. Problems and challenges of no-till farming for the rice–wheat systems of the Indo-Gangetic Plains in South Asia. Pp. 101–119 in 'Sustainable agriculture and the rice-wheat system', ed. by R. Lal, P. Hobbs, N. Uphoff and D.O. Hansen. Ohio State University and Marcel Dekker Inc: Columbus and New York.

Hossain M.F., White S.K., Elahi S.F., Sultana N., Choudhury M.H.K., Alam Q.K., Rother J.A. and Gaunt J.L. 2005. The efficiency of nitrogen fertiliser for rice in Bangladeshi farmers' fields. Field Crops Research 93, 94–107.

Keating B.A., Carberry P.S., Hammer G.L., Probert M.E., Robertson M.J., Holzworth D., Huth N.I., Hargreaves J.N.G., Meinke H., Hochman Z., McLean G., Verburg K., Snow V.O., Dimes J.P., Silburn M., Wang E., Brown S., Bristow K.L., Asseng S., Chapman S.C., McCown R.L., Freebairn D.M. and Smith C.J. 2003. An overview of APSIM, a model designed for farming systems simulation. European Journal of Agronomy 18, 267–288.

Meharg A.A. and Rahman M. 2003. Arsenic contamination of Bangladesh paddy field soils: implications for rice contribution to arsenic consumption. Environmental Science and Technology 37, 229–234.

Rawson H.M. 1985. High-temperature-tolerant wheat: a description of variation and a search for some limitations to productivity. Field Crops Research 14, 197–212.

Rawson H.M. 1988. Constraints associated with rice–wheat rotations: effects of high temperatures on the development and yield of wheat and practices to reduce deleterious effects. Pp. 44–62 in 'Wheat production constraints in tropical environments: proceedings of an international conference, Chiang Mai, Thailand, 19–23 January 1987', ed. by A.R. Klatt. International Maize and Wheat Improvement Center (CIMMYT): Mexico DF.

Rawson H.M. 1993. Radiation effects on rate of development of wheat under different photoperiods and high and low temperatures. Australian Journal of Plant Physiology 20, 719–727.

Rawson H.M. 1996. The developmental stage during which boron limitation causes sterility in wheat genotypes and its recovery of fertility. Australian Journal of Plant Physiology 23, 709–717.

Rawson H.M., Gomez-Macpherson H., Hossain A.B.S., Rashid H., Saifuzzaman M., Sufian M.A., Samad M.A., Sarker A.Z., Ahmed F., Talukder Z.I., Rahman M., Siddique M.M.A.B., Hossain I. and Amin M. 2007. On-farm wheat trials in Bangladesh: a study to reduce perceived constraints to yield in traditional wheat areas and southern lands that remain fallow during the dry season. Experimental Agriculture 43, 21–40.

Rawson H.M. and Noppakoonwong R.N. 1996. Effects of boron limitation in combination with changes in temperature, light and humidity on floret fertility in wheat. In 'Sterility in wheat in subtropical Asia: extent, causes and solutions', ed. by H.M. Rawson and K.D. Subedi. ACIAR Proceedings No. 72, 85–89. Australian Centre for International Agricultural Research: Canberra.

Rawson H.M., Richards R.A. and Munns R. 1988. An examination of selection criteria for salt tolerance in wheat, barley and triticale genotypes. Australian Journal of Agricultural Research 39, 759–772.

Rawson H.M. and Subedi K.D. (eds) 1996. Sterility in wheat in subtropical Asia: extent, causes and solution. Proceedings of a workshop, 18–20 September 1995, Lumle Agricultural Research Centre, Pokhara, Nepal. ACIAR Proceedings No. 72. Australian Centre for International Agricultural Research: Canberra.

Sattar S.A. 2000. Bridging the rice yield gap in Bangladesh. In 'Bridging the rice yield gap in the Asia–Pacific region', ed. by M.K. Papademetriou, F.J. Dent and E.M. Herath. Food and Agriculture Organization, Regional Office for Asia and the Pacific (RAP) Publication 2000/16. Available at <www.fao.org/docrep/003/x6905e/x6905e07.htm>.

Slafer G.A. and Rawson H.M. 1995. Base and optimum temperatures vary with genotype and stage of development in wheat. Plant, Cell and Environment 18, 661–679.

Timsina J. and Connor, D.J. 2001. Productivity and management of rice–wheat cropping systems: issues and challenges. Field Crops Research 69, 93–132.

Timsina J., Singh U., Badaruddin M., Meisner C. and Amin M.R. 2001. Cultivar, nitrogen, and water effects on productivity, and nitrogen-use efficiency and balance for rice–wheat sequences of Bangladesh. Field Crops Research 72, 143–161.

van der Steen B. 2005. The jute industry: a statistical overview. At <http://www.iisg.nl/research/jute-industry.pdf>, accessed 6 April 2011.

1.2 Farmers' perceptions

Iqbal Alam Khan, Sharmin Afroz and Himu Bain

Abstract

Although agricultural researchers and policymakers may argue that a particular change in crops, cropping patterns and agronomy is achievable and in the best interests of a region or the country, without the wholehearted support of the farming community such change cannot occur. Farmers make decisions about how they will use their land on the basis of their resources, their indigenous knowledge, their experience and local and family pressures, and on their assessment of risk, which should be minimal. This chapter discusses the cropping preferences of farmers and some of their viewed constraints in relation to adopting wheat into their cropping patterns. It compares views of farmers living in villages where there has been a wheat trial hosted by the Australian Centre for International Agricultural Research (ACIAR) with opinions of farmers in villages that have little or no exposure to the wheat crop. Such paired villages were compared in Noakhali and Bhola districts. Additional comments were sought from farmers not included in the pairing survey.

If sufficient high-quality irrigation water was readily available, boro rice was the number one preferred crop choice for the Rabi season, as it offered food security, reasonable profits and required minimal expenditure to start the crop. Overall fertiliser costs were high but they were spread over the season. Farmers were comfortable and familiar with boro. By contrast, although wheat was more profitable than boro, up-front costs were considered high, and farmers had minimal confidence in their ability to realise the good yields demonstrated in trials. They commonly said they didn't know how to grow wheat, particularly those farmers in non-trial villages. The latter farmers had a wide range of crop preferences that reflected availability of seed, often stored on-farm, and ease of sale of produce in local markets.

The overriding message from farmers was that, if they are to grow wheat, seed must be available at the local market in sufficient quantities at sowing time, technical support for growing the crop correctly must be available locally and on-call, and there must be assured sales of their produce in local markets. Finally, the wheat-cropping time window must fit into their current time-honoured cropping patterns without disruption.

Introduction

The previous chapter in this volume (Chapter 1.1) pointed out that wheat consumption in Bangladesh is steadily increasing and production is declining, so that the deficit needed to be filled by imports currently is around 2 million tonnes. Chapter 2.3 (this volume) indicates that around 800,000 ha of land in the southern coastal zone that could be used for wheat production is either left fallow or underutilised during the Rabi season. Section 3 (this volume) describes the tools and methodologies needed to produce wheat on these fallow lands. It shows that farmers cooperating in trials throughout the region have achieved average yields exceeding 2.5 t/ha following these methods. Conceptually, therefore, the scene is set for the southern farmers to make a major contribution to providing wheat for the country by adding it into their normal cropping rotation. The question to be addressed in this chapter is whether farmers can or want to grow wheat on their land. The data presented here are primarily from interviews with farmers in two paired villages, one with an Australian Centre for International Agricultural Research (ACIAR)-funded wheat trial nearby and one at least 4 km distant and not affected by the trials. Such paired trial and non-trial villages were targeted in the Noakhali and Bhola districts. Additional farmers from other trial villages in the regions, not included in the core sociology studies, were also asked for brief comments.

To understand what lies behind the opinions of the farmers requires a mental picture of the history of the land they farm and their personal constraints. Due to gradual silt deposition around the Padma and Meghna river systems, the coastal districts of southern Bangladesh are progressively changing and expanding towards the Bay of Bengal. During successive wet seasons and associated leaching by fresh water, any salinity of these soils and underlying aquifers gradually declines. With salinity reducing, options for crop choices to follow the ubiquitous wet-season rice, transplanted (T.) aman, increase, although the choices remain constrained by land topography, land height relative to surrounding landforms, which determines drainage, and the relative wetness of the soil at any time during Rabi.

Because of varying land topography, underutilised or fallow lands may not exist in large homogeneous tracts in all regions, but often in scattered parcels of land that can be less than 0.5 ha. Fragmented micro-relief creates areas often differing in elevation by less than 0.5 m, sometimes with locally differing soil characteristics; slow drainage and salinity are factors in some lower lying areas (see Chapter 2.2, this volume, for details of land types in the south). Generally, these areas can either be left fallow during the Rabi season, or apparently remain fallow but in fact are used for grazing or for low-yielding forage crops such as grasspea.

During Rabi, farmers would like to grow boro rice in lowlands and vegetables on their uplands but both can be constrained by inadequate availability of water for irrigation. Surface water is temporal and often minimal, and geological conditions or salinity intrusion can restrict the installation of deep and shallow tube wells to tap off the large bodies of groundwater. In Noakhali, for instance, only 14% of land is irrigated and only 14% of that water comes from tube wells (Chapter 2.2, this volume). Virtually all the limited tube well irrigation water in Noakhali is allocated to boro rice. Under such circumstances, low-water-requiring crops such as wheat and pulses might be realisable and profitable options for farmers on the underutilised lands.

Rabi-season cropping intensification, if it is profitable, not only enhances the productivity of local land and labour, but it also creates livelihood options at a greater community scale through adding off-farm employment opportunities and reducing underemployment of labour.

The agricultural research and development system in Bangladesh generally does not involve farmers and end users as active participants in policy formulation and in developing technologies. At least in the final stages of introducing new crop varieties and technologies into a region, farmers' needs, their preferences and their resources, which influence their willingness to change, should be considered. Farmers each have their own indigenous knowledge special to their own circumstances. They formulate livelihood strategies based on that knowledge and that learnt from their ancestors. They adapt only after assessing the risk they take in doing so, and after concluding that the risk is very small and less than their current proven choices. This chapter presents a snapshot of views of 56 Noakhali farmers and 58 Bhola farmers reporting why or why not they would grow wheat on their farms.

Farmers' crop preferences

The farmers of Noakhali and Bhola districts told the interviewers in the project their Rabi-season crop preferences and the reasons behind their preferences.

Figure 1 illustrates farmers' Rabi-season crop preferences in Noakhali. In the trial village, which has irrigation facilities, boro rice is the predominant first preference of 90% of farmers. Farmers also cultivate wheat and vegetables but most of them argued that these are very much their second preference. By contrast, in a non-trial village, which had no access to irrigation, crop preferences had no dominant trend. Crops were chosen that required less water and these included sweetpotato, chilli, pulses, vegetables and peanut. Boro rice was preferred by only 15% of farmers because of their difficulty in accessing sufficient water. Farmers were most comfortable with diversified crops.

Figure 2 illustrates Rabi-season crop preferences in Bhola. Chilli was the preferred Rabi crop of 36% of farmers in the trial village, primarily because it costs little to produce and has low initial investment. Despite that, the yield is high and profitable. Potato ranked well for the same reasons. Wheat was preferred by 21% of farmers as villagers here consume wheat breads, thus they cultivate wheat in order to ensure food security. Boro rice was not popular (4%) because of inappropriate soil and limited water; it was not grown by any farmers in the non-trial village.

In the non-trial village, around 64% respondents preferred chilli, very much the dominant crop choice, with wheat being preferred by 25% of farmers. Pulses and vegetables were popular second-choice crops.

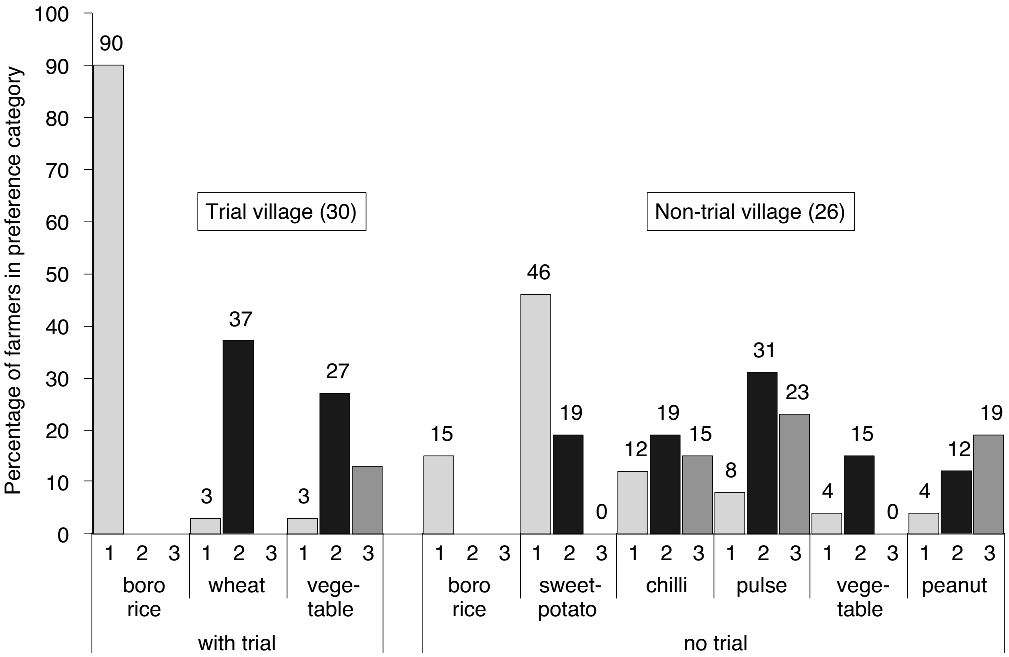


Figure 1. Farmer first (1), second (2) and third (3) preferences for Rabi-season crops in villages with or without an Australian Centre for International Agricultural Research (ACIAR)-funded wheat trial in Noakhali district (number of farmers interviewed shown in brackets)

In their interviews, farmers explained what led them to make their cropping choices for the Rabi season. These factors are now discussed:

Food security/household consumption

Food security for household consumption is one main reason for cultivating a crop. In a trial village in Noakhali, most farmers chose boro rice because they considered that this crop ensures their first need of food security. Other crops like vegetables, chilli, pulses and potato are also used first for daily household consumption and any production above those requirements is sold at the village market.

Profit

After ensuring food security, farmers are interested in making the best profits from selling their crops at the market. Wheat and vegetables were both considered profitable. Some of their crops, like chilli and pulses, did not ensure food security but gave them good profits at local markets with low investment.

Market demand

Farmers were also concerned about current local market demand for crops. They wanted to grow crops that are always in demand. They felt that high-demand crops are not likely to drop their market price; therefore they, as farmers, are not likely to make losses from growing those crops. Their risk is small.

Traditional crops

Farmers mentioned that they always preferred to grow those crops that are cultivated traditionally in their locality, since they understand the whole scenario of crop production and marketing. In addition, they do not need any technical guidance from others to cultivate these types of crops. Apart from this, as these crops were cultivated traditionally, they preserved the seeds for sowing in the following season so there was no direct cost for seed. For cultivating wheat they had to buy seeds, and if they came from the local market there was no assurance of quality. By contrast, they knew the quality of their own farm-grown seed.

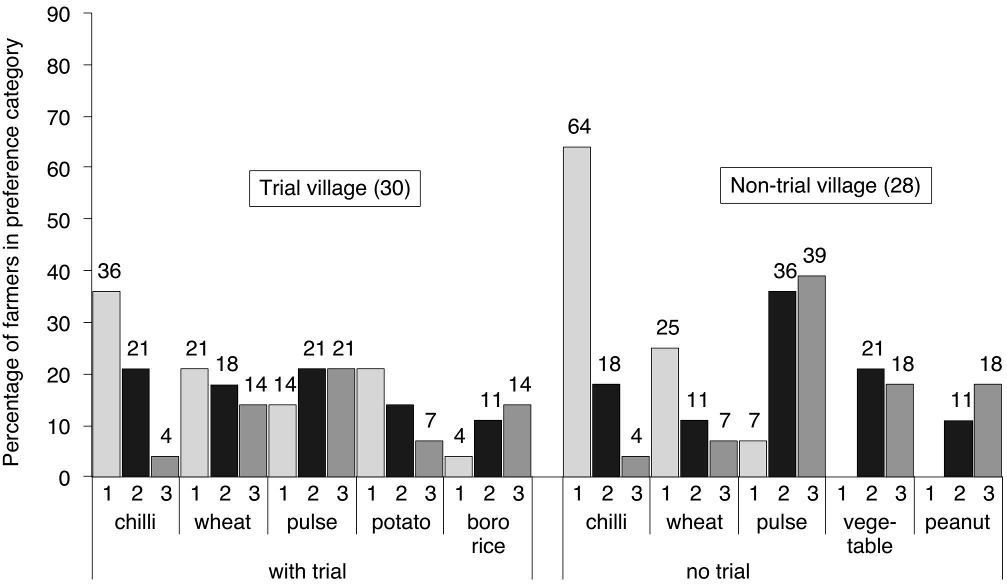


Figure 2. Farmer first (1), second (2) and third (3) preferences for Rabi-season crops in villages with or without an Australian Centre for International Agricultural Research (ACIAR)-funded wheat trial in Bhola district (number of farmers interviewed shown in brackets)

Growing wheat: the farmers' point of view

The survey data revealed that the cultivation of wheat is very limited in both districts. In Bhola, 5–15% of the land and 30–40% of households are engaged in wheat cultivation in the Rabi season, while in Noakhali, it involves only 2–3% of the land and 5–10% of households. Farmers discussed the opportunities and limitations of cultivating wheat compared with other Rabi-season crops. They pointed out that, since wheat is more profitable than traditional crops, if there were a range of support to help with the adoption of wheat, it could enhance their income. These additional supports include training to improve farmers' knowledge about growing wheat, improved physical infrastructure to make irrigation feasible, and some financial support, perhaps as loans with easy terms.

Current knowledge of wheat cultivation

In the survey data, Noakhali farmers scored 'very low' in their experiences of cultivating wheat whereas the farmers of Bhola district scored 'low'. However, farmers of both districts scored 'high' on their cultivation of other crops in the Rabi season.

In both districts, wheat was considered to be not very common and so they personally did not know how to cultivate it properly. Non-trial farmers of Noakhali did not know the type of land that is suitable for wheat, the proper time to plant it, how to prepare the land for sowing, or how to manage the crop to realise high yield. On the other hand, non-trial farmers of Bhola had some knowledge about wheat since wheat had been grown in their region by their forebears. Some who had tried wheat recently, but harvested poor yields due to lack of knowledge, were very interested in being included in any future wheat trials to learn correct management.

Inadequate training

The farmers of both districts stated that only trial farmers received training about growing wheat and they were very slow to pass on their knowledge to others. For instance, in Sallah village in Noakhali, only two farmers out of about 1,300 households got an ACIAR-funded trial plot and training. The trial farmers of both districts also said that although they got trial plots and training, they did not personally do all the practical work required in their trial plot; this was done in demonstration by the trainers. As a result, the trained farmers forgot the training within a short period.

A trial farmer in Noakhali said:

> Most of us do not have the practical knowledge about wheat cultivation but we have the long experience of cultivating boro rice and other Rabi-season crops. We do not know the doses of fertiliser and pesticide or the amount of irrigation. So we farmers are less willing to cultivate a new crop like wheat which is not common in the village. The trial farmers like me who get the training and got a trial plot also do not know the proper cultivation method because they do not get opportunity to work in trial plot, because DAE [Department of Agricultural Extension] people do all the works in trial plot. After a year, trial farmers have forgotten many things about cultivation of wheat like me.

Irrigation practice for wheat

Some farmers in the trial villages had learnt that timely irrigation is an important factor leading to high-yielding wheat crops. Uninvolved farmers knew how much and when to irrigate rice and their traditional crops but no non-trial farmers in Noakhali had any idea how to irrigate wheat. Non-trial farmers of Bhola never realised that irrigation was an essential element for a good yield of wheat. They have grown wheat only with natural rainfall in the past. Due to lack of knowledge they do not irrigate their lands even although they had scope to do so. However, the farmers who irrigate do not know how much and how many times it should be applied. (*Editor's note: see Section 3 in this volume, which describes irrigation practices for growing wheat. A single irrigation at 20 days after sowing (DAS) is required for high yield. By contrast, boro rice needs many flood irrigations applied throughout the season.*)

> Md Siraj, age 45, is an inhabitant of North Joynagar village in Dulatkhan upazila (subdistrict), Bhola. He is a non-trial farmer. He said that he never knew irrigation is an essential element of wheat growth. He mainly relies on rainfall for irrigation. But after observing the local trial plots in the current season he realised that irrigation is a major element for a good yield of wheat. He is now interested in irrigating his wheat field in the coming season.

Fertiliser practice for wheat

Farmers recognise that without fertiliser a good yield of any crop cannot be achieved due to the reduction in soil fertility. Although farmers do not know the scientific doses of fertiliser required for boro rice and other traditional crops, it is their past experience that enables them to apply appropriate fertilisers at appropriate times to achieve what they claim is a better yield.

All trial and non-trial farmers of both Noakhali and Bhola districts showed that they do not know the recommended fertilisers and their application rates for wheat. Some non-trial farmers in Bhola indicated they are unable to apply fertilisers anyway because they cannot afford them. (Section 3 in this volume explains that most fertiliser should be applied when sowing and a top-dressing of urea should be applied with the single irrigation at 20 DAS. Farmers broadcast fertiliser onto boro rice throughout the season, the timing in part being based on the colour of the crop.)

> Md Abdul Owab, age 43, is an inhabitant of Arjuntala village in Senbag upazila, Noakhali. He is a non-trial farmer. He said that he has grown wheat this season and he has applied more fertiliser and seed than the trial plot, but got a lower yield compared to the trial plot. So he became very upset.

The trial farmers in both districts were trained about fertilisers to apply to wheat but commented that they did not get the opportunity to practise their learning in their trial plot because applications were done by the trainers in demonstrations. Because they had no hands-on experience, when they tried to cultivate wheat on their own they were not able to follow the correct management, which resulted in bad yields.

> Md Mizanur Rahman, age 42, is an inhabitant of Moutipy village in Bhola Sadar upazila, Bhola. He is a trial farmer. When asked whether he will apply the recommended dose of fertiliser in the upcoming season, he said he will still maintain the previous dose since he got a good yield using that dose. Thus, he does not have a clear concept about recommended dose because when the extension officer applied fertiliser in his field he was not present and he did not recall the recommended dose. (*Editor's note: Mizanur Rahman harvested 3.76 t/ha wheat from his trial using the recommended dose of fertiliser.*)

Preservation of wheat seed for planting next season

The respondents of both districts stated that they preserve harvested seeds of their traditional crop species for sowing in the following season. Having their own seed available ensures that they can plant at the optimal time and, critically, the seed costs them nothing.

Non-trial farmers in Noakhali mentioned that they do not know how to preserve wheat seed because they have never grown the crop. Non-trial farmers in Bhola claimed some knowledge about wheat seed preservation, although considered their knowledge was inadequate. On the other hand, trial farmers of both districts stated that although they received training in wheat seed preservation from the ACIAR-funded project, they were unable to apply all steps properly since they forgot the lessons. As a result, their preserved seeds were damaged by insects.

> Md Abdul Motin, age 42, is a trial farmer in Noakhali Sadar upazila, Noakhali. He had received seed preservation training from the project. He said that he had stored 80 kg of wheat seed but all his seeds were damaged by insects. So he had consumed this wheat later on. He also said that he did not follow the proper steps in seed preservation. According to him, he left little vacant places in his seed drum and, as a result, the seed was attacked by insects. However, now he has realised that the seed drum should never be left empty.

Issues relating to physical support

Availability and price of high-quality seed

The availability of high-quality seed of the best varieties of wheat in local markets at sowing time is one of the major concerns for farmers wishing to grow wheat.

The non-trial respondents of Noakhali and Bhola who have never grown wheat and who have no wheat seed stored in their home are totally dependent on their local market for wheat seed. The trial farmers of both districts explained that as their number and their trial area planted to wheat are small, the amount of seed of the new varieties produced is inadequate to fulfil the demand for sowing of all farmers in their locality. In addition, as there is not a high demand for wheat seed, it is unavailable in local markets. As a result, farmers are unable to sow wheat and default back to their traditional Rabi crops.

> Karimual Islam, age 58, is a non-trial farmer in Arjuntala, Noakhali. After observing the result of a trial plot, he was very interested in growing wheat in the last season. However, finally he was unable to grow due to the poor supply of wheat seeds in the local market. In addition, he did not get the elite wheat seeds from the trial farmers of his village.

All farmers of Noakhali complained that the price of wheat seed is higher than that of any other Rabi-season crop. For this reason, to grow wheat is mostly impossible for the marginal farmers who lack adequate capital during sowing time. In addition, as they have the seed of boro rice and other traditional crops of the Rabi season, they see it is free of cost to them. As a result, they are less interested in spending a large amount on wheat seed since it might put them in debt. (*Editor's note: enough elite wheat seed to sow 30 decimals of land, equivalent to about 0.12 ha (100 decimals = 1 acre = 0.4 ha), should cost about Tk400, although some trial farmers sold their produce for 20% more.*)

> Abdul Karin, age 45, is a non-trial farmer in Sallah, Noakhali. He said that he was very interested in growing wheat in the previous season after seeing the success of the trial plot. But he could not afford to buy the high-priced wheat seed. So he ended up cultivating boro rice as he already had a store of boro seed at his home.

Limitation of irrigation facilities

The respondents of both districts mentioned that there are few water bodies, canals or rivers in their villages. In addition, certain croplands have the disadvantage of being distant from canals, particularly as farmers beside canals can object to distant farmers trespassing on their land to access the water. Lack of electricity in the villages is one factor that can interrupt irrigation supply. The respondents of Arjuntala (trial village) in Noakhali said that their main source of irrigation is a local deep tube well that uses electricity to drive its pumps. This year, yields of boro were reduced due to cuts in electricity supply limiting their irrigation. (*Editor's note: wheat requires one irrigation compared to 20 or more for boro rice.*)

According to the farmers, there is a lack of irrigation machinery support like deep or shallow tube wells in their village. In addition, they are unable to apply irrigation at the proper time and amount due to poor access to water and the high rental cost of irrigation machinery. As a result, they got poor yields and thus have lost interest in cultivating wheat. However, they commented that with the low availability of irrigation machinery and its costs they first ensure irrigation in their boro field which assures their food security. Wheat may not be irrigated at all.

> Abdul Salam, age 45, is a non-trial farmer in Arjuntala, Noakhali (a trial village). He said that he has received only 5 kg wheat from 25 decimals (1,000 m^2) of land since he was unable to apply irrigation in his field due to lack of electricity supply.

The cultivation of wheat is greater in Bhola than in Noakhali but the respondents of both districts pointed out that the sizes of the wheat fields are very small and it becomes cost ineffective for poor farmers to rent irrigation pumps. Since the renter calculates that it might be risky for the machinery to be transported to small fields, they charge higher rent. In some instances, farmers have to arrange manual irrigation for small plots of wheat. However, such irrigation problems are not faced by cultivators of boro because where boro is grown it covers very large contiguous areas of farm land.

Md Shiraz, age 45, is a non-trial farmer in Moutipy, Bhola. He said that he could not apply irrigation in his wheat field due to lack of a shallow tube well. As a result, he had received a low yield at the end of harvesting.

Threshing difficulties

The respondents of both districts pointed out that the threshing of wheat requires intense manual labour, being more difficult than for crops like boro rice. While threshing machines are available for boro, they are very rare for wheat in the study areas. The respondents of both Noakhali and Bhola districts stated that women are mainly involved in postharvest activities. In many cases, women discourage men from cultivating wheat due to the hard work involved and the lack of threshing machines.

Abdul Salam, age 45, is a non-trial farmer in Arjuntala, Noakhali. He said that he cultivated wheat in the last year, but the threshing of wheat was very laborious. So he is not interested in harvesting wheat in this season.

Issues relating to finance and crop profitability

Investment before planting wheat

Farmers identified initial investment as the most vital factor when deciding to cultivate a new crop. They said the initial investment for wheat is high compared to boro rice and other crops, due to the high price of both seed and fertiliser. Fertiliser must be applied at sowing for wheat. They believe wheat needs more fertiliser overall than other Rabi crops. Also, all respondents of both districts mentioned that the price of fertiliser is increasing day by day so they see that as a further impediment to growing wheat.

They explained that most of the farmers are poor and so can only manage the expenditure involved in growing a crop in instalments.

Abdul Karim, age 45, is a non-trial farmer in Arjuntala, Noakhali. He said that he wanted to grow wheat on 40 decimals of land in the last year. But he grew only 25 decimals due to the high price of seed. Since he did not have adequate money at that time he grew cowpea on the rest of the land. He already had the cowpea seed at his home.

Availability of loans

The respondents of both districts identified loans as the most vital issue to help them take a decision to cultivate a new crop. They said the conditions for taking out loans to grow wheat were only 'reasonable' whereas for boro and other Rabi crops they were encouraging. They detailed the constraints for getting loans for wheat.

They said that the farmers who owned land got government agriculture loans but most of the farmers of their village are share-croppers or tenants, so they are always deprived of government financial initiatives. Wheat needs an initial investment that is difficult to manage for a share-cropper without a loan. So share-croppers could not cultivate wheat, due to lack of capital.

The respondents of both districts mentioned that the union of businessmen (Bepari) gave capital support to farmers for growing crops like soybean, peanut and mungbean but usually hesitated to provide financial support for wheat.

Md Abdul Jalil, age 50, is an inhabitant of Noakhali Sadar. He is a non-trial farmer; he got Tk10,000 from Bepari for growing soybean and peanut this year. So he has cultivated soybean on 50 decimals of land and peanut on 40 decimals. He said, 'I do not need to bear any cultivation cost of these crops whereas I would have to bear all the costs of growing wheat, which is not affordable for me.'

Potential profit

The assurance of profit from agricultural production is crucial for farmers. Noakhali farmers pointed out there are 'moderate' profits to be made from wheat and 'reasonable' profits from boro and other Rabi crops. The respondents of Bhola said there was 'good' profit from wheat against only 'moderate' profit from boro and other Rabi crops. The reasons are given below.

Some farmers said the overall production cost of wheat is lower than boro rice and the selling price of wheat at market is higher, so on both counts wheat is more profitable than boro. Actual profit is higher in Bhola than Noakhali because of higher soil fertility, fewer areas of salinity and more land that is otherwise well suited to wheat cultivation.

Farmers of both districts also stated that there is zero weight loss in wheat output of flour from grain but there is 30–37% weight loss in boro rice. For example, they can mill almost 40 kg flour from 40 kg wheat, whereas they receive only 25–28 kg rice from 40 kg paddy. On these grounds, also, wheat is more profitable.

Issues relating to nature

Timing constraints

Respondents of both Noakhali and Bhola districts believed that wheat is more time-sensitive than any other crop. If it is not sown at the proper time, they say, the yield will be very low. This is one perceived major problem in cultivating wheat. Farmers have never faced this problem when cultivating boro and other Rabi crops.

Most farmers cultivate local varieties of T. aman rice which need a long time to mature, thus delaying wheat sowing beyond their guessed proper time to get a good yield. (*Editor's note: Chapter 3.3, this volume, presents data for three seasons in Bhola and Noakhali showing the effects of planting date on yield in wheat and shows that wheat can be planted even after local late T. aman varieties and still provide good yield, providing farmers follow agronomy methods recommended in trials and use good seed of recent varieties.)*

Waterlogging/lowland

Waterlogging is a major problem in parts of Noakhali. Both trial and non-trial farmers said that they cannot sow wheat at the proper time due to lateness of the land drying after the wet season; they are compelled to cultivate wheat late. Sometimes they have to sow wheat in wet land and that leads to a lower rate of germination. So they get a lower yield. The respondents mentioned that the main reason for waterlogging is lack of a good drainage system. In Bhola, most of the land is high and medium–high so this problem is comparatively less. Comparing boro, waterlogging is not a problem since boro cultivation requires more water.

> Md Abdul Jalil, age 50, is an inhabitant of Noakhali Sadar. He is a non-trial farmer. He said that he was very interested in growing wheat. So he bought 50 kg of wheat seed from market at Tk32/kg. He was unable to sow wheat because of waterlogged conditions. His land was inundated for a long period. The land was wet, thus he had to cultivate cowpea instead of wheat. As a result, he has to use the wheat seeds for household food.

Rat problems

All respondents of Noakhali and Bhola districts mentioned that rat attack is a problem for wheat cultivation. Rats mainly attack when the wheat grain is mature and they can cause major damage, flattening sections of crop to eat the grain. As a result, farmers get a lower yield, particularly if they delay harvesting for too long. According to the farmers, they are unable to prevent such rat attack on their croplands. Rat attack is apparently absent in boro and other Rabi crops.

> Md Jashin, age 50, is an inhabitant of Arjuntala, Noakhali. He is a non-trial farmer. According to him, the quality of last year's cultivated wheat was very good, but overall yield was reduced due to rat attack just before harvest.

Social issues

Poor farmers are wary of change

As noted above, poor farmers are usually reluctant to adopt non-traditional crops. The respondents of Noakhali believe that they have no knowledge about wheat cultivation so they do not want to take the risk of growing it.

Community security

In rural areas, relationships with neighbours, friends and relatives play a vital role in farmers' lives. Farmers consult with their neighbours before cultivation and they follow each other's suggestions. They feel secure cultivating crops that their neighbours grow. Neighbours' perceptions regarding adoption of wheat are important. Noakhali respondents said their neighbours had little interest in growing wheat while in Bhola interest was reasonable. In both districts, neighbours strongly preferred to remain with traditional crops. They are naturally cautious. Noakhali farmers were cautious not to lead a new pattern. They worried that if one became the only wheat-growing farmer in their village, their crops might be damaged by goats, crows, insects (as it is green) and by waterlogging caused by neighbouring rice flooding. Bhola farmers questioned said their neighbours are interested in wheat.

> Md Nurul islam, age 45, is an inhabitant of Arjuntala, Noakhali. He is a non-trial farmer, has cultivated wheat last season and now his cousin is going to cultivate wheat this year. (*Editor's note: a neighbour harvested 2.9 t/ha wheat in 2009 from a mid-December sowing as a trial farmer and was happy with the result.*)

Conclusion

In spite of the financial benefits expected from growing wheat, farmers were mostly unprepared to adopt wheat as a sequence crop due to many constraints (actual and perceived). Knowledge is the first stepping stone to adopting a new crop and this can be either individual or community based, although the latter appeared to be more important. Farmers are reluctant to take a risk with something they or neighbours do not have knowledge about. Preferably, that knowledge should be drawn from long local experience which provides the breadth of lows and potential highs of crop performance through the years. The risk to be taken can then be placed in the context of the livelihood of the individual. Once knowledge is implanted and understood, the imminent practical aspects of growing the crop become paramount. The availability of seed and fertilisers before sowing time becomes crucial and the seed that is in the farmer's hand, grown by them and of known quality is preferred. Then there must be local financial support available even if not used. And there must be an assured market for the product locally, meaning the product must be used locally. In some areas, adopting a new crop, irrespective of its benefits, requires a paradigm shift in the local community.

Chapter 4.1 and Section 5 in this volume provide details of what farmers of different categories in village society own and earn and generally how they survive. In addition, some cropping option opportunities are presented that could make their livelihoods less difficult.

1.3 Women in rural agricultural livelihoods

Nasrin Sultana

Abstract

Rural households in Bangladesh are highly dependent on agriculture for their livelihoods. In a patriarchal rural agricultural context, men and women have distinct roles and women have a subordinate position in farming and other household issues. But women's roles and status are changing. Government, non-government and donor agencies have long been promoting innovations in the agricultural sector, but the level and sustainability of adoption depends on multiple factors with both technical and socioeconomic aspects. However, the socioeconomic aspects of the intervention and innovation processes have not been considered adequately. Again, the lack of attention to women's roles in household decision-making and in the implementation of new practices has been a major deficiency. Following the rural livelihoods framework of Ellis (2000), this paper sets out to analyse how access to and control over assets influence gender roles in agricultural rural livelihoods. Drawing on case histories of women in two contrasting villages in Noakhali district, this chapter shows the current role of women in farming and how that role is being renegotiated by the influence of household composition, household assets, seasonal and international migration of men, the weakening of extended family norms, and interventions by government and non-government agencies. It is anticipated that the recognition of the active role of women in farming and the changing status of women will help a reassessment of the balance of rural livelihoods. In future, development planning and implementation should recognise that women are increasingly active agents along with men in agriculture.

Introduction

In the traditional patriarchal society of rural Bangladesh, men and women have distinct roles and women have a subordinate position. However, the traditional roles and status of women are changing in response to changes (shocks and trends) in household livelihoods. This chapter analyses how gender roles and status are being redefined and adapted in relation to farming. This will help to uncover and explain the diversity of practice in farming, household decision-making and household livelihood strategies. This analysis is based on the case histories in two contrasting villages in Noakhali district, which is part of the Australian Centre for International Agricultural Research's (ACIAR) wheat research areas in southern Bangladesh. One of the study villages is Arjuntala, where wheat was trialled. It is a traditional, long-established village that is easily accessible and has peri-urban features. The other village is Charbaishakhi, where wheat was not trialled. It is in a relatively remote char area, formed by river deposition, resettled by people from eroded areas. The discussion focuses on how access to and control over assets influence gender roles in rural livelihoods.

The rural livelihoods approach

The livelihoods approach, as outlined by Ellis (2000), provides a useful framework to understand the dynamics of rural life in Bangladesh. According to Ellis, 'a livelihood comprises the assets (natural, physical, human, financial and social capital), the activities, and the access to these (mediated by institutions and social relations) that together determine the living gained by the individual or household'. This livelihoods framework regards the asset status of poor individuals or households as fundamental to understanding the options open to them, the strategies they adopt for survival, and their vulnerability to adverse trends and events. The livelihoods approach looks positively at what is possible rather than negatively at how distressed things are. The most important aspect of the livelihoods approach is noted by Moser (1998): 'to identify what the poor have rather than what they do not have and [to] strengthen people's own inventive solutions, rather than substitute for, block or undermine them'. Ellis (2000) summarises the livelihoods approach to rural poverty reduction as comprising three main dimensions:

1. assets of the rural poor (divided between natural, physical, human, financial and social capital)
2. mediating processes that influence access to those assets and the uses to which they can be put
3. strategies adopted by the rural poor for survival (comprising a collection of activities made possible by the interaction of assets and opportunities).

Based on their asset status, households are able to carry out production and become involved in labour markets. Asset status also influences reciprocal exchanges with other households.

Ellis (2000) also considers the impact of the social relations and institutions that mediate an individual's or household's capacity to achieve its consumption and other requirements. Social relations are taken to be those of gender, family, kin, class, caste, ethnicity, belief systems, and so on. Social and kinship networks are essential for facilitating and sustaining diverse income portfolios (Berry 1989). Also, norms of social participation, such as permitted actions by women, can make big differences to the livelihood options available for women compared to men (Davies and Hossain 1997). Institutions are seen as regularised patterns of behaviour structured by rules that have widespread use in society (Carswell 1997). Institutions determine how markets work in practice, including the degree of trust (or lack of it) in markets, and the mechanisms adopted to overcome lack of trust, as well as the local rules governing access to community resources.

Gender and livelihoods

The term 'gender relations' refers to 'the social construction of roles and relationships between women and men' (Baden and Goetz 1998, as cited in Ellis 2000). These socially constructed roles are about power, decision-making, control over events, freedom of action and ownership of resources, and are usually unequal for men and women. Hence, gender is fundamentally about power, subordination and inequality. The gender approach recognises the immense diversity of relations between men and women across cultures, but nevertheless emphasises the lessening of the social inequalities experienced by women as an overriding goal (Ellis 2000).

Regarding gender and poverty, female-headed households are found to be poorer than male-headed households (World Bank 1990); in fact, the people within such households are typically the 'poorest of the poor'. Kabeer (1997) notes key issues for rural poverty: one is that rural women are poorer than rural men on average, and that additional cash income obtained by male or female household members has quite different effects on the family welfare, especially for women and children. Not only discrimination in inheritance by religious law but social norms and customs give women lower status than men, which influences rural livelihoods.

Acknowledging this unequal position, this chapter explores both the complexities and the positive aspects of rural women's lives as the livelihoods approach emphasises a positive perspective rather than seeing things only from a negative aspect. Gender is a key concern because in livelihood relationships between men and women, partnership is not equal within the household as well as in broader rural life.

Women's farming role is underestimated

In a rural and agricultural context, land is the primary asset. Lack of land ownership reinforces women's dependence on men and curtails their capability to make independent livelihood choices. Women's access to land occurs through men and is therefore dependent on them for any decision. In patriarchal societies, women get involved in farming as subordinate members because men inherit most land and women have a low position in power relations.

In rural Bangladesh, some local research pointed out that one crucial problem is women's unrecognised role because of patriarchal society. Findings in the current study also show that many women have decision-making roles along with men and active participation in farming which is not officially acknowledged. *(Editor's note: all names in this chapter have been changed to protect their sources who were speaking contrary to their husbands.)*

> For example, in the ACIAR wheat-trial village in Noakhali, a woman farmer, Rushi Ara, who is the wife of a wheat project farmer named Julhas, plays an equal role with her husband in wheat cultivation and vegetable gardening, which they do on a commercial basis.

Women's level of involvement in agriculture varies with social and economic setting

Women's significant participation in agricultural production in developing countries was first highlighted by Boserup (1970). She identified three types of participation:

1. high female participation combined with low technology in Sub-Saharan Africa
2. low female participation associated with animal draught technology, hired labour, and cultural proscriptions on women's work outside the home
3. sharing of farm work between women and men when associated with intensive cultivation, land scarcity and small farm size.

While this simple classification was a useful starting point, women's roles in agriculture are much more heterogeneous, varying between different types of farming system, between ethnic groups, and between different levels of income and wealth within the same cultural system.

Findings of the current study also support this. In both traditional village Arjuntala and remote village Charbaishakhi, women play various roles in agriculture based on income level and variable social norms, even in the same religious and cultural system. On the one hand, in Arjuntala, people are more conservative in observing the segregation of men and women and the prohibition on women working in a public place (purdah) in farming as well as other practices. On the other hand, in Charbaishakhi the social system is not so restrictive because people migrated here from different areas and also do not stay long in the same char. Therefore social bonding is weaker. Hence, it is comparatively easier for women to go against the restrictive social system of purdah.

Lack of access to assets restricts women's contribution in farming

In rural Bangladesh, lack of access to assets is a crucial issue. Agriculture is the primary livelihood strategy for rural people but land availability is declining as a result of high population growth. The high incidence of poverty in rural areas means that rural people have less financial capital as well. Although most rural people are engaged in agriculture, not all have the same decision-making power. There is a high percentage of small farmers who are share-croppers, and landless people whose lack of control over land restricts their decisions regarding crop management. Women are similarly affected.

In the Bangladesh social system, in most cases, men have the land ownership and therefore women have a lower status than men. Evidence from study villages in Noakhali district suggests that many women who make significant contributions to farming along with men are not formally recognised as such because of the social expectation that men are farm managers and women have only a dependent role.

Generally, gender inequalities and differences occur not only with respect to land ownership, but also with respect to other assets, which reinforces the socioeconomic differences between women and men. For example, discrimination against girls in education results in gender inequality in human capital. It influences access to labour markets where, due to lower educational qualifications, women have access only to unskilled labour markets offering low wages and little job security. Therefore, while men rely more on markets for crop sales and hiring wage labour, women have to rely more on social networks and on setting up and maintaining informal reciprocal exchanges to ensure survival and improve livelihood security (Berry 1989).

In Charbaishakhi, it is seen that women have less contact with the market and are not allowed to go to the market. Many women who are directly involved in crop cultivation and are managing all pre- and post-cropping activities are dependent on male members to sell their products at the market.

> Amina, a woman from a remote village, who produces the crop, rears the goat and plants trees, has to depend on her husband or adolescent son to sell these at the market. In most cases, her husband keeps the money or takes the money from the son. If she had scope to sell by herself, she could have control over her own income.

Control over assets affects household power relationships

Usually, family members with more access to and control over resources have greater influence in decision-making, and the rest of the family carry out these decisions. Control over income into the household can make significant differences to the consumption patterns of men, women and children. In general, it is found that cash resources in women's hands are more likely to be spent on basic household needs (Dwyer and Bruce 1988, cited in Ellis 2000; Kabeer 1997).

In rural households in Bangladesh, it is not much highlighted but there are a number of examples where men and women share household decision-making or women's strong influence shows their power in decision-making (Figure 1).

> In Arjuntala, Mariyum is a woman who inherited her father's property and has key authority in household decision-making. This is not common but as an only child she received all her father's property and has been staying at her natal home. So, she has a strong position compared to other women who stay in their husband's home after marriage. Mariyam's husband is the official household head but as she has the land ownership and lives in her natal home, she is the key decision-maker in farming and other household issues. She has better negotiation capacity compared to other women.
>
> Similarly, in Charbaishakhi, one widow, Montazunnesa, manages farming on her 0.8 ha (2 acres) of land. In the absence of any male member she is the key decision-maker about share-cropping, managing by herself or with the help of hired labour or keeping the land fallow. She works in the field and also hires both male and female labour in the harvesting period. Her control of her asset gives her this power to decide by herself rather than depending on others as many widows have to do.

The current study also provided evidence for how women struggle to share the decision-making with male members of the household (Figure 2).

> In a remote village of Noakhali, one woman, Amina, suffers from her husband's negative attitudes towards women making decisions. She tried to cultivate crops in three seasons, which her husband did not appreciate and created hurdles. Also, he tried to make trouble at every step of his wife's and three of their daughters' efforts. In their household, every time there is a conflicting opinion, domestic violence occurs. Her husband tortures her physically and mentally as he cannot accept her decisions and say on household issues. But she is initiating new crops like boro rice, going against her husband.

But the study also showed that not only is there difference in power between men and women but there is often a struggle between women to capture the higher position in the household. This is especially the case between generations, namely between mothers-in-law and daughters-in-law who each try to take the lead based on their son's or husband's household position.

> In Arjuntala, the three grown-up sons of one widow woman, Salima, migrated overseas, so she managed the farming and all household issues. She even sold the crops to buyers directly and hired labour whenever she needed, although this is not common for women in that village. Due to the absence of all male members, she took all responsibilities on her shoulders. But the situation changed after her sons' marriages and the household turned into an extended family with daughters-in-law and grandchildren. Over a period during which her sons increasingly sent their remittances in their wives' names instead of their mother's name, Salima gradually became less powerful and shared the household management with her sons and daughters-in-law. Finally, when one of her sons moved to a nuclear family from the extended family, the other sons also changed their practice and Salima lost her decision-making position and her daughters-in-law got some power in household issues.

Reasons for women's increasing visibility in farming

In the agricultural sector, women farmers are now more visible, partly due to greater outsider awareness and partly due to structural change. Major reasons are discussed below.

Poverty breaks social customs

To cope with increasing poverty, women are getting more involved in field labour activities (Figure 3). Male agricultural wage rates are rising and economic pressure drives women to assist male household members on their land to reduce the household's production costs (Lewis 1993).

To survive poverty, even in a rigid social setting, poor women are getting involved in certain activities of agricultural work in the field that are traditionally within the male domain. This is particularly the case for landless women who largely belong to the extreme-poor group. This shows that traditional beliefs and norms regarding women's outside work are changing due to growing economic pressure and breakdown of familial support (ADB 2001).

In both study villages in Noakhali district, women from poorer households are involved in direct field-based farming work in higher numbers. In the traditional village, Arjuntala, although they are few in number, only poorer women break the chain of social custom and go to the field to help their male family member to save the higher cost of hiring labour. In Noakhali, generally male day-labourers get Tk250–300 (A$3–4) and two meals a day but women labourers do not get paid in cash. They get only food and some paddy/rice but not at any fixed rate.

Figure 1. A woman in Arjuntala with land ownership and hence decision-making authority

Figure 2. A woman struggling to share the decision-making power with her husband

Figure 3. A poor woman head of household in Charbaishakhi survives by working as a day labourer for lower wages than men

Informal social network and household type influence women's mediating and decision-making role

A key issue is women's role in agricultural decision-making. White (1992) and Lewis (1993) specifically raise this issue against traditional images of women and are critical of conventional assumptions held by the key actors, including policymakers, researchers and operational agents, who ignore women's participation in the agricultural decision-making process. Study findings support this criticism and strongly suggest that women have a significant role in household farming decisions (see Chapter 5.2, this volume, for data on this issue). Women are becoming engaged in agricultural decision-making such as adoption of new crop seeds, irrigation and fertiliser; taking part in field-based farm management and participation in production activities; and becoming organised into group-based cultivation activities on owned, leased or share-cropped land. Lewis (1993) points to the important role of assistance from non-government organisations (NGOs) such as PROSHIKA, BRAC and the Grameen Bank in this regard. Other studies show that there are many activities in which the extent of women's participation is often concealed. Women are frequently involved, alone or with their husbands, in decisions about seed storage and care, the quantities of paddy to be husked, the purchase or sale of land, and the sale of farm animals (Quddus et al. 1985, cited in Lewis 1993). Women have a role in taking decisions about adoption of high-yielding varieties (HYVs), particularly in households with small landholdings. But in most cases these roles of women are not recognised and do not attract the attention of policymakers and implementing agencies.

White (1992) draws attention to another important role of women in Bangladesh—regular livelihood negotiations—an activity that is common but overlooked. That is, women have a strong role as intermediaries. Issues like requests for loans or share-crop land often go first to women in wealthier households, in the hope that they will be able to influence their husbands. With flexible terms and conditions for contracts, women in wealthier households play the key role of a broker and may have considerable leverage over poorer people.

White (1992) argues that 'just because women do not enjoy sole authority does not mean that they have no power'. She suggests thinking about how women conceive of their own interests and how notions of gender figure in interpersonal negotiations of power. The absence or sickness of male members of the household makes women more visible in decision-making. Strict social segregation of the roles of men and women as a cultural ideal may face challenges in changing household situations and this trend is increasing (White 1992).

Diversified livelihood strategies create opportunities for women's decision-making

In rural Bangladesh, people wish to take advantage of new livelihood opportunities along with agricultural livelihoods. New opportunities enhance the capacity of households to shift from one livelihood level to another or to combine livelihood strategies. For many people today, livelihood strategies comprise both agricultural and non-agricultural contributions. A major diversification strategy, migration, has strongly influenced rural livelihoods and changed gender roles in negotiations in farming. Data from Noakhali district suggest that in many households where men have migrated, women play the key role in farm decisions (Figure 4).

In Arjuntala, one woman named Mortaja Begum manages their farming with the help of hired labour, as her husband lives in the Middle East. Not only does she make cropping choices but she also decides whether to share-crop or do it all on her own. She deals with buyers and hires labourers. She also makes the decisions about her children's education and other household issues.

Agricultural institutions and extension influence women's status and role

To get access to assets and improving livelihoods, the role of institutions and organisations is very important. In the case of rural agricultural livelihoods in Bangladesh, both class and gender need to be taken into account by the major organisations. From the government side, the Department of Agricultural Extension (DAE) is mainly responsible for operational work in promoting new technologies to farmers. Getting access to such institutional support is more difficult for women. In many cases women are excluded on the basis of accepted cultural barriers. Notions of gender segregation in farming are strongly linked with social norms and expectations. One perception is that women's active participation

Figure 4. A migrant's wife in Arjuntala takes farming decisions

in farm-related training or programs is sometimes constrained by other family responsibilities, especially child rearing and other domestic activities.

Another practical limitation is the lack of female staff at both policy and field levels. Hence women's concerns are not understood and met properly. There is no separate gender policy for the agricultural sector, but according to government policy women have a 30% quota in all government jobs. DAE has a lack of female scientific officers to post in all areas. Scientific officers are the key agents at the field level who deliver knowledge to the farmers directly. Due to a shortage of female staff, male supervisors are allocated for both men and women farmers and women are thus excluded due to the cultural barrier. The reason behind the lack of female staff is linked with broader gender segregation in education. Agriculture is considered a technical subject that is not 'women friendly'. Therefore, the 30% quota is not always filled. In recent years, many girls have enrolled in agricultural courses and there is hope that, in the future, this problem will be reduced.

Conclusion

There is a contradictory situation with regard to gender and livelihoods in rural Bangladesh. On the one hand, long-term patriarchal values and subordination of women are still strong, while on the other hand, changing livelihood strategies due to the financial crisis, flow of migration, changing social values, and state initiatives, are advancing the status of women and bringing changes in gender roles. Building on an awareness of these changes will increase the effectiveness of projects and programs that aim to enhance rural livelihoods.

References

ADB (Asian Development Bank) 2001. Women in Bangladesh. Programs Department (West), Asian Development Bank: Manila.

Berry S. 1989. Social institutions and access to resources. Africa 59(1), 41–55.

Boserup E. 1970. Woman's role in economic development. St Martin's Press: New York.

Carswell G. 1997. Agricultural intensification and rural sustainable livelihoods: a think piece. Institute of Development Studies (IDS) Working Paper. IDS: Brighton, United Kingdom.

Davies S. and Hossain N. 1997. Livelihood adaptation, public action and civil society: a review of the literature. Institute of Development Studies (IDS) Working Paper. IDS: Brighton, United Kingdom.

Ellis F. 2000. Rural livelihoods and diversity in developing countries. Oxford University Press: New York.

Kabeer N. 1997. Tactics and trade-offs, revisiting the links between gender and poverty. Institute of Development Studies (IDS) Bulletin 28(3), 1–13.

Lewis D.J. 1993. Going it alone; female headed households, rights and resources in rural Bangladesh. Centre for Development Studies, University of Bath: Bath.

Moser C. 1998. The asset vulnerability framework: reassessing urban poverty reduction strategies. World Development 26(1), 1–19.

White S.C. 1992. Arguing with the crocodile: gender and class in Bangladesh. The University Press Limited: Dhaka.

World Bank 1990. Bangladesh: strategies for enhancing the role of women in economic development. The World Bank: Washington, DC.

Section 2

Physical constraints to cropping in southern Bangladesh

2.1 Climate

Perry L. Poulton and H.M. Rawson

Abstract

The perception that wheat cropping in the south of Bangladesh is constrained to unproductive levels by climate, specifically by high temperatures, is examined in this chapter.

Assuming the Rabi window of December to March is available for wheat in the south means destructive cyclones are avoided as they are most likely to occur outside this period. Temperatures during this Rabi period are higher than in the north, averaging 22 °C across the southern region compared with 20 °C, and ranging between mean maxima and minima of 28 and 16 °C, respectively. Using current varieties of wheat, this mean temperature of 22 °C allows for average crop durations of 90 days, 10 days less than in the north, so 10 days less for crops to assimilate sunlight for biomass production. Crops developing in the south during January are subject to short day lengths of less than 11 hours and are exposed to low levels of solar radiation averaging 14 MJ/m^2/day then, but during biomass accumulation just before anthesis in mid February, radiation has risen to 16–17 MJ/m^2/day. Such radiation levels occur despite an increase in low-level atmospheric pollution and haze in the Bangladesh region contributing to a reduction in intercepted solar radiation of 0.05 MJ/m^2/day each year. Despite these temperature and radiation constraints, yields of 3.5–4 t/ha have been achieved by farmers who use good farm management to overcome water and nutrition limitations. By comparison, the national Bangladesh wheat yield for the 2007–08 Rabi averaged only 2.17 t/ha.

Temperature has increased over the past two decades at 0.035 °C/year. If this trend continues, temperatures will have increased over 1990 levels by 2.13 °C by 2050. This means that by 2050 current wheat-growing areas in the north (Dinajpur) will have mean temperatures around 25 °C, as currently experienced in the southern districts of Bhola and Noakhali. As long as global sunlight levels are not diminished further, potential wheat yields will still approximate 3 t/ha in the south, assuming photothermal quotients in the 3 weeks before anthesis of 0.75 MJ/m^2/°C at current CO_2 levels.

The current potential for increasing wheat production in the south is positive but considering future climatic constraints associated with increased temperature and higher rainfall variability by 2050, other crops—probably with the C_4 photosynthetic pathway and with its associated much better water-use efficiency—may be better options.

Introduction

Farming in Bangladesh is dependent on the arrival of the monsoon for wet-season rice (aus and transplanted (T.) aman), and on the amount of rain (Figure 1) filling the soil profile and water storages in order to cultivate crops during the winter months of the dry (Rabi) season; Rabi crops may include animal fodder, cereals and vegetables and irrigated (boro) rice. Rice production, particularly the area planted to boro, currently accounts for 71% of the cropped land area (Rahman and Khan 2005) and 94% of the country's food grain production (Hossain et al. 2005). Production of wheat is relatively minor (around 1 million t in 2009–10) and contributes about a third of the 2.96 million t consumed annually (USDA 2009). Hossain et al. (2005) describe Bangladesh as having no favourable agroclimatic environments for growing wheat because of the short, mild winter and heavy soils. Until recently, the focus of wheat production and research has been in the north of the country. Irrigation resources in the south are limited, due to the general unsuitability of the area for deep tube wells, and when irrigation infrastructure is available it is used for boro rice, not wheat. Additionally, there are perceptions that growing-season temperatures in the south are too high for wheat and sowing times too late for acceptable yields because of having to wait for harvesting of late-maturing local T. aman rice. And finally, the coastal regions have saline soils, not considered suitable for salt-sensitive crops like wheat and are more prone to the possible threat of cyclones and associated tidal surges that could destroy crops.

This chapter explores whether the subtropical climate of southern Bangladesh is likely to constrain wheat production as perceived. It primarily considers temperatures, solar radiation and photoperiod. Rainfall during the Rabi is not considered in detail in this chapter as wheat crops grown in the south of Bangladesh are sown into full soil-water profiles at the end of the monsoon; then aboveground water storage is abundant and shallow groundwater tables are close to the surface. Soil and water issues in the region are discussed in Chapter 2.2 (this volume).

Timing and scale of agro-climatic events over years

The country of Bangladesh (see Figure 14) is located within the flood plain of a river delta system and has a subtropical monsoon climate with a high degree of temporal and spatial variability in rainfall; from over 5,600 mm in the north-east to 1,100 mm in the west. About 80% of annual rainfall occurs during the monsoon between June and October, with only minimal falls of 50 mm or so occurring during the Rabi season from December to March. Monsoonal rainfall, accompanied by floodwaters flowing from neighbouring countries along three major rivers, the Ganges, Brahmaputra and Meghna, provides the main source for groundwater recharge. At the end of the Kharif (wet) season in October or November, as surface floodwaters drain into ponds, canals and river systems, much of the landscape is saturated, with watertables close to the surface. The degree that floodwater recharge raises the groundwater levels depends on the timing and severity of the monsoon and on the base groundwater levels at the end of the dry season in May.

Bangladesh is vulnerable to severe cyclonic activity throughout the monsoon and pre-monsoon period (Figure 2) with most cyclones occurring during May and in October and November (Islam and Peterson 2009). The strength of the storms is greater in the southern parts of Bangladesh, particularly across exposed islands, and in the cities/towns/provinces of Chittagong, Noakhali, Barisal, Patuakhali and Khulna (see Figure 14), as well as in some inland areas in Comilla, Faridpur and Dhaka (Khalil 1992). Wind gusts and associated water inundation from tidal surges along the 704 km of coastline have caused major destruction and loss of life over the years (Khalil 1992; Islam and Peterson 2009). The Rabi season after the end of the monsoon in late November to early December, when wheat might be sown, is essentially cyclone-free.

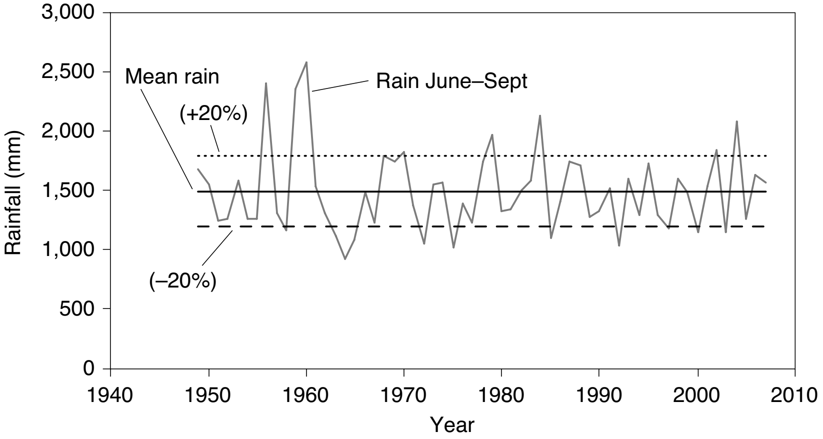


Figure 1. Variation in monsoonal rain from June to end September over the past 60 years in Barisal. The red line is the average for the period and the green and brown lines plus and minus 20% of that average. Amounts vary for different parts of the country (see text).

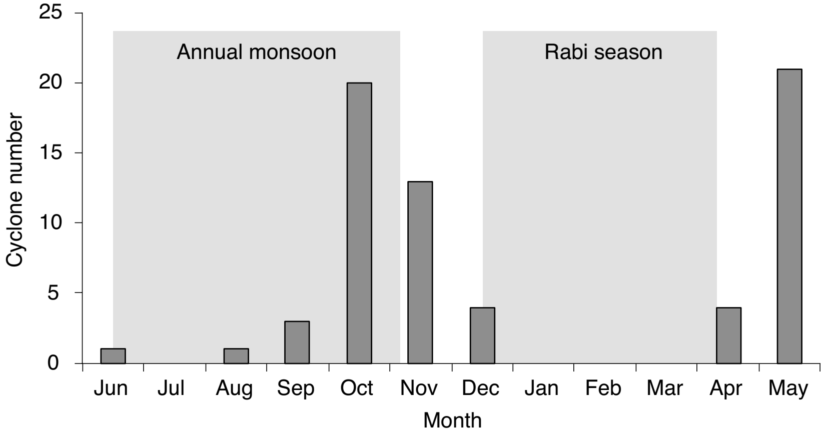


Figure 2. Number and monthly distribution of cyclones between 1877 and 2007 in Bangladesh (redrawn from Islam and Peterson 2009)

Comparison of temperature and solar radiation in the north and south

The southern region is generally considered hotter than the north (see Chapter 1.1, this volume). Analysis of daily temperatures during 1960–90 show that, on average, there are 40–70 days with minimum temperatures below 15 °C compared with an average of 70–90 days for the northern region (BARC 1995). Average daily temperatures range from a minimum of 7.2 °C in winter to a maximum of 36.5 °C in summer, with some districts recording extremes greater than 41 °C. Highest evaporation (an average of 183 mm/month) occurs during the summer months before the start of the monsoon; mean monthly values are much lower (50 mm/month) during winter.

Figure 3 illustrates daily temperatures for the island of Bhola in the southern region from July 2008 to June 2009 (with preceding years 2005–08 included in Figure 13). Over those 12 months, the lowest temperature recorded was 10.2 °C in January, while the maximum was 36.0 °C in April. The average minimum, maximum and mean temperatures for the Rabi period from 15 December 2008 to 15 March 2009, when land would be presumed free to grow a wheat crop, were 16.1 °C, 27.9 °C and 22.0 °C, respectively. This equates to a heat sum of 2,004 °Cd > 0 °C for the 91 days of the Rabi period, approximately the amount required for current Bangladesh wheat varieties to complete their life cycles (Chapter 3.1, this volume). By contrast, at the Wheat Research Centre (WRC) at Dinajpur, north of Bhola by 3.4° latitude, equivalent average values for minimum, maximum and mean temperatures were 14.0 °C, 25.8 °C and 19.9 °C, respectively, or 2.1 °C cooler overall than on Bhola in that Rabi season. The lowest and highest daily values for the year were 7.8 °C and 38 °C, respectively 2.4 °C cooler and 2 °C hotter than temperatures on Bhola. These values, in addition to mean temperatures during December–March (1990–2009), presented later in Figure 10, demonstrate the south is hotter than the north but the differences appear minimal. Cumulatively, however, the differences become large when considering crop growth and development. Heat sums (degree days) for the 15 December 2008 – 15 March 2009 Rabi period differed by 196 °Cd, or by 10–11 days at the mean temperature for Dinajpur, indicating that wheat crops would need at least 10 days more to complete their life cycles in the northern region than in the southern region. The same varieties would take 102 rather than 91 days to grow (this difference is shown in field crops in Chapter 3.1, this volume).

Figure 3 also illustrates the daily solar radiation values for Bhola for 2008–09. Solar radiation is an indicator of the amount of light that crops use in photosynthesis and in biomass production. Low solar radiation totals for a season often equate with low biomass production and low yield (Evans 1978). Solar radiation varies from day to day much more than temperature, although the two are related. Factors that

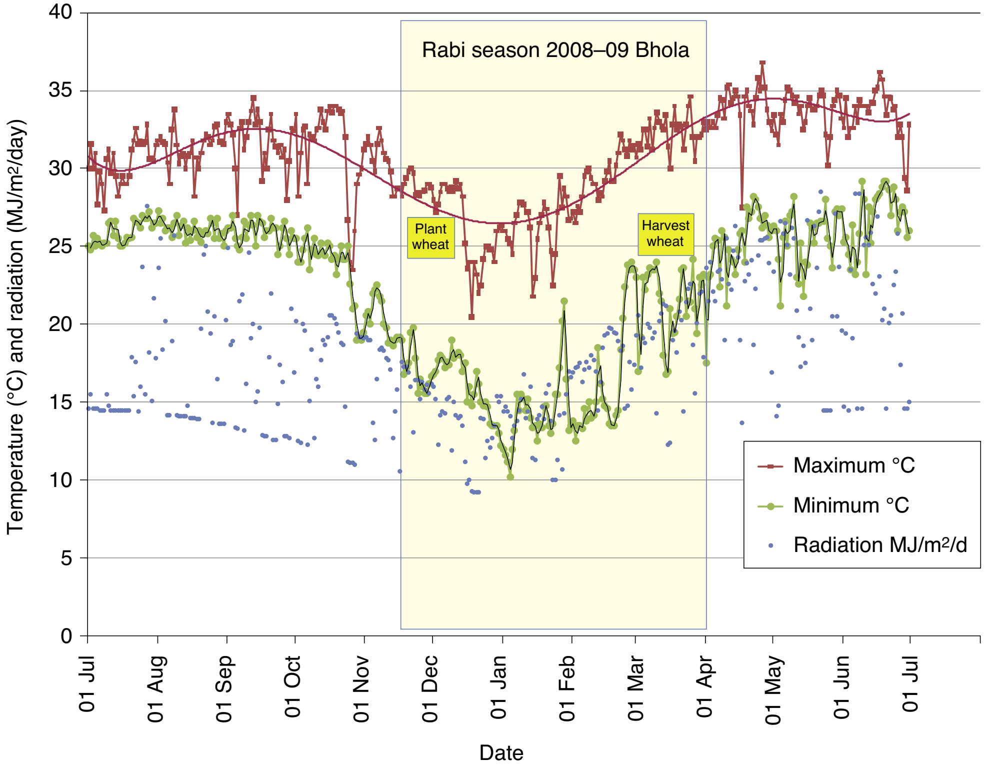


Figure 3. Maximum and minimum daily temperatures and solar radiation, Bhola, 2008–09. Data were sourced from the Bangladesh Meteorological Department (BMD), and solar radiation was calculated from daily sunshine hours using the Angstrom equation (Angstrom 1924). Additional years 2005–08 are shown in Figure 13.

affect the amount of solar radiation received by plants each day include concentrations of air-borne industrial pollutants, fogs and cloud cover. The overall determinant of potential solar radiation each day is day length or photoperiod (Figure 4) and is discussed in detail, inclusive of calculations, by Ligr et al. (1995).

In winter, when days are shortest (e.g. 10 hours 36 minutes on Bhola on 1 January), there are 3 hours fewer each day for crops to receive sunshine than later in the year when the photoperiod has lengthened. Day-length changes associated with the differences in latitude between the northern and southern regions affect photoperiod, resulting in crops on Bhola having 12 minutes more time to photosynthesise each day in early January than crops in Dinajpur. This small difference between locations has disappeared by the end of February. Potential solar radiation per day in early January on Bhola is around 16 MJ/m²/day whereas in early March it is over 20 MJ/m²/day.

Impacts of fogs and particulate matter on solar radiation

Winter is characterised by widespread fogs and extensive cloud coverage. Figure 5 shows a band of fog forming and moving across Bangladesh in early January 2006. Spatial occurrences of such events have the potential to reduce solar radiation intercepted by a crop and daily maximum temperature, and can cause significant spatial variation in growing-season environments between districts. Figure 6 shows the impact of this fog event on temperature and solar radiation at Dinajpur, Jessore and Patuakhali. This fog band almost missed the Patuakhali coastal region (see Figure 14) but data from the meteorological station in Dinajpur showed a drop in solar radiation during the 7 days from 15 to 9 MJ/m²/day (Figure 6a) and also a reduction in maximum daily temperature of up to 10 °C (Figure 6b). As discussed in Chapter 3.1

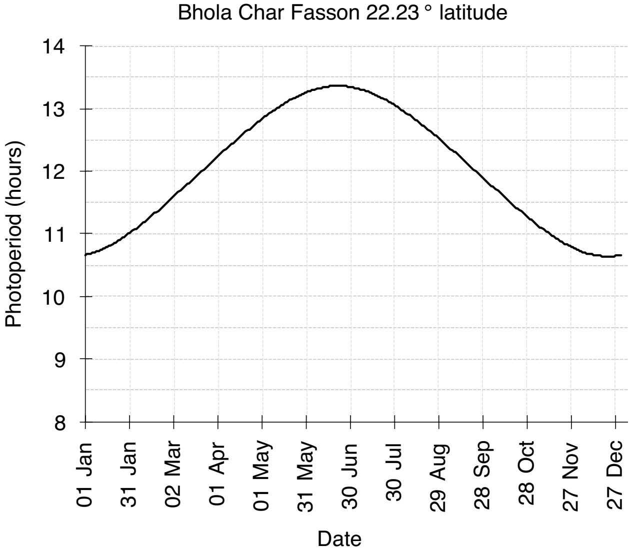


Figure 4. Change in photoperiod throughout each year at Bhola, Bangladesh

(this volume), such reductions in radiation can reduce yield both via retarding effects on the accumulation of florets (grain sites) and on sterilising pollen, particularly during January when crops are passing through the sensitive stages between flag-leaf ligule emergence and anthesis.

Rain, which can wash pollutants from the air, is infrequent during Rabi. During this period, atmospheric pollutants from industrial activities, power plants, brick kilns (Figure 7) and from vehicular traffic add to the suspended particulate matter concentrations over Bangladesh (ESCAP 2006). Kumari (2007) found that these pollutants contribute to 'global dimming' in the region, reducing solar radiation between 1981 and 2004 by 0.86 W/m^2/year. This low-level atmospheric pollution covering parts of India and Bangladesh occurs annually during January to March and is visible in Figure 8 as a grey haze.

Variation in radiation between regions in January

Given the generally positive relationship between solar radiation and crop biomass production (Monteith 1994; Muchow et al. 1994) when water or nutrients are not limiting, is radiation likely to limit

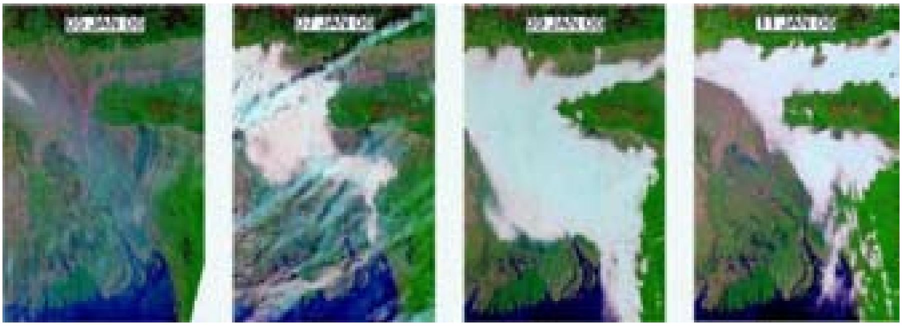


Figure 5. Satellite images of a cold wave, 5–11 January 2006 (Source: Bangladesh Space Research and Remote Sensing Org (SPARRSO) presentation, APRSAF-16 (Asia–Pacific Regional Space Agency Forum), Bangkok, 26 January 2010)

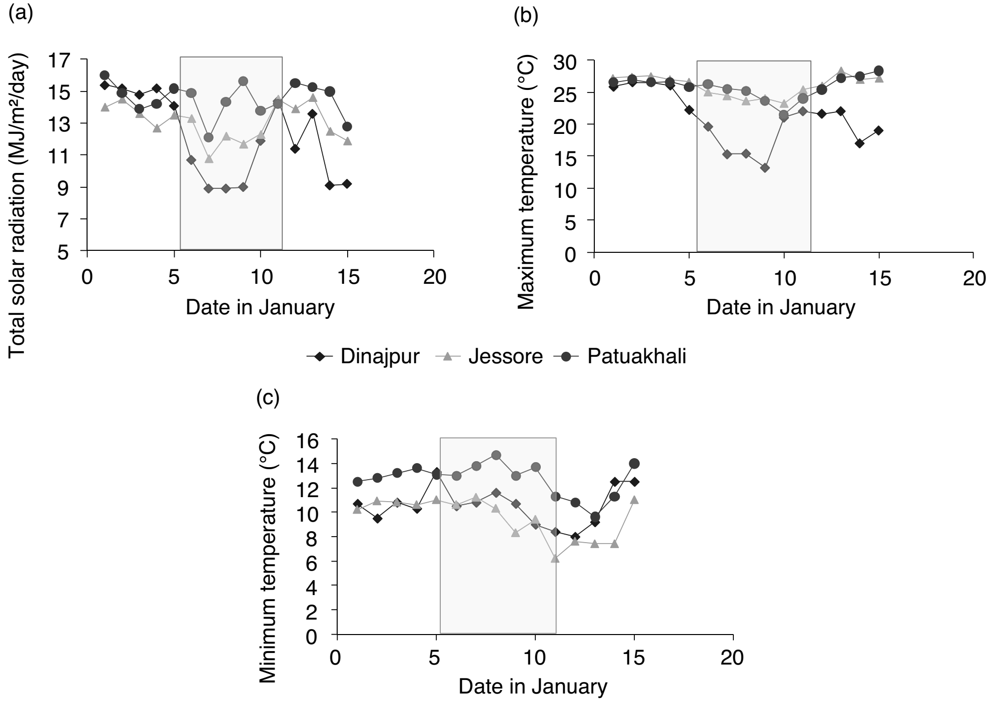


Figure 6. Impact on radiation (a) and temperature (b, c) in Dinajpur (northern Bangladesh), Jessore (central) and Patuakhali (southern) of a fog band (bar) moving across Bangladesh, 5–11 January 2006 (data from Bangladesh Meteorological Department)

growth more in the south than in the north? Figure 9 shows the variability of solar radiation from year to year, particularly in Dinajpur, but also demonstrates that the more southerly locations have consistently higher radiation than Dinajpur in the north by around 1.5 MJ/m²/day on average. In many years and overall, little separated values for Bhola, Barisal and Noakhali and they invariably had higher radiation than Jessore. There was a trend for reduction in radiation over the 20 years of 0.05 MJ/m²/year in Jessore and 0.03 MJ/m²/year in Dinajpur and Noakhali, but this was absent in Barisal and Bhola; if data back to 1948 were included, Barisal and Bhola also declined overall at 0.05 MJ/m²/year. By February, differences in radiation between north and south had reduced to less than 1 MJ/m²/day, and by the end of Rabi in March all locations had become the same, both in daily solar radiation and length of photoperiod.

On the basis of daily radiation alone, ignoring temperature differences, it might be expected that the southern coastal zones might have higher potential biomass production and yield than the north. However, due to spatial differences in daily temperatures, northern crops grow for an extra 10 days to reach the same phenological stage of southern crops. That extra 10 days' radiation results in no significant difference in accumulated intercepted radiation between north and south (1,453 and 1,433 MJ/m², respectively).

Spatial and temporal differences in Rabi temperatures

The following discussion pertains only to the December–March Rabi period shown in Figure 2 as a shaded box. Figure 10 confirms again that the south is hotter than the north, with Dinajpur recording the lowest maximum and minimum temperatures. However, in the past four Rabi seasons, its minimum has become closer to that of Jessore. Despite that, Dinajpur averaged around 2 °C cooler than the south. Interestingly, location rankings in the south for maximum and minimum were reversed. So Jessore had low night temperatures but high day temperatures

Figure 7. One source of particulate matter causing low-level atmospheric pollution during the Rabi season in Bangladesh (Photo: HMR)

Figure 8. Satellite image of low-level industrial pollution over Bangladesh on 27 January 2007 (Photo: <www.nasaimages.org>)

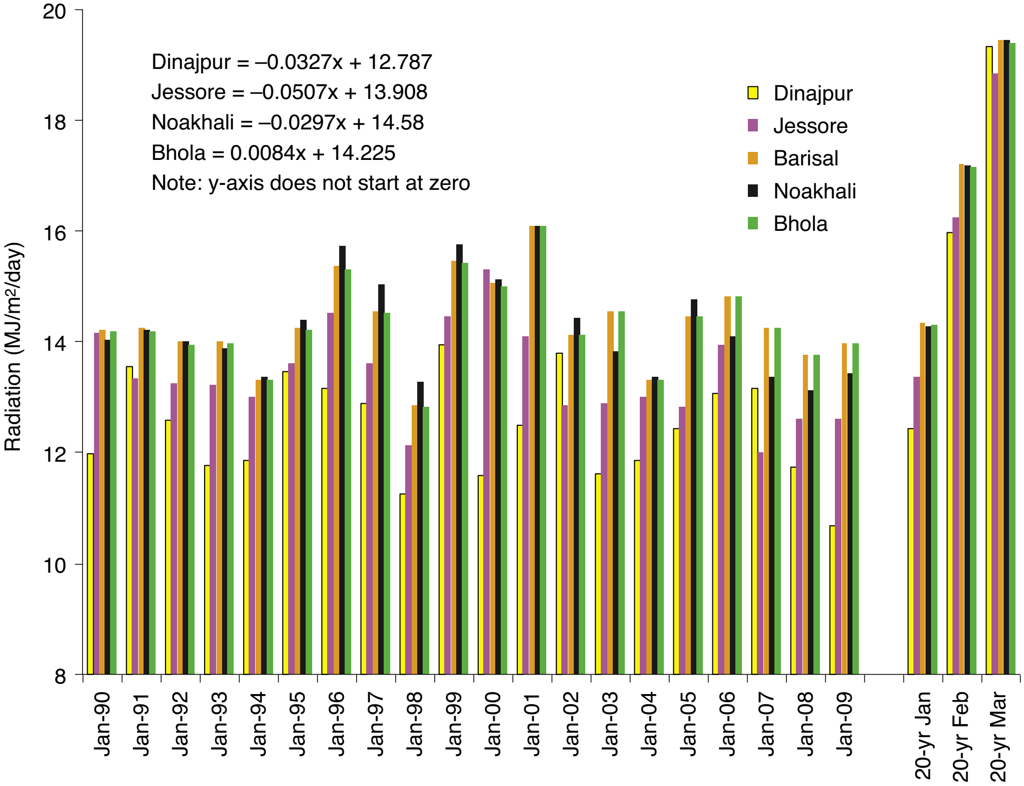


Figure 9. Solar radiation in January for Dinajpur, Jessore, and the coastal regions of Barisal, Noakhali and Bhola over the past 20 years. Long-term averages over 20 years for the months of January, February and March are included for comparison. (Source data from Bangladesh Meteorological Department)

while the reverse held for Noakhali. Trends reflect changes in mean daily temperature during December to March, 1990–2009.

Figure 10 demonstrates differences in Rabi temperature between years can approach 2 °C. The linear trend lines on the figure show that mean Rabi (December–March) temperature is increasing between 0.033 and 0.048 °C/year.

Mean temperatures for Dinajpur are cooler compared to regions in the south (Table 1) but more closely aligned with the traditional wheat-growing area of Jessore. Patuakhali is warmer overall, resulting in wheat varieties losing around 11 sunshine days, compared with Dinajpur, as the result of an increase in accumulated thermal time. Mean Rabi temperatures of 21.6 °C (Table 1) are not considered high for wheat growth. Crops grown at 27.5 °C to maturity in glasshouses in Australia produced average yields of 5–6 t/ha with growth rates during tillering of up to 40 g/m²/day and averaging 22 g/m²/day across 24 genotypes that were tested (Rawson 1986). These mini crops reached anthesis in 50 days from sowing in most instances. The key difference in that Australian study from the environment of southern Bangladesh is that radiation levels averaged 25 MJ/m²/day for the full study. So despite the short crop durations of 65 days, summed radiation receipt was 25% more than would be received in Bangladesh during the Rabi by a 90-day crop, solely because days were 14 hours long at 35°18′ south compared with 10–11 hours at 22–26° north in Bangladesh (Figure 4).

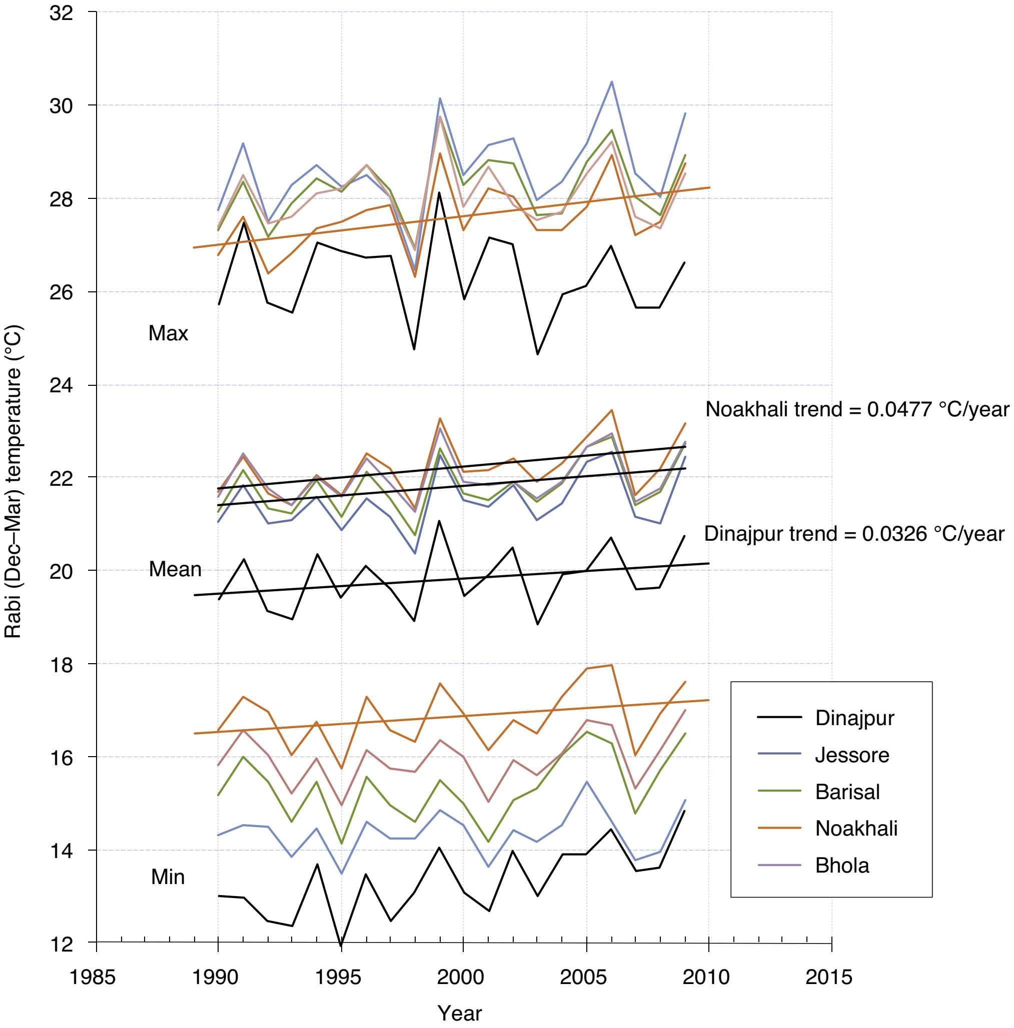


Figure 10. Average maximum, minimum and mean Rabi (December to March inclusive) temperatures for the past 20 years for the inland/northern regions/towns of Dinajpur and Jessore, and the southern coastal regions of Barisal, Bhola and Noakhali. The year on the graph is for the end of Rabi, i.e. '1990' is the 1989–90 Rabi. (Source data from Bangladesh Meteorological Department)

Future warming in Bangladesh

The Organisation for Economic Co-operation and Development (Agrawala 2003) estimated a rise of 1.4 °C by 2050 accompanied by sea-level rise, increased evapotranspiration losses, enhanced monsoon precipitation and run-off, potentially reduced dry-season precipitation and an increase in cyclone intensity. The current assessment for Bangladesh by the Intergovernmental Panel on Climate Change (IPCC 2007) predicts warming of 1.5–2.0 °C by 2050, with increased rainfall of 10–15% (2030) and increased evaporation of 12%. A study by Islam (2009), using 34 Bangladesh Meteorological Department (BMD) climate sites, estimated increases in temperature over the past 100 years for all Bangladesh of 0.62 °C (maximum temperature) and 1.54 °C (minimum) with extreme increases of 3.4 °C (minimum) occurring in

Table 1. Average mean temperatures during the Rabi season for the locations in Figure 9 (plus Patuakhali) comparing southern sites against Dinajpur (north) and estimating temperature rise by 2050

Location	Average temperature (°C)	°C hotter than Dinajpur	Crop °Cd greater than at Dinajpur (°C*100d)	Days crop needs less than at Dinajpur	Temperature change 1990–2009 (°C/year)	Temperature change 2050 (°C over 1990)
Dinajpur	19.82	0	0	0	+0.0326	+1.96
Jessore	21.48	1.66	166	7.7	+0.0373	+2.24
Barisal	21.79	1.97	197	9.0	+0.0379	+2.27
Bhola	22.01	2.19	219	10.0	+0.0219	+1.31
Noakhali	22.22	2.40	240	10.8	+0.0477	+2.86
Patuakhali	22.27	2.45	245	11.0	incomplete data	
Average	21.60				+0.035	+2.13

Source: data from the Bangladesh Meteorological Department

February. A regression analysis of 20 years of daily climatic data for the regional locations discussed in this chapter, and presented in Figure 10, indicates a mean temperature rise of 0.66 °C since 1990. To extend the current temperature trends beyond 2009, a linear extrapolation is applied to each location. This simple analysis results in an estimated rise of 2.13 °C by 2050 over 1990 levels and is comparable with current IPCC estimates. Within the 20-year period covered by the regression analyses, carbon dioxide (CO_2) in the atmosphere, as a major contributor driving temperature rise, has risen from 355 to 390 parts per million by volume (ppmv) and is currently rising at about 2 ppmv/year (NOAA 2011). However, the solar cycle is just completing its 11-year low phase, the phase which has been linked with some atmospheric cooling (Marshall 2010). The rate at which atmospheric CO_2 levels continue to increase will directly influence global temperature trends and therefore the accuracy of future projections. Nevertheless, Bangladesh can expect a rise in temperature in the order of 1.4–2.3 °C by 2050, which means that the Dinajpur growing temperature for wheat will become as it is in Barisal and Bhola now. Noakhali will average 25 °C during Rabi.

How increases in CO_2 affect wheat growth

So can the positive effects of increased CO_2 on growth and yield offset the negative effects of increased temperature? Plants respond to higher atmospheric concentrations of CO_2 through a reduction in leaf stomatal conductance, reducing evapotranspiration or the flow of water through the plant which results in more efficient use of water by a crop. Water-use efficiency of a crop is important in water-limited environments, but the more obvious effect of more CO_2 is the direct boost to photosynthesis and yield. Experimental results from Australia have demonstrated a 35% increase in yield with a doubling of CO_2 from 350 to 700 ppmv when temperature remains the same (Rawson 1992). Were it not for the effects of CO_2 on atmospheric warming, this would be good news for wheat, as CO_2 is the primary source of carbon for photosynthesis. Current IPCC (2007) projections for greenhouse gas emissions predict a doubling of CO_2 by 2100 (in the absence of additional climate mitigation policies) and an increase of 1.5–4.5 °C by 2050. In the early 1990s, field experiments were undertaken with wheat crops enclosed in long, plastic, temperature-gradient tunnels (Rawson 1995). These crops were exposed throughout growth to 350 or 700 ppm CO_2 and to a temperature rise of 2.5–3.0 °C. The temperature rise was against an average temperature background for the full season of 22 °C, equivalent to southern Bangladesh Rabi temperatures (Table 1), but radiation averaged 19 MJ/m^2/day up to anthesis, equivalent to March radiation in Bangladesh. Two wheat varieties were used, the high-yielding cultivar Hartog and a late-maturing variant of Hartog called Late Hartog. Late Hartog was included to see whether yield loss due to increased temperature was associated with faster development and shortened duration. Increasing crop duration helped offset the effects of increased temperature on grain yield as demonstrated for Late Hartog in Figure 11.

Increased temperature reduced yield by 30–40%, while doubling CO_2 increased yield by 15–40%; increased variety duration also increased yield (Figure 11). Doubling CO_2 did not quite recoup the effects of increased temperature in the short-duration variety Hartog but did so in the later variety. While this study

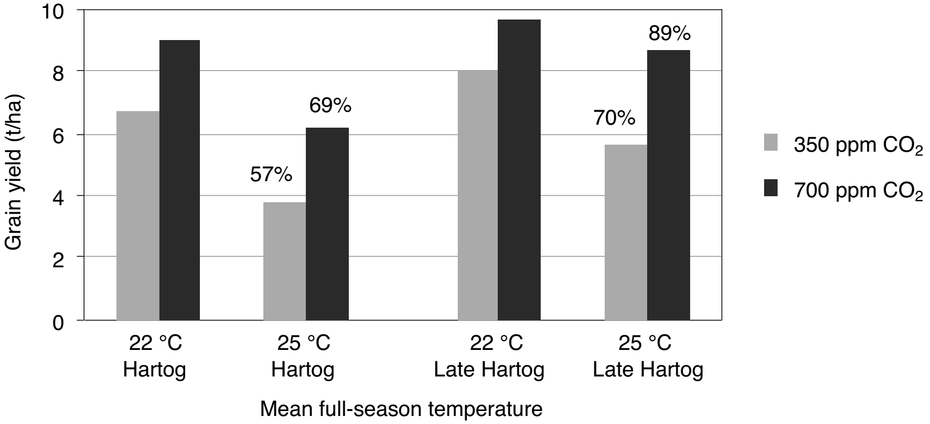


Figure 11. Effects on field wheat yield of doubling CO_2 from 350 to 700 ppm and increasing mean temperature from 22 to 25 °C in wheat variety Hartog and its late-maturing variant Late Hartog (redrawn from Rawson 1995). Percentages are the relative yields less losses due to increased temperatures.

has weaknesses through some of its uncontrolled field variables, it does indicate that if all global warming were due to CO_2, the increased CO_2 would largely offset the negative temperature effects on yield.

In the future, higher CO_2 efficiencies could be gained through use of crops with the C_4 photosynthetic pathway. In field studies that compared the carbon fixation and water use of a C_3 with a C_4 crop, carbon fixation per unit leaf area was around 2.3 times greater in the C_4 crop while water used to achieve this was much less (Rawson et al. 1978). Ways to improve photosynthetic pathways are discussed by MacKenzie (2010). However, these types of cross-species genetic manipulations of C_4 photosynthesis into C_3 plants as discussed by Leegood (2002) are complex and have potentially long lead times of 20–40 years before they arrive at the farm as usable varieties.

How balance between temperature and solar radiation (and CO_2) affects yield

Poor yields in hot regions like Bangladesh are usually blamed on high temperature. This assumption has been confirmed by careful observations and experimentation (Warrington et al. 1977; Muchow et al. 1990; Al-Khatib and Paulsen 1999). But in many such studies, temperature has been changed while radiation has remained constant, thus changing the balance between temperature and radiation. In controlled environment studies in which temperature was doubled (base 0 °C) and radiation kept in proportion, biomass production in thermal time was unchanged by temperature (Rawson 1990b).

Temperature affects plants primarily by altering their rate of development (Wardlaw et al. 1980). So, as temperature increases, leaves and tillers appear faster, spikelets and florets on the primordial ears arise more quickly, and heading happens earlier. Because the rate of development increases with temperature, for plant size to be maintained, the rate of availability of substrates (solar radiation, water, nutrients) for the production of carbon must also increase in proportion. This idea of the balance between temperature and substrate availability setting growth and yield is the basis of the photothermal quotient (PTQ) (Nix 1976; Rawson 1987) and is used as one driver of growth in the Agricultural Production Systems Simulator (APSIM) model (Keating et al. 2003). PTQ uses a summation of solar radiation over the 3 weeks before anthesis to assess substrate (photosynthate) availability, and a summation of mean daily temperature over the same period to ascertain growth rate. Substrate divided by rate provides the PTQ. Yields of diverse wheat crops from New Zealand to Bangladesh with very different growing conditions fit this relationship well (Figure 12; Peake and Angus 2009). The values for Bhola (Figure 12) are calculated from temperature and solar radiation data presented in Figures 9 and 10, with measured grain yields from experimental farm sites at Bhola (data reported in Chapter 3.3, this volume).

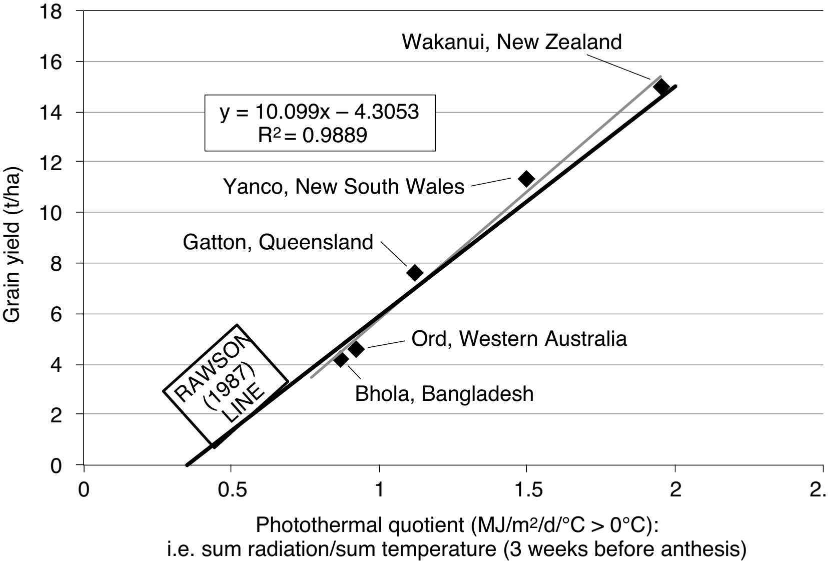


Figure 12. Grain yield as related to the balance between temperature and radiation at various global locations (Source: Peake and Angus 2009, using an earlier photothermal quotient relationship from Rawson 1987)

This relationship demonstrates a yield response to increased radiation in relation to temperature (primarily through increases in day length) or as temperature reduces in relation to day length. CO_2 doubling adds about 4 MJ/m²/d equivalents to the numerator (Rawson 1995).

The future

Of real concern for Bangladesh is that temperature is increasing (Figure 10) in line with predicted global climate change (IPCC 2007) and levels of solar radiation intercepted by crops may be subject to increasing levels of atmospheric pollution during Rabi. Both of these trends have the potential to reduce grain yield (Figure 12), although the CO_2 effect will modulate the former to a small extent. In the future, Bangladesh crops will require improved radiation-use efficiency to keep grain yield steady or increasing. With the national average wheat yield of 2.1 t/ha (2008), then 4 t/ha yields achieved on Bhola as predicted by current PTQ is a lot of wheat that could be produced in the south if the crop were grown with optimal agronomy. Chapter 2.2 (this volume) assesses whether soil and water constraints in the south will allow the achievement of yields that are possible within the climate envelope.

References

Agrawala S., Ota, T., Ahmed A.U., Smith J. and van Aalst M. 2003. Development and climate change in Bangladesh: focus on coastal flooding and the Sundarbans. Organisation for Economic Co-operation and Development: Paris. Accessible at <http://www.oecd.org/dataoecd/46/55/21055658.pdf>.

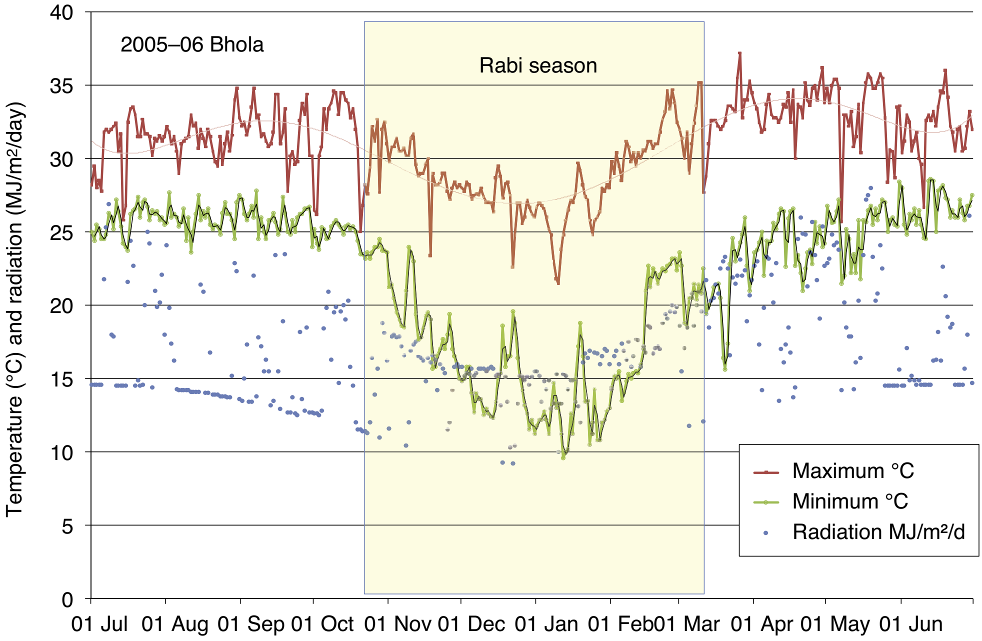
Angstrom A. 1924. Solar and terrestrial radiation. Quarterly Journal of the Royal Meteorological Society 50, 121–125.

Evans L.T. 1978. The influence of irradiance before and after anthesis on grain yield and its components in microcrops of wheat grown in a constant daylength and temperature regime. Field Crops Research 1, 5–19.

Hossain M., Naher F. and Shahabuddin Q. 2005. Food security and nutrition in Bangladesh: progress and determinants. Journal of Agricultural and Development Economics 2(2), 103–132.

IPCC (Intergovernmental Panel on Climate Change) 2007. Climate change 2007: synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri, R.K and A. Reisinger (eds)]. IPCC: Geneva, Switzerland, 104 pp.

Islam A.S. 2009. Analyzing changes of temperature over Bangladesh due to global warming using historic data. Young Scientists of Asia Conclave, Jawaharlal Nehru Centre for Advanced Scientific Research (JNCASR), 15–17 January, Jakkur, Bangalore.



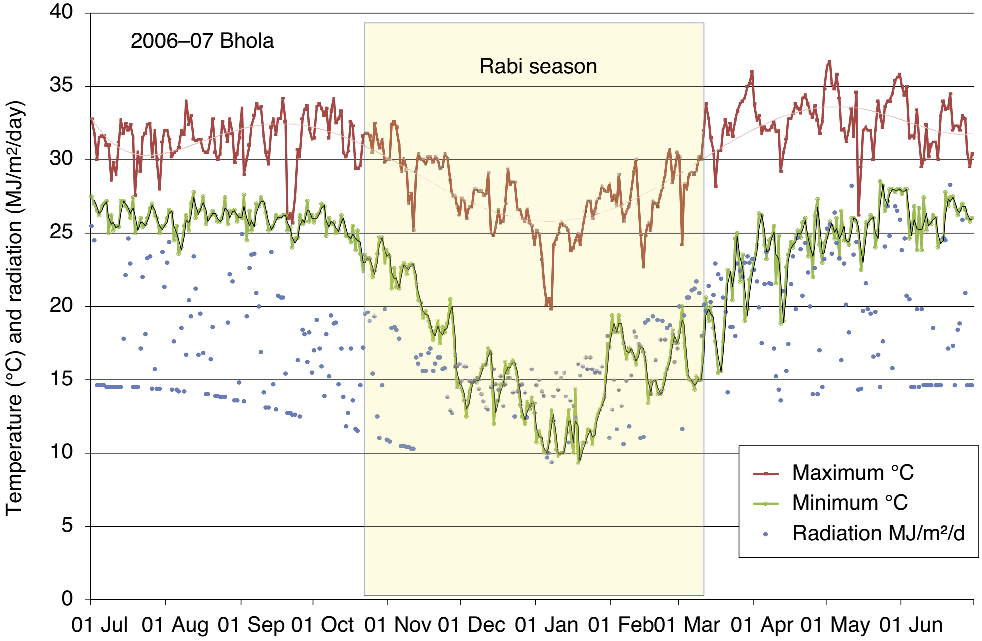


Figure 13. Bhola temperatures and radiation 2005–08 (Source data: Bangladesh Meteorological Department)

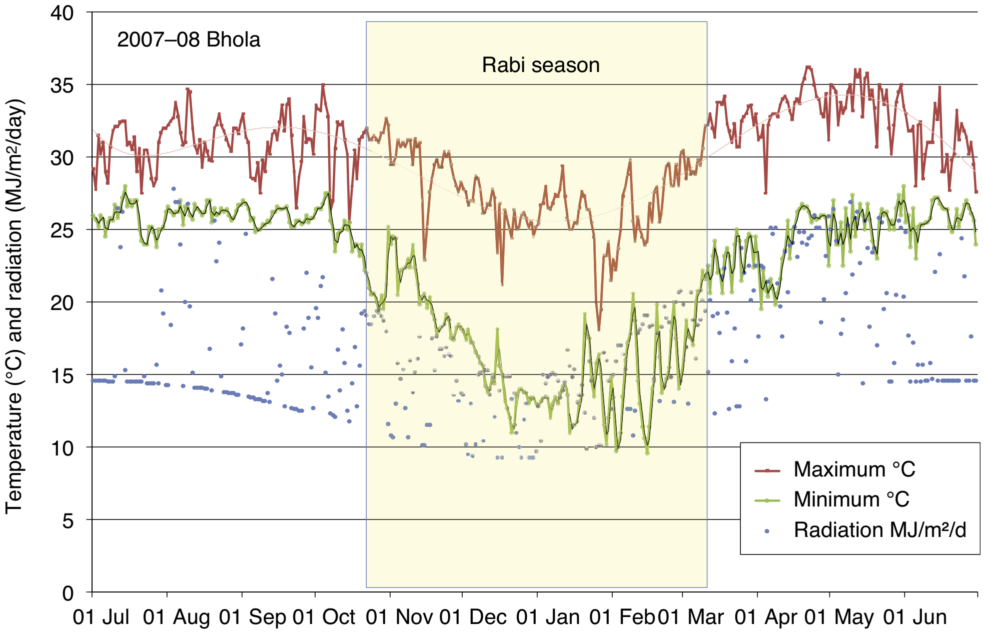


Figure 13. (continued)

Islam T. and Peterson R.E. 2009. Climatology of landfalling tropical cyclones in Bangladesh 1877–2003. Journal of Natural Hazards 48, 115–135.

Keating B.A., Carberry P.S., Hammer G.L., Probert M.E., Robertson M.J., Holzworth D., Huth N.I., Hargreaves J.N.G., Meinke H., Hochman Z., McLean G., Verburg K., Snow V., Dimes J.P., Silburn M., Wang E., Brown S., Bristow K.L., Asseng S., Chapman S., McCown R.L., Freebairn D.M. and Smith C.J. 2002. The Agricultural Production Systems Simulator (APSIM): its history and current capability. European Journal of Agronomy 18, 267–288.

Khalil G.M. 1992. Cyclones and storm surges in Bangladesh: some mitigative measures. Natural Hazards 6, 11–24.

Kumari B.P., Londhe A.L., Daniel S. and Jadhav D.B. 2007. Observational evidence of solar dimming : offsetting surface warming over India. Geophysical Research Letters 34, 1–5.

Leegood R.C. 2002. C_4 photosynthesis: principles of CO_2 concentration and prospects for its introduction into C_3 plants. Journal of Experimental Botany 53(369), 581–590.

Ligr M., Ron C. and Natr L. 1995. Calculation of the photo period length. Computer Applications in the Biosciences 11, 133–139.

MacKenzie D. 2010. Supercrops. New Scientist 207, 41–43.

Marshall, M. 2010. The sun joins the climate club. New Scientist 207, 10–11.

Monteith J.L. 1994. Validity of the correlation between intercepted radiation and biomass. Agricultural and Forest meteorology 68, 213–220.

Muchow R.C., Sinclair T.R. and Bennett J.M. 1990. Temperature and solar radiation effects on potential maize yield across locations. Agronomy Journal 82(2), 338–343.

Muchow R.C., Spillman M.F., Wood A.W. and Thomas M.R. 1994. Radiation interception and biomass accumulation in a sugarcane crop grown under irrigated tropical conditions. Australian Journal of Agricultural Research 45, 37–49.

Nix H.A. 1976. Climate and crop productivity in Australia. Pp. 495–507 in 'Climate and rice', ed. by S. Yoshida. International Rice Research Institute: Los Baños, the Philippines.

Peake A.S. and Angus J.F. 2009. Increasing yield of irrigated wheat in Queensland and northern NSW. Grains Research and Development Corporation: Canberra. Accessible at: <http://www.grdc.com.au/director/events/researchupdates?item_id=C74251AFAF66F58B897D33A8CACEB22E&pageNumber=1>.

Rahman M.M. and Khan S.I. 2005. Food security and nutrition in Bangladesh. Pp. 7–15 in 'Food Availability Workshop Proceedings, Dhaka, 19–20 October 2005'.

Figure 14. Map featuring major administrative districts of Bangladesh. Wheat cultivation areas (red dots) for the 2007–08 Rabi season are indicated and demonstrate regional differences between the traditional northern wheat growing regions and the southern regions bordering the Bay of Bengal. Dinajpur, discussed in the text, is in the far north-west of the country. (Reproduced from WFP 2010)

Ministry of Food and Disaster Management Bangladesh and United Nations World Food Programme: Dhaka.

Rawson H.M. 1986. High-temperature-tolerant wheat: a description of variation and a search for some limitations to productivity. Field Crops Research 14, 197–212.

Rawson H.M. 1987. Constraints associated with rice–wheat rotations: effects of high temperatures on the development and yield of wheat and practices to reduce deleterious effects. Pp. 44–62 in 'Wheat production constraints in tropical environments'. Proceedings of International Conference. International Maize and Wheat Improvement Center (CIMMYT): Chiang Mai, Thailand.

Rawson H.M. 1990. Potential opportunities for rural industries: field crops. Rural Industries workshop on climate change. Bureau of Rural Resources Report R/3/90, 20–24.

Rawson H.M. 1990. High temperature is not a stress. Pp. 923–928 in 'Proceedings of the International Congress of Plant Physiology, New Delhi, India, 15–20 February 1988', ed. by S.K. Sinha, P.V. Sane, S.C. Bhargava and P.K. Agrawal, volume 2.

Rawson H.M. 1992. Plant responses to temperature under conditions of elevated CO_2. Australian Journal of Botany 40, 473–490.

Rawson H.M. 1995. Yield responses of two wheat genotypes to carbon dioxide and temperature in field studies using temperature gradient tunnels. Australian Journal of Plant Physiology 22, 23–32.

Rawson H.M., Turner N.C. and Begg J.E. 1978. Agronomic and physiological responses of soybean and sorghum crops to water deficits. IV. Photosynthesis, transpiration and water use efficiency of leaves. Australian Journal of Plant Physiology 5, 195–209.

USDA (United States Department of Agriculture) 2009. Bangladesh grain and feed annual 2009. Global Agriculture Information Network (GAIN) Report No. BG9003. USDA Foreign Agricultural Service: Washington DC. Accessible at <http://www.fas.usda.gov/gainfiles/200902/146327245.pdf>.

Wardlaw I.F., Sofield I. and Cartwright P.M. 1980. Factors limiting the rate of dry matter accumulation in the grain of wheat grown at high temperature. Australian Journal of Plant Physiology 7, 387–400.

Warrington I.J., Dunstone R.L. and Green L.M. 1977. Temperature effects at three developmental stages on the yield of the wheat ear. Australian Journal of Agricultural Research 28, 11–22.

WFP (United Nations World Food Programme) 2010. Agricultural production & national food balance, Bangladesh. WFP: Rome. At <http://foodsecurityatlas.org/bgd/country/availability/agricultural-production>, accessed 12 April 2011.

2.2 Soil and water

Neal P. Dalgliesh and Perry L. Poulton

Abstract

Because of high temperatures and a short dry season, southern Bangladesh has not been seen by policymakers, extension agencies or farmers as a region suited to the production of wheat and pulses during the dry Rabi season. Northern Bangladesh, with its cooler dry-season temperatures and longer growing season, has always been considered the 'bread basket' of the nation. However, as a result of population pressures and national food security issues, interest in more fully exploiting the south's agricultural potential is increasing.

The main food-producing areas of the south fall within two main agroecological zones: the Ganges Estuarine Floodplain in the south-west and the more recently formed Young Meghna Estuarine Floodplain to the south-east. The main soils within these two zones are the calcareous grey floodplain soils and the calcareous alluvium of which there is a total area of over 2 million ha. While these soils have a capacity to store approximately 140 mm of available water for crop production, their nutritional status tends to be low, resulting in the need to apply nutrients to achieve high yield.

It has been estimated that over 800,000 ha of land of a suitable elevation class (medium–high and medium–low lands) is underutilised during the Rabi season and available for increased agricultural production. Research indicates that wheat yields of greater than 3 t/ha are achievable under good management across much of southern Bangladesh. Salinity is often raised as a major southern constraint, however, in general, the issue relates to the newly formed char lands adjacent to the Bay of Bengal in the far south, and lands vulnerable to tidal surge: around 60% of soils in the south-west and 15% in the south-east are salt affected to some degree. While reductions in wheat yield are in the order of 1 t/ha in salt-affected areas, the episodic nature of rainfall and flooding, and the consequent seasonal leaching of salts, still allows for economically significant crop production in the region.

Due to the slower pace of development in the south, irrigation infrastructure is less advanced than in the north where increasing production of irrigated boro rice has been achieved through exploitation of the underground aquifer. While a lack of infrastructure could be considered a constraint of the south, research indicates that it is compensated for by the wheat crops' ability to access shallow watertables, which underlie much of the region and contribute up to 3 mm/day to crop production through capillary rise. This, together with the 140 mm of water stored in the soil and available to germinate and establish the crop after sowing, means that optimal yields can be achieved from a single irrigation applied with a nitrogen top-dressing 20 days after sowing. This is a sustainable system.

Consequently, the south of Bangladesh has the potential to contribute significantly to national food security and to the livelihoods of subsistence farmers through increased Rabi production. Large areas of suitable land and soils with sufficient water are available and, while temperatures are higher than in the north and the season shorter, significant yields are achievable where good farm management is practised.

Introduction

Wheat in Bangladesh has traditionally been grown under irrigation in the cooler northern regions of the country, relying on groundwater reserves for optimal production. Wheat competes for land and water resources with a range of other Rabi (dry) season crops including boro rice, maize and pulses. Boro rice is predominant, using the majority of available resources and supplying 16 million t (2008–09) or >50% of national rice production (USDA 2009). However, the heavy demand for water for rice production, where individual crops may require up to 30 irrigations, is placing the water resource under stress. Currently, increased supply is being met through the installation of additional tube wells; however, this is not sustainable, with extraction levels above the extraction–recharge equilibrium (Harvey et al. 2006).

In comparison, southern Bangladesh has never been considered, from either the biophysical or resource-supply perspective, as a suitable environment for widespread production of wheat. Growing-season temperatures have been considered too hot, the soils too saline, and the growing season too short for high yield. This has resulted from the perception that the late harvest of Kharif (wet) season rice, transplanted (T.) aman, and wet soil conditions precluded the sowing of wheat within the optimal northern planting window of mid to late November. Consequently, while boro rice has been the predominant Rabi-season crop, there has been relatively limited investment in tube wells and irrigation infrastructure, with 71% of production undertaken using water sourced from the sometimes-limited surface storages and canals.

Despite the lack of irrigation infrastructure and the longstanding view that southern wheat production was not feasible, researchers again began to explore its potential as a result of increasing domestic demand (approximately 4 million t/year) and declining national production (<0.844 million t in 2007–08) (WFP 2010).

Preliminary studies funded by the Food and Agriculture Organization of the United Nations (FAO) in 2003–05 and Australian Centre for International Agricultural Research (ACIAR) (2005–06) indicated that there may be significant areas (800,000 ha) of underutilised fallow land in southern Bangladesh during the Rabi season which had the potential to contribute significantly to national food security (Rawson et al. 2007; Carberry et al. 2008). Research results from this period supported the premise that there was potential for wheat in the south; in particular, where varieties were used that have improved disease resistance and increased tolerance to soil salinity and high growing-season temperatures.

Natural resource availability for increased Rabi-season crop production

A companion chapter of this report (2.3) calculated that approximately 850,000 ha of land in the south currently remain fallow during Rabi, a similar area to that estimated in the previous FAO and ACIAR studies (Chapter 1.1, this volume). They indicated that wheat crops could be managed within the constraints of climate to produce economic yields on those lands. The current chapter discusses two other components of the natural system essential to southern crop production:

- the agronomic suitability of the soil resource identified as being potentially available for increased Rabi-season production
- the availability of water resources to sustain increased Rabi-season production at a level both financially and socially attractive to farmers.

The soils resource

Bangladesh is located in the delta of three of the major river systems of South Asia: the Ganges, the Brahmaputra and the Meghna. These river systems drain an area of some 1.76 million km^2 with their sediments forming 80% of the land area of Bangladesh (FAO/UNDP 1986). The majority of the country's broad-scale agriculture, and therefore its national food security, is dependent on these alluvial soils.

Soil type, texture and distribution

The cropping soils of southern Bangladesh fall into two groups: the calcareous alluvium which are more recently laid alluvial deposits located predominately in the districts of Bhola and Noakhali (falling within the Young Meghna Estuarine Floodplain agroecological zone (AEZ)) and earlier depositions described as calcareous grey and dark grey floodplain soils, which are found in the districts of Barisal, Patuakhali, Jhalakati and Pirojpur (part of the Ganges Estuarine Floodplain AEZ) (Figure 1). The soils in all districts are fine-textured alluvial deposits ranging from silty loams to silty clay loams with little evidence of horizon formation (FAO/UNDP 1986, 1988) (Figure 2 and Table 1).

Impact of land elevation on crop choice

While the mean elevation of the river and estuarine flood plains of southern Bangladesh ranges between 1 and 3 m (Rashid 1991), relatively small variations in elevation have a major impact on land use. Land types are described in terms of depth of wet-season inundation, with six classifications in use (Table 2) (BARC 1999). Land inundation type is particularly significant at the end of the monsoon period when Kharif-season rice is being harvested and cropping decisions are made for the subsequent Rabi season.

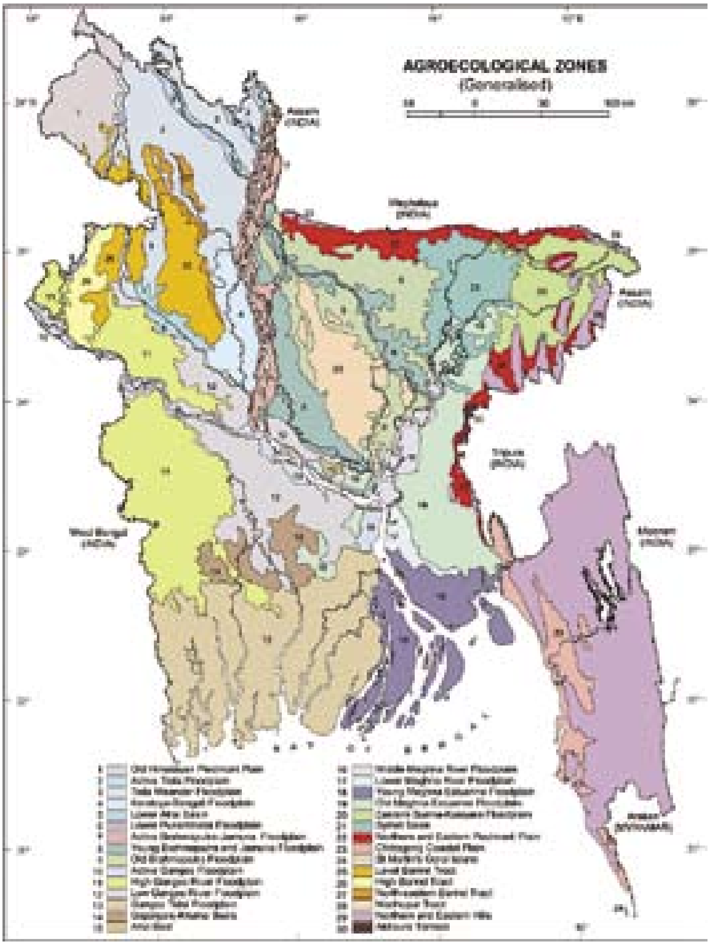


Figure 1. The southern region of Bangladesh, where there is potential for increased Rabi-season crop production, falls within two agro-ecological zones: the Ganges Estuarine Floodplain (13) (Barisal, Patuakhali, Barguna and Jhalakati) and the more recently deposited Young Meghna Estuarine Floodplain (18) (Bhola and Noakhali districts) (Reproduced from FAO/UNDP 1988)

Low and very low lands are used by farmers for boro rice production due to the longer wet-season inundation periods and residual surface water; together these are considered to improve crop establishment and overall water-use efficiency. High lands, on the other hand, which are normally above inundation level, are selected by farmers for domestic use, cattle production and high-value fruit and vegetable cropping. Consequently, the land classifications which are most likely to be available for the production of crops such as wheat tend to be in the medium–high and medium–low categories. These lands drain early enough for wheat to be sown within the recommended southern planting window of mid November to mid to late December (Chapter 3.3, this volume). Poulton (Chapter 2.3, this volume) indicates that there are 2.7 million ha of such suitable arable land in the 20 upazilas of the south. Currently, 32% of this land (0.85 million ha) remains in fallow during the Rabi season with 55% (0.48 million ha) located within the seven districts in which the research described in this volume was undertaken.

Nutrient supply

The average cropping intensity in Bangladesh is approximately 1.7 crops/year, with up to 3 crops/year being common for particular cropping sequences.

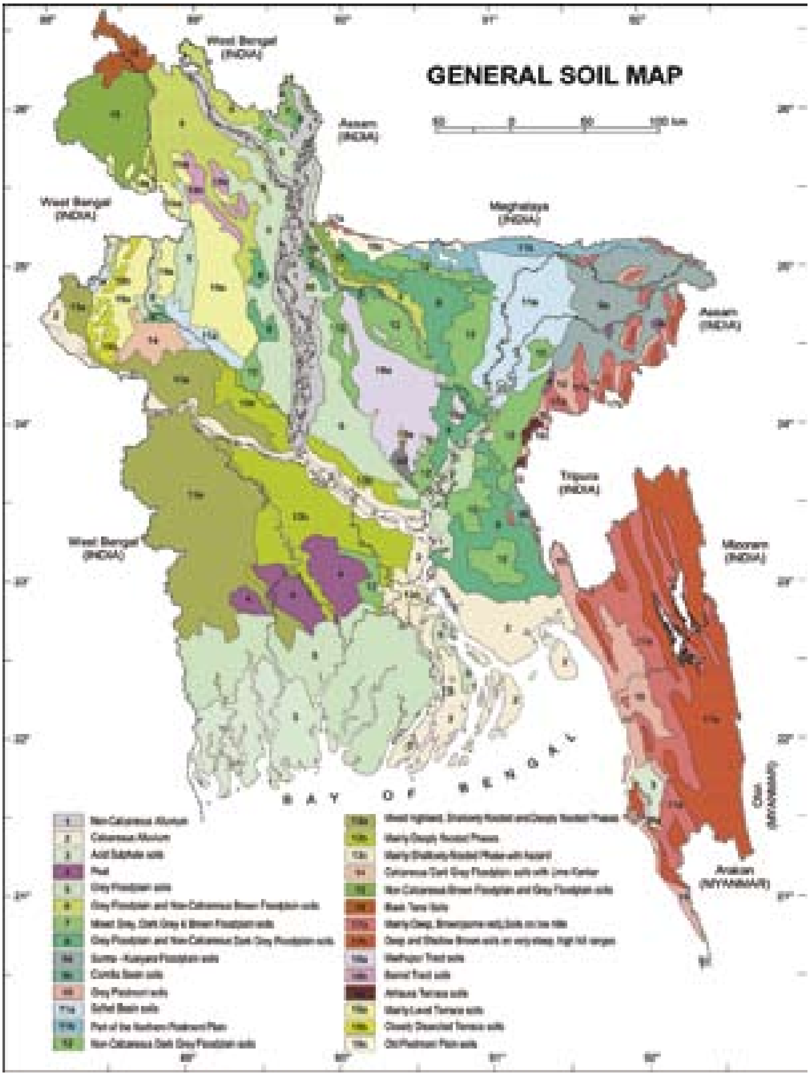


Figure 2. Soils map of Bangladesh showing the distribution of calcareous alluvium (2) and calcareous grey floodplain soils (5) in the south (Reproduced from FAO/UNDP 1986)

This results in high levels of nutrient removal and inadequate replacement through mineralisation and applications of fertiliser from either organic or inorganic sources (Hobbs and Morris 1996; Adhikari et al. 1999). Routine soil monitoring undertaken before crop planting, as well as directed nutrient-management research undertaken during the course of the current research, supports this premise. As an example, Figure 3 provides data for soils collected at trial sites in the Barisal and Noakhali districts at the time of wheat planting in December 2005. The mean nitrate nitrogen (NO_3-N) levels of <10 kg/ha, found to a depth of 150 cm at three of the locations, is low (Figure 3a), while the 40 kg/ha found in the profile at Kashipur still provides less than half of the nitrogen requirements of a 3 t/ha (at a protein content of 10%) wheat crop. Given that 35 kg/ha N is required for each tonne of wheat grain produced, such

Table 1. Description and distribution of alluvial soils used for crop production in southern Bangladesh

Soil type	Physical information	Area of soil type (ha)
Calcareous grey and dark grey floodplain	Silty loam to silty clay loam on river banks to silty clays in basins; lime through profile	1,605,445
Calcareous alluvium	Stratified or raw alluvium throughout; no soil horizons; calcareous grey to olive finely stratified silts	591,796

Source: FAO/UNDP (1986)

Table 2. Land inundation types and depth of water inundation during the Kharif (wet) season in Bangladesh

Land inundation type	Depth of inundation
High	Above normal inundation level
Medium–high 1	Normally inundated up to 30 cm depth
Medium–high 2	Normally inundated 30–90 cm depth
Medium–low	Normally inundated 90–180 cm depth
Low	Normally inundated 180–300 cm depth
Very low	Normally inundated >300 cm depth

Source: BARC (1999)

a crop would require at least 105 kg/ha N, assuming a nitrogen-use efficiency of 50% (Dalgliesh and Foale 1998).

It should also be noted, however, that the monitoring of NO_3-N accounts for only a portion of crop N supply in soils that are submerged for a prolonged period as part of irrigated rice-based farming systems. In the anaerobic soil conditions present in submerged systems, inorganic N is not converted from ammonium (NH_4^+) to NO_3^-, resulting in the NH_4^+ being of more importance to the N balance than would be the case in drained aerated soils (Buresh et al. 2008). While, by the time of wheat planting, soils are in a drying phase, it is considered likely that there will be more N present in the ammonium form than would otherwise be the case. However, due to logistical issues relating to the collection, appropriate storage and transport of samples to the laboratory, NH_4-N was not measured.

Soils in southern Bangladesh generally have a pH within the range considered suitable for unrestrained crop production. This is reflected in the data for the four sites provided as examples in Figure 3b with pH values of between 6 and 8 (water 1:5) for the full 150 cm soil profile. Organic carbon levels of 0.80–1.25% (Walkley and Black analysis) (Walkley and Black 1934; Walkley 1947) found in the top 15 cm of the soil (Figure 3c) are likely to result in levels of mineralisation and nutrient supply below those required to sustain the average Bangladesh cropping intensity of 1.7 crops/year. The need for additional nutrient supply is reflected in the Wheat Research Centre (WRC) fertiliser recommendations for wheat, which advise the application of fertiliser at the rates of: nitrogen (100 kg/ha), phosphorus (27 kg/ha), potassium (50 kg/ha), sulfur (20 kg/ha), boron (1 kg/ha), calcium (36 kg/ha) and, in zinc-deficient soils, zinc (4 kg/ha). While the organic carbon levels are lower than optimal, they are by no means uncommon in cereal production systems around the world where, apart from grain removal, carbon is also removed as biomass for animal feeding and to facilitate farming practice, i.e. to provide physical access to tillage equipment (Dalal and Mayer 1986). The situation is likely to be further exacerbated in Bangladesh as a result of higher breakdown rates of organic material and potential nitrogen losses through leaching and denitrification resulting from the hot and moist environmental conditions experienced for much of the year (Kirschbaum 1995; Huth et al. 2010).

Soil salinity

There are two dimensions to salinity, the concentration of salt in the soil at a particular point in the growing season and the temporal change in concentration as the season progresses, a result of the upward movement of water and salt in the soil through capillary rise (see Figures 5 and 6). Threshold levels for salt impact on plant growth of 0.3 dS/m

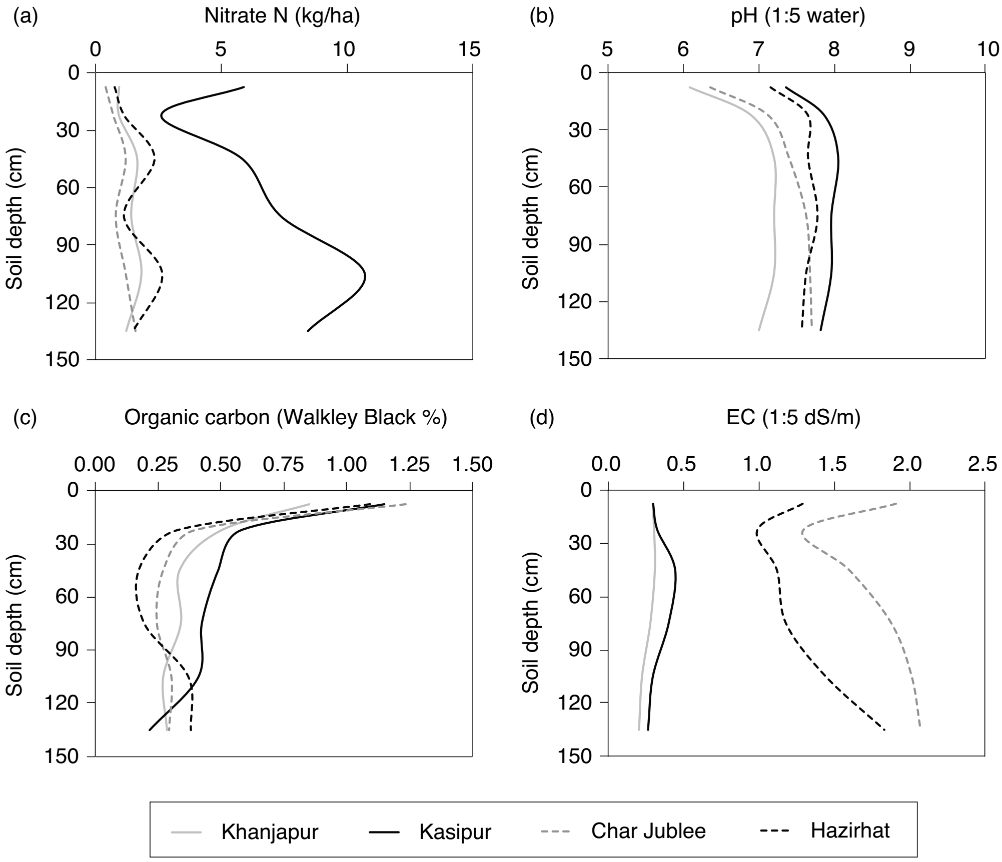


Figure 3. Soil analysis in November 2005 before the planting of wheat at four villages in two districts of southern Bangladesh; Khanjapur and Kasipur in Barisal district and Hazirhat and Char Jublee in Noakhali district. Analyses were for soil depths down the profile of 0–15, 15–30, 30–60, 60–90, 90–120 and 120–150 cm: (a) nitrate nitrogen (NO_3-N), showing levels of NO_3-N for the full profile of 6–10 kg/ha at Khanjapur, Hazirhat and Char Jublee and 40 kg/ha at Kasipur; (b) pH in water (1:5); (c) organic carbon (Walkley Black %); and (d) electrical conductivity ($EC_{1:5}$ dS/m)

measured as electrical conductivity ($EC_{1:5}$) for the soil surface (10 cm) and 0.7 dS/m for deeper in the profile are suggested by Dang (2007) in the report 'Combating subsoil constraints'. The data provided as an example in Figure 3d show benign EC levels of approximately 0.3 dS/m in the surface and <0.5 dS/m at depth for the Barisal sites at wheat planting in December, whereas the concentrations at Noakhali are high in both the surface and subsurface and would retard plant growth through restriction of water and nutrient uptake. As the season progresses it could be expected that surface salt levels would rise at all sites through the impacts of capillary rise (see Figure 6).

Distribution

Approximately 60% of arable lands in the south-west and 15% in the south-east of Bangladesh may be affected by salinity in dry periods (Tables 3 and 4, Figure 4) (Rahman and Bhattacharya 2006). Salinity at levels potentially detrimental to plant growth are most likely to occur in the low, more recently formed char lands in districts that border the Bay of Bengal, including Noakhali, southern and central Bhola, Patuakhali, Jhalakati, Barguna and Pirojpur (see Table 3 for examples of salt levels in the Noakhali villages of Char Jublee and Hazirhat), although lands up to 180 km from the sea may also be affected (Haque 2006).

Capillary rise of salt

Salt in agricultural land comes from direct inundation by sea water, tidal flooding during the monsoon season and the upward or lateral movement of saline groundwater during the Rabi season (Haque 2006). While direct inundation and tidal surge are important contributors to decline or total loss of crop production, the most common contributor to yield reduction in Rabi-season crops occurs through capillary rise (Rahman and Bhattacharya 2006) (Figure 5).

At the end of the monsoon season, as Rabi crops are planted, surface soil salinity levels are usually low, a result of the dilution of salt deposits during the monsoon and their leaching below the root zone.

Table 3. Salinity concentration range for surface water and surface soils in the districts of southern Bangladesh, ranked from highest to lowest soil salinity

District	Surface water (mg/kg)	Surface soil (mg/kg)	District	Surface water (mg/kg)	Surface soil (mg/kg)
Khulna	5–>10	8–>15	Gopalganj	<1	0–15
Patuakhali[a]	1–10	8–>15	Jessore	<1	4–8
Bagerhat	5–>10	4–>15	Jhalakati[b]	<1	4–8
Bhola[b]	1–10	4–>15	Lakshmipur	<1	4–8
Barguna[b]	1–5	4–>15	Narail	0	<4–8
Noakhali[a]	<1–10	0–>15	Chittagong	0–<1	0–8
Satkhira[a]	5–<10	4–<15	Barisal[b]	0	0–4
Cox's Bazar	<1	>15	Chandpur	<1	0
Feni	0–10	0–15	Shariatpur	<1	0
Pirojpur[b]	0–10	0–15			

[a] Districts in which wheat varieties were also screened for salinity tolerance

[b] Districts in which the ACIAR-funded project tested for increased Rabi-season crop production

Source: SRDI (2001)

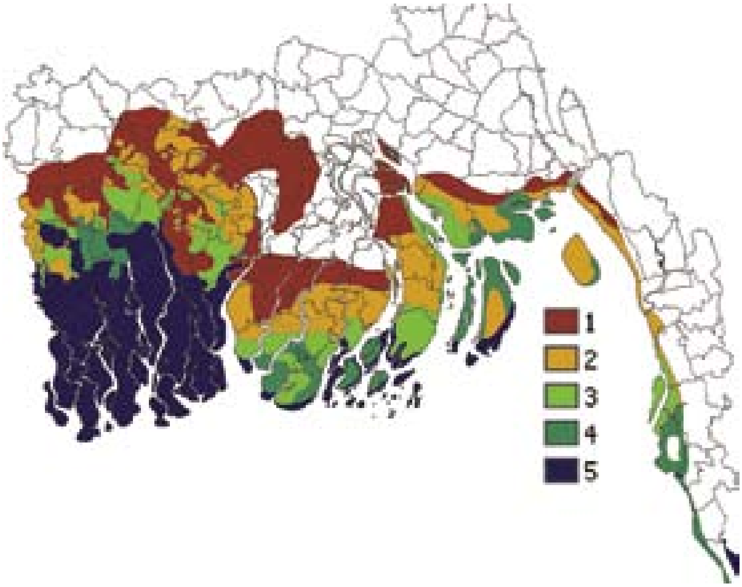


Figure 4. Soil electrical conductivity (EC) or salinity classes for coastal regions of southern Bangladesh: (1) very slightly saline (2.1–4.0 dS/m); (2) slightly saline (4.1–8.0 dS/m); (3) moderately saline (8.1–12.0 dS/m); (4) strongly saline (12.1–15.0 dS/m); (5) very strongly saline (>15.0 dS/m) (Source: Bangladesh Agricultural Research Council GIS project BGD/95/006)

However, as the season progresses, salt within the root zone increases (Figure 6) as it rises by capillary action from the shallow and saline watertables that underlie much of the southern production area. This episodic variation in surface salt concentration allows crops such as wheat to be planted and successfully established while concentrations are low and to be grown into an environment of increasing salinity.

Groundwater data obtained from the Bangladesh Water Development Board (BWDB) and from 41 ACIAR-project on-farm research sites during the 2007–08 and 2008–09 seasons, indicate that watertables under southern cropping areas are commonly sufficiently shallow for capillary rise to be an important contributor to crop water supply and, as a consequence, to seasonal soil salinity. The above monitoring programs indicate that the watertable at crop sowing in November/December is usually around 1 m below the soil surface and 1.5–3.0 m by crop maturity in March (Figures 7 and 8; see also Figures 15 and 16).

Spatial as well as temporal variability in salt concentration is also high, with crop symptoms within the one field varying from general poor growth of plants to

Table 4. Soil salinity status by land type under agroecological zones (refer to Figure 1 for location of the zones)

Agro-ecological zone (AEZ)	Soil salinity status (dS/m)	Area (ha)					Table total
		Inundation land type					
		High land	Medium–high land	Medium–low land	Lowland	Very low land	
Ganges Tidal Floodplain	<2	32,522	399,252	6,929	68	.	438,771
	2–4	.	174,338	.	.	.	174,338
	4–8	5,668	299,049	9,340	.	.	314,057
	8–15	.	30,429	.	.	.	30,429
	Group total	38,190	903,068	16,269	68		957,595
Young Meghna Estuarine Floodplain	<2	.	129,564	9,450	.	.	139,014
	2–4	734	189,797	2,761	.	.	193,292
	4–8	.	98,936	56,019	.	.	154,955
	Group total	734	418,297	68,230			487,261

Source: based on the Land Resource Information database of the Bangladesh Agricultural Research Council

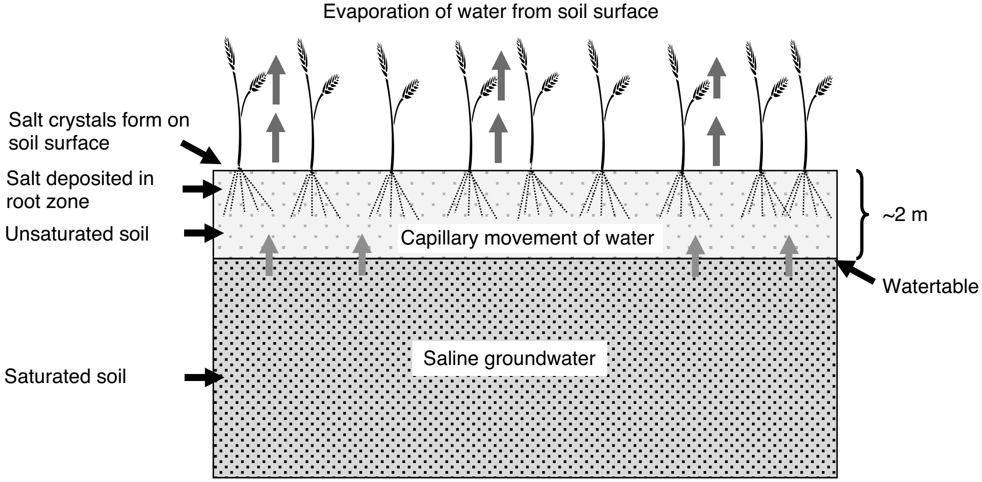


Figure 5. Schematic depicting the capillary rise of water and associated salts from the saline groundwater towards the soil surface, thereby concentrating salts in the plant root zone and on the soil surface

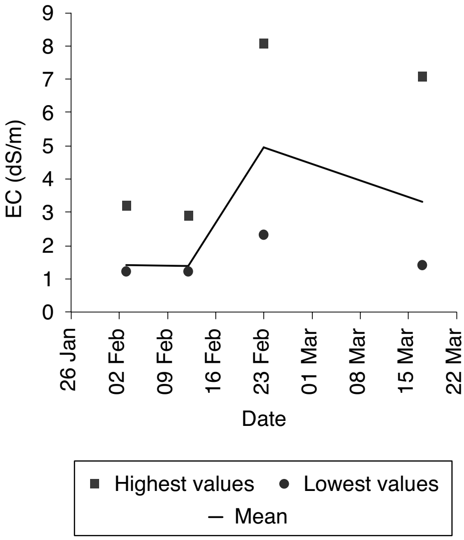


Figure 6. Mean, highest and lowest values in electrical conductivity (EC 1:5) of the soil surface (0–5 cm) in a wheat variety trial at Hazirhat, Noakhali, during the 2007–08 Rabi season. Data represent the sequential monitoring of 42 plots (in an area of approx. 200 m^2) from crop sowing to post crop maturity. High variability within measured data is an indicator of the inherent spatial variability in salt concentration often found in this environment.

spatial mosaics in which areas of healthy high-yielding crop are interspersed with areas of unthrifty low-yielding crop, or areas of scald where the crop has died (Figure 9). EC values of salt variation at these scales are presented and discussed in Chapter 3.6 (this volume).

Water for crop production

A primary driver of high yield in the usually dry Rabi season in southern Bangladesh is the availability of water. Water can potentially come from the four resources of in-season rainfall, irrigation accessed from surface ponds and groundwater, moisture stored in the root zone of the crop, and capillary rise of water from shallow groundwater tables. Rahman et al. (1995) found that well-grown crops of the then current wheat variety, Kanchan, grown in a salt-affected soil of southern Bangladesh had a water-use efficiency (WUE) (French and Schultz 1984a, b) of between 10 and 13 kg of grain/ha/mm of water, which was supplied through rainfall, stored moisture and irrigation. Given that this experiment was undertaken in a saline environment that would reduce the efficiency of water use, and that modern varieties with improved heat and salinity tolerance are now available, it can be assumed that the WUE of well-managed crops grown in non-saline southern environments are likely to have a WUE of between 15 and 20 kg/ha/mm. Assuming a WUE of 15 kg/ha/mm, a wheat crop that yields 3,500 kg/ha would utilise 233 mm of water to grow

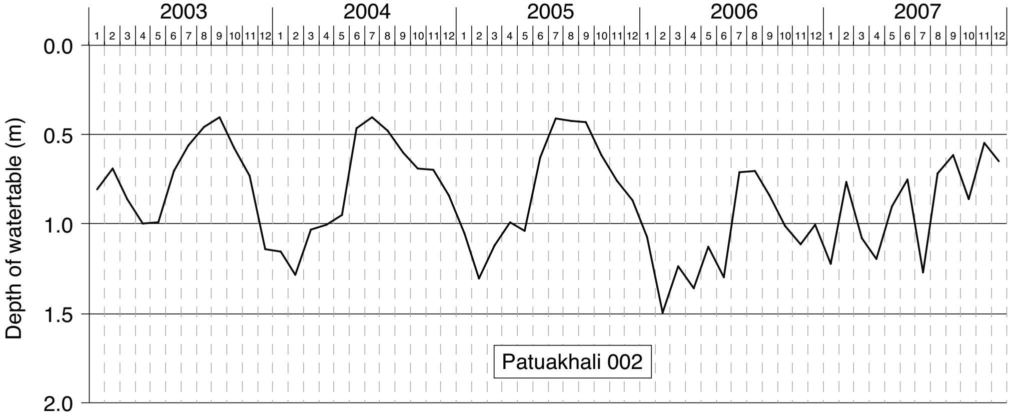


Figure 7. Watertable depth from the soil surface for Patuakhali, southern Bangladesh, from 2003 to 2007, showing monthly fluctuations due to the balance between rainfall and water removal. Watertable depth during the Rabi season ranges from 60 to 110 cm at time of crop sowing in November–December to 80–150 cm at crop maturity in mid March. (Source: data from Bangladesh Water Development Board)

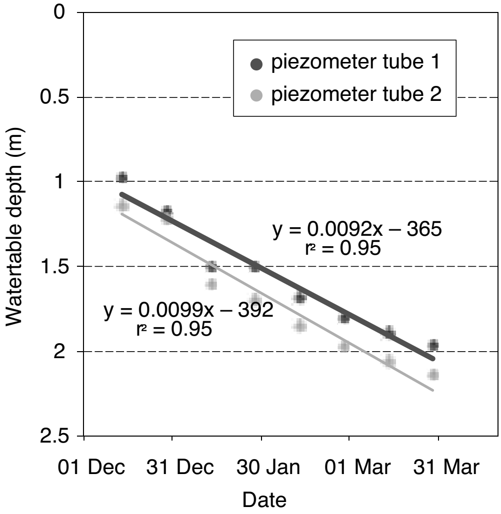


Figure 8. Changes in watertable depth monitored in Jhalakati during Rabi 2008–09 using two tube piezometers, each 3 m long, located within a 1,000 m^2 on-farm wheat crop. The crop was not irrigated. The watertable dropped linearly from 1 m at sowing to 2 m at crop harvest in March.

vegetatively and produce its yield. This water has to be supplied from the above sources.

The question to be discussed below is whether this quantity of water is available in southern fallow lands from the four resources. Without this quantity of water for cropping, the fallow lands must remain fallow or yield expectations revised.

In-season rainfall

Long-term rainfall records for Bhola and Barisal in the south, and Dinajpur in the north of Bangladesh, show median rainfall was 55–60 mm in all three districts from 1 January to 31 March (Figure 10), which is during the wheat-growing period.

The probability of little or no rainfall being recorded (<10 mm) is greater in Bhola (25%) than in Barisal or Dinajpur (10%). While there have been more seasons without rain in Bhola, all three districts had a similar chance (25–30%) of receiving >100 mm of rainfall during this period. What is also evident from the rainfall record is the probability of high rainfall in around 5% of years, when >200 mm is recorded for Dinajpur and Barisal and >280 mm for Bhola. There is also a small chance (1–2%) of very high rainfall, generally associated with severe local convective storm (SLCS) activity occurring during the pre-monsoon season from March to May (Yamane et al. 2010), when falls of >300 mm have been recorded for Bhola and Barisal. SLCS events occurring in March are not associated with the traditional cyclone period described in Chapter 2.1 (this volume), but result in significant crop and property damage and loss of life.

Depending on its seasonal distribution and quantity, rainfall either contributes beneficially to crop production through increased yield and reduced demand for irrigation, or negatively, particularly in years of high rainfall, through increased crop lodging and grain spoilage.

A month-by-month analysis of rainfall distribution (Figure 11) for southern locations shows that the probability of receiving high levels of rainfall during

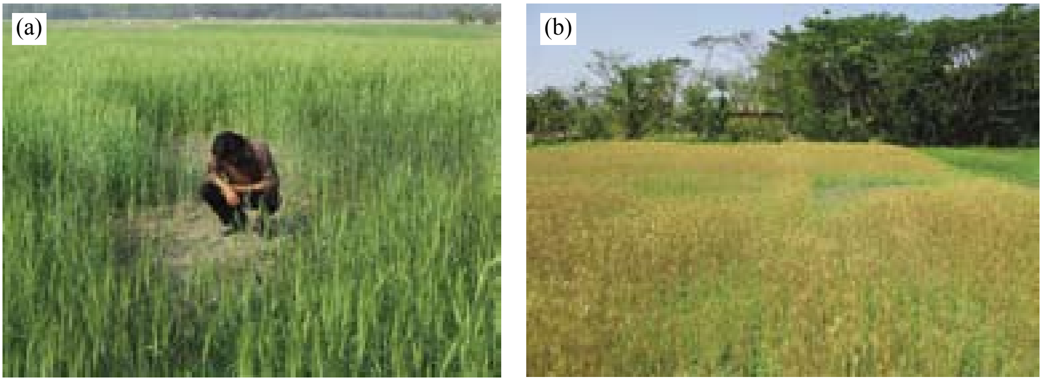


Figure 9. (a) Saline patches in a generally healthy wheat crop at Hazirhat, Noakhali; (b) spatial mosaic of wheat plant growth in response to variable levels of soil salinity—high levels of salinity often result in a thin crop, allowing increased weed infestation (Photos: M. Saifuzzaman; NPD)

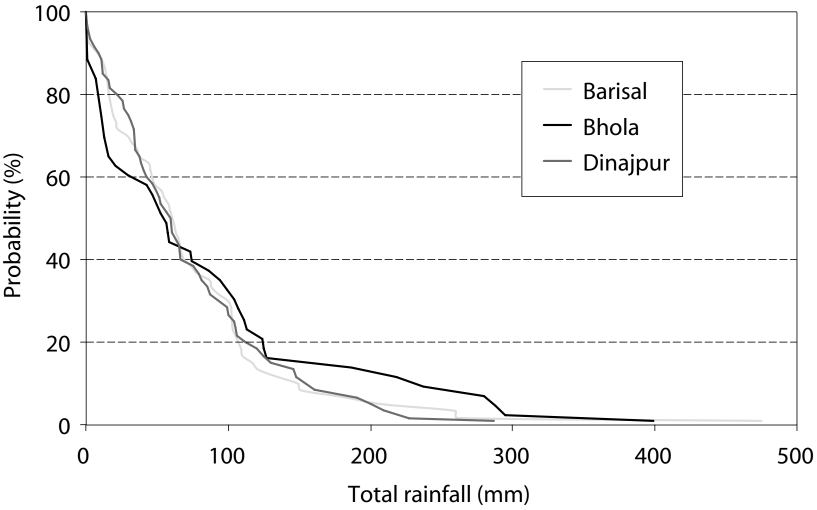


Figure 10. Probability of exceedence for rainfall during the Rabi-season growing period of January–March for 1949–2009 (Dinajpur and Barisal) and 1949–92 (Bhola)

the vegetative phases of crop production is relatively low, with an 80% chance of receiving 8 mm or less during January for both Bhola and Barisal. While the probability of beneficial rains increases in February as the crop enters the reproductive phase (25% chance of at least 35–40 mm in both regions), there is still a 46–50% chance of 10 mm or less during this period. In March, as the crop nears maturity and the productive benefits of in-crop rainfall decline, the potential for rainfall increases. Rain falls in 70–80% of years during March, with a 30% chance of exceeding 56–60 mm. Substantial falls of rain during this period are a major contributor to the crop losses mentioned earlier, coinciding with the period of maximum vulnerability to physical crop damage and resultant drops in yield and quality.

On-farm research undertaken in this project has shown that unirrigated wheat can produce 2.0–3.5 t/ha when well managed (Chapter 3.4, this volume, and Figure 12). Rainfall, therefore, at any stage during the crop vegetative and reproductive phases, is likely to be beneficial to crop production, supplementing stored soil water and water made available through capillary rise.

Irrigation

FAO reported that in 1991 there was 9.1 million ha of land available for crop production in Bangladesh, with 33% (3 million ha) being irrigated. By 2001, the land area available for crop production had reduced to 8.4 million ha with 52% (4.4 million ha) irrigable (FAO 1998, 1999). These statistics highlight two issues of Bangladesh agriculture: crop land is being lost to urbanisation (Chowdhury 2009), and increasing irrigation intensity and infrastructure are required to meet the food security demands of a rapidly growing population.

In the country as a whole, most of the surface and groundwater reserves are used to support the increasing irrigation requirements of boro rice production during the Rabi season (Chapter 1.1, this volume) (Bhuiyan 1984). Irrigation intensification has been most pronounced in northern Bangladesh, with between 29 and 54% of land in the 11 districts surveyed irrigable (Table 5). This compares to the south where the area under irrigation across eight districts ranged between 2 and 30% (Table 5). Irrigation potential, in conjunction with more benign climatic and environmental conditions, has resulted in northern Bangladesh being seen as a reliable producer of high-yielding dry-season crops (Ministry of Agriculture 2007).

The main drivers of the move to irrigation intensification have been the improved access to groundwater resources, made possible through the increased availability of pumping infrastructure, including tube wells, and the expansion of electrical supply networks to rural areas (Table 6) (Ministry of Agriculture 2007;

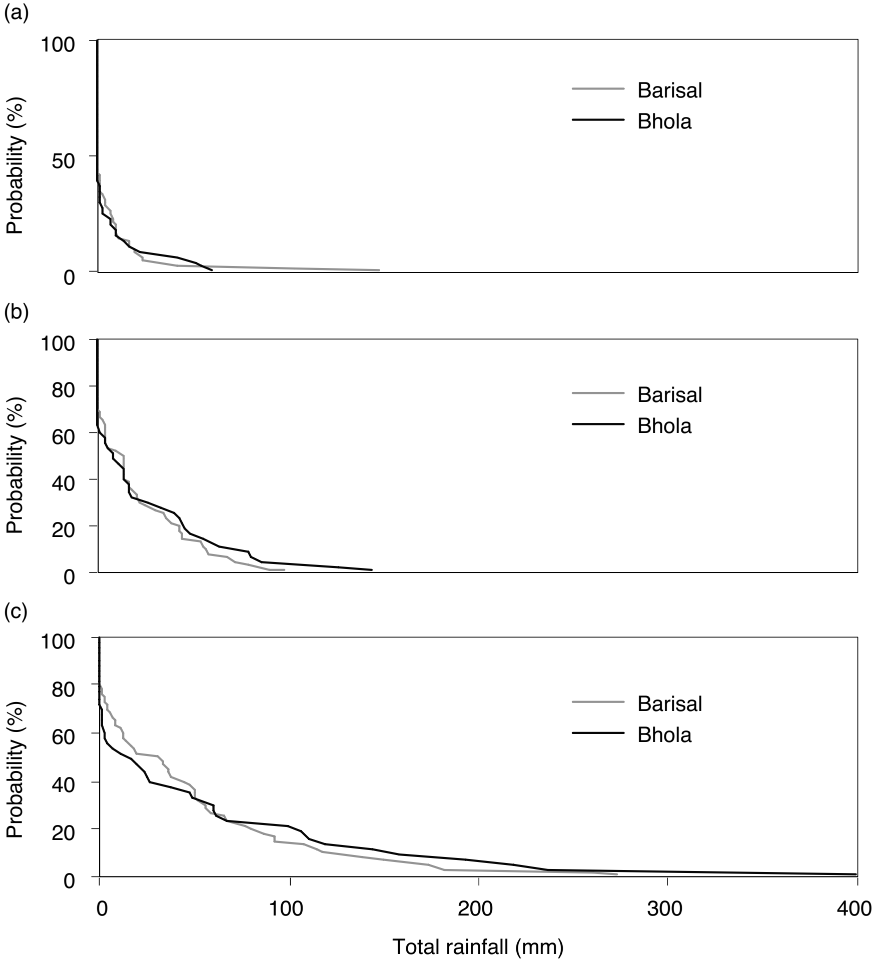


Figure 11. Rainfall probability distributions for the individual Rabi-season growing months of (a) January, (b) February and (c) March, for 1949–2009 (Barisal) and 1949–92 (Bhola)

Shelley 2010). In 2002–03, tube wells supplied 82% of the irrigation water used in the 11 northern districts surveyed by the Bangladesh Bureau of Statistics (BBS) (Table 6) (Ministry of Agriculture 2007). While this has resulted in significant increases in northern crop production, it has come at the cost of a regional lowering of the groundwater table and associated concerns over the long-term sustainability of the water resource (Harvey et al. 2006). A study by Shahid (2010) in north-west Bangladesh concluded that annual irrigation use for cropping varied between 839 and 1,212 mm/ha, which equated to 96.5% of total groundwater demand. From a broader infrastructure perspective, the extra pumping requirements of irrigated boro rice production have resulted in seasonal electricity shortages and daily load shedding as the supply system struggles to cope (Shelley 2010).

The important difference between the northern and southern regions of Bangladesh is the way that water is supplied for irrigation. In the north, 82% is supplied from groundwater using shallow and deep tube wells, and only 12% comes from canals and surface storages. In the south, trends are reversed with 71% of irrigation water supplied from surface storages and canals and only 24% coming from groundwater (Ministry of Agriculture 2007) (Table 6).

Table 5. Area of arable land and the percentage irrigated in 19 districts representing the northern and southern Bangladesh production regions (2002–03 data) and the percentage of irrigated land used for the production of two of the major crops (2004–05 data)

Region	District	Arable area ('000 ha)	Area irrigated ('000 ha)	Area irrigated (%)	Irrigated land used for boro rice (%)	Irrigated land used for wheat (%)
North	Dinajpur	868	379	43	56	25
	Rajshahi	1,057	577	49	58	11
	Dhaka	707	270	37	83	0
	Jamalpur	462	194	40	79	9
	Kishoreganj	577	273	46	96	1
	Mymensingh	584	198	29	91	1
	Jessore	826	389	42	67	7
	Kushtia	435	236	50	33	13
	Bogra	603	336	54	76	3
	Pabna	580	210	34	75	8
	Rangpur	1,255	501	49	71	10
South	Noakhali	587	88	14	88	1
	Barisal	765	101	14	84	1
	Patuakhali	509	12	2	3	0
	Chittagong	499	146	28	78	0
	Comilla	955	305	30	86	2
	Rangamati	63	7	12	78	0
	Faridpur	817	223	24	69	13
	Khulna	512	121	19	80	2

Source: Ministry of Agriculture (2007)

Table 6. Source of irrigation water for 19 districts (2002–03 data) representing the north and south of Bangladesh, indicating the increased use of groundwater and tube wells in the north compared to the south

Region	District	Irrigation water source (%)			
		Ponds (pumped)	Tube wells (shallow and deep)	Canal	Traditional
North	Dinajpur	1	96	1	2
	Rajshahi	7	88	0	5
	Dhaka	23	71	4	2
	Jamalpur	3	93	1	3
	Kishoreganj	35	56	1	9
	Mymensingh	5	88	3	4
	Jessore	3	94	2	1
	Kushtia	2	85	12	1
	Bogra	0	98	0	1
	Pabna	3	94	1	2
	Rangpur	1	92	1	6
South	Noakhali	79	14	0	7
	Barisal	83	0	7	10
	Patuakhali	48	0	40	12
	Chittagong	59	14	12	15
	Comilla	36	54	2	9
	Rangamati	45	0	28	28
	Faridpur	39	57	2	2
	Khulna	13	74	5	8

Source: Ministry of Agriculture (2007)

The predominance of groundwater as the irrigation resource of choice in the northern region is a reflection of a longer history of intensive Rabi-season cropping and the subsequent higher investment in irrigation infrastructure. This compares to the south where, with the exceptions of longer established districts such as Khulna and Comilla, there is a much shorter history of Rabi-season cropping, resulting in a greater reliance on surface water and portable pumps for irrigation. However, where farmers do utilise the underground water resource, such as in Senbag, Noakhali, there is emerging anecdotal evidence of salt contamination of the water resource resulting in reductions in boro rice yields (M. Saifuzzaman, pers. comm.).

At the field scale, the introduction of Rabi crops such as wheat into the southern rice-based farming system has a number of benefits in terms of efficiency of irrigation water use. First, research has demonstrated that one irrigation of 100 mm, applied 20 days after sowing (DAS), is sufficient to optimise yield in most seasons (Chapter 3.4, this volume). This compares to the north, where three irrigations of 100 mm are recommended for wheat and 20–30 irrigations for boro rice are not uncommon (Poulton et al. 2010; Shahid 2010).

While research is recommending irrigation applications of 100 mm (one application in the south and three in the north), the practical reality in the field appears to be different. In 2007–08, the irrigation water applied to 31 fields in the districts of Barisal, Bhola and Noakhali was measured (Table 7). These data show that the actual amount of applied water varied widely and never reached the recommended rate of 100 mm. In addition, Figure 12 indicates a lack of consistent yield response to this irrigation. While in some cases this can be attributed to differences in the application rate (Table 7), the issue is further confounded in the districts of Bhola and Barisal where, in 30% of cases, rainfed crops out-yielded those receiving irrigation.

Only in Noakhali, where irrigation rates were the lowest recorded, did all irrigated fields out-yield those grown under rainfed conditions. These results show that, while irrigation is important, there are other factors in play, including differences in seasonal conditions between districts and variation in the relative contribution to water supply from other sources including stored soil water, rainfall and capillary rise.

Furthermore, the variability in response raises questions regarding the actual amount of irrigation water required, and the process by which an irrigation, only 20 DAS, affects yield—is its value related directly to improved crop water supply, or to release of nutrients or to some other process? Irrigation application and timing are discussed in Chapter 3.4 (this volume).

Stored soil water

To understand the water balance for an individual crop, it is necessary to know the amount of water the soil can store that is potentially accessible to the crop (plant available water capacity, PAWC) (Figure 13a) and how much water is available to the crop at any point in time (plant available water, PAW) (Figure 13b) (Dalgliesh and Foale 1998). These data can be used not only to assess whether there is sufficient water available for the growth of a particular crop, or an irrigation-management practice is working optimally to produce yield, but also as inputs into farming systems models such as the Agricultural Production Systems Simulator (APSIM) (Keating et al. 2003; Chapter 4.2, this volume). Modelling tools can be used to examine the risks associated with a whole range of interacting farming approaches within changed climatic conditions at a much higher level of complexity than can be examined by experimentation alone. Their success relies on well-described soil parameters.

Characterisation for plant available water capacity (PAWC)

From 2006 to 2010, crops of wheat and mungbean were grown by collaborating farmers on over 200 farms distributed throughout the southern region. These were the seed multiplication trials (SMT)

Table 7. Actual irrigation water applied (mean, lowest and highest) to 31 farmer fields in three districts of southern Bangladesh in the 2007–08 Rabi season

District	Number of fields	Mean application rate (mm)	Lowest application rate (mm)	Highest application rate (mm)
Bhola	10	39	1	71
Barisal	11	65	53	92
Noakhali	10	8	2	12

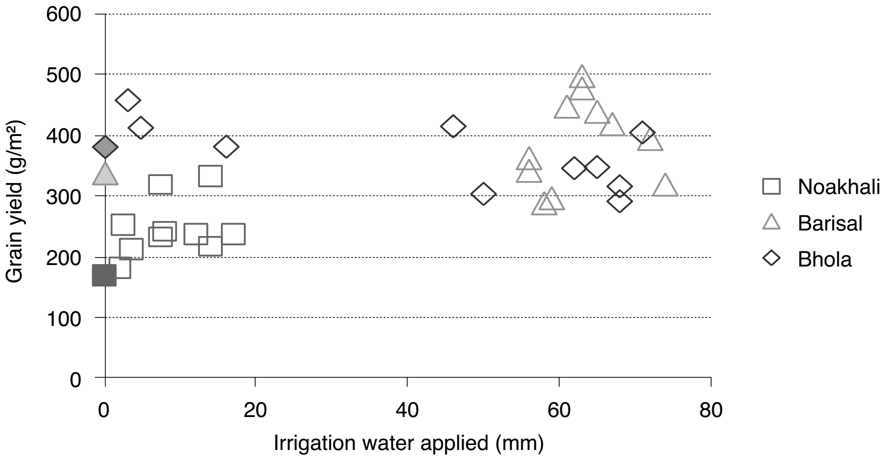


Figure 12. Wheat grain yields (2007–08 Rabi season) for 31 irrigated fields in the districts of Noakhali, Barisal and Bhola (open symbols) compared to rainfed yields (filled symbols) for crops grown on soil moisture reserves and in-crop rainfall

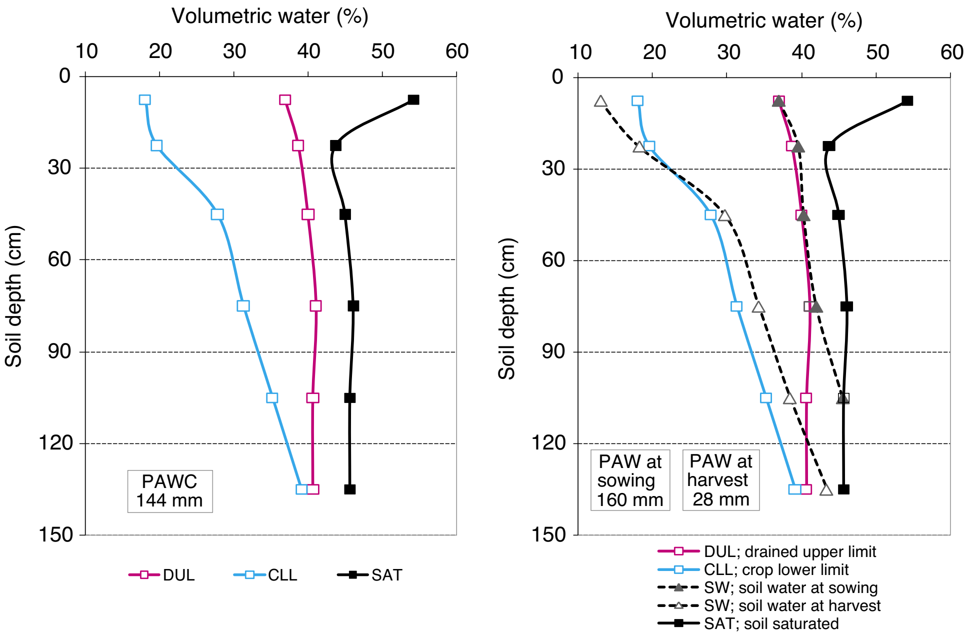


Figure 13. A typical silt soil from Bhola in southern Bangladesh: (a) with a plant available water capacity (PAWC) of 144 mm for wheat showing percentage volumetric water held at saturation (SAT), after drainage (DUL) and after the crop had completed its extraction at maturity (CLL) (see text for how to calculate the parameters); (b) per cent volumetric water present at crop sowing (December) and harvest (March), indicating available water (PAW) of 160 mm at crop sowing with 28 mm remaining at harvest. These soil-water profiles are typical of those found in southern Bangladesh during the Rabi season with saturated soil conditions at depths below 1 m at sowing and indications of water extraction in the 120–150 cm soil layer by season end. Roots were observed in the 120–150 cm soil layer.

described in Chapter 3.3 (this volume). As part of this program, 29 soils were characterised to represent the spatial variability among soils across the seven regions in which research was being undertaken (Table 8). These included 12 soils representing the more recently formed Young Meghna Estuarine Floodplain AEZ and 15 representing the Ganges Tidal Floodplain AEZ. Additional sites were characterised at the Bangladesh Agricultural Research Institute (BARI) research station at Joydebpur near Dhaka and at an on-farm research site at Jessore, one of the more southerly districts in which wheat has traditionally been grown. Detailed information on the field procedures and calculations associated with the characterisation of soils for PAWC are provided in the Appendix.

Monitoring the plant available water (PAW)

If the characterisation of a soil for PAWC determines the capacity of the soil to hold water for the production of a particular crop grown on that soil, then monitoring involves knowing the proportion of that capacity that is occupied by water at any given point in time. A useful analogy is to consider PAWC as a bucket for which the volume is known. At any point in time, however, the bucket (or PAWC) may be full of water, or empty, or somewhere in between, depending on seasonal and crop conditions (Figure 13). The level of water in the bucket, at the particular point in time, is described as the plant available water (PAW) and may be referred to in millimetres (mm) of available water or as a percentage of PAWC. PAW is measured using the same driven tube technology as described for PAWC. Detailed information on these procedures is provided in the Appendix.

More detailed data relating to the particular measurements gathered at each site are available for download as an APSoil file for direct use in the APSIM model, or as a *.kml file for viewing and download in Google Earth (<http://earth.google.com>) (Dalgliesh et al. 2006 2009). The web links for access to both APSoil and Google Earth files are available at <http://www.apsim.info/Wiki/APSoil.ashx>.

Groundwater resources and impact on Rabi-season crop production

The majority of the cropping regions of Bangladesh are underlain by shallow (to 300 m depth) and deep (to 1,600 m) groundwater aquifers that are recharged annually through rainfall and flooding (Faruque and Alam 2002). Analyses of data from long-term groundwater monitoring sites (Figure 14) show significant differences in depth to groundwater and in the annual amplitude of the extraction/recharge equilibrium between northern and southern regions (Figure 15). Increases in irrigated agriculture have resulted in large annual fluxes in shallow groundwater by as much as 3–6 m in the north, with levels

Table 8. Plant available water capacity (PAWC) for 29 soils of southern Bangladesh, representing the range of soil types on which on-farm research was undertaken during 2006–09

Season	District	Site	PAWC (wheat) to 1.5 m (mm)
2005–06	Dhaka	Joydebpur	132
	Jessore	Monirampur	124
	Barisal	Khanjapur	132
	Barisal	Kashipur	137
	Noakhali	Char Jublee	128
	Noakhali	Hazirhat	144
2006–07	Barisal	Babugong	140
	Noakhali	Hazirhat	145
	Noakhali	Bariopur	144
	Bhola	South Balia	137
	Bhola	North Joynagar	139
2007–08	Barisal	West Narayanpur	228
2008–09	Bhola	Moutobi	148
	Bhola	Moutobi	148
	Bhola	Shachia	146
2008–09	Bhola	South Balia	161
	Bhola	Kachia	143
	Bhola	South Digholdi	147
	Patuakhali	Shially	172
	Patuakhali	Gabua	137
	Patuakhali	Badarpur	148
	Patuakhali	Badarpur	139
	Patuakhali	West Angaria	131
	Patuakhali	Lebukhali	157
	Jhalakathi	Baghri	162
	Jhalakathi	Poddar Hawla	144
	Jhalakathi	Koibortta Khali	164
	Pirojpur	East Amrajhuri	134
	Pirojpur	East Amrajhuri	134

Figure 14. Distribution of the Bangladesh Water Development Board (BWDB) gauging stations measuring fortnightly or monthly depth to groundwater (black dots). Marked red symbols represent case study sites in northern and southern regions. (Source: data supplied by BWDB)

in the south tending to be closer to the surface at the start of the Rabi and declining to >1.5 m during the growing season (November–March) (Table 9).

These regional data are supported by in-field piezometer data from within wheat crops at 41 of the southern on-farm research sites during the 2007–08 and 2008–09 Rabi cropping seasons. These data showed that watertables were commonly at a depth of approximately 1 m at sowing in December and at 1.5–3.0 m by crop maturity (Figures 8 and 16).

These differences in Rabi season watertable depth have important implications for crop production and, in particular, the potential for crops to access groundwater through capillary rise. Capillary rise is described as ‘the movement of soil moisture through fine soil as a result of surface tension forces between the water and individual soil particles’ (Figure 5) (QDNR 1997). This results in the movement of water from the groundwater vertically into the unsaturated soil above, and is of benefit to crops in terms of water supply when within 1–2 m of the crop rooting front.

Given the soil and water conditions under which capillary rise is a significant contributor to crop water supply, watertables in the north during the Rabi season are too deep to aid crop production (Figure 15a and Table 9). This is reflected in the WRC recommendations for wheat production which suggest that three irrigation applications, each of 100 mm, are required. In the south, however, where Rabi-season watertables are regularly at depths of 1–2 m, capillary rise is a much more significant contributor to crop production (Figure 5). Using the water balance model SWIM (Verburg 1996) to simulate the contribution of capillary rise to crop water supply at Bhola from 1971 to 2007 shows that capillary rise contributed between 60 and 105 mm of water to crop production, resulting in additional yield increases of between 0 and 1.5 t/ha above that of crops without access to shallow groundwater (Figure 17) (Poulton and Saifuzzaman 2010).

Lysimeter studies undertaken in Pakistan on a loam soil support the hypothesis that capillary rise is an important contributor to crop production. Kahlown et al. (2005) showed that the contribution to total water supply was at a maximum when the watertable was at depths of <1 m, with 32% of water demand in wheat

Table 9. Depth to watertable at five long-term monitoring sites in northern and southern Bangladesh showing the depth to watertable at the start of the wheat-planting window (November) and at crop maturity (March)

Region	District	Bore hole	Depth to groundwater in November (m ± SD[a])	Depth to groundwater in March (m ± SD[a])
North	Dinajpur	DIN010	1.75 ± 0.51	2.79 ± 0.78
		DIN003	2.64 ± 0.52	4.36 ± 0.27
South	Bhola	BH002	1.24 ± 0.21	2.38 ± 0.36
		BH003	0.91 ± 0.34	2.38 ± 0.51
	Noakhali	NOA010	1.25 ± 0.37	2.31 ± 0.67

[a] SD = standard deviation
Source: Data supplied by Bangladesh Water Development Board

being met, although maximum yield was achieved when the watertable was at a depth of 1.5 m.

Not only does this analysis show the importance of groundwater to southern crop production, but it also provides insight into the potential for the region to contribute significantly to national food security without additional major irrigation infrastructure development. The lack of deep tube wells for irrigation in the south has in the past directly influenced the cropping options of farmers. However, the use of deep tube wells and excessive groundwater use above the extraction–recharge equilibrium has the potential

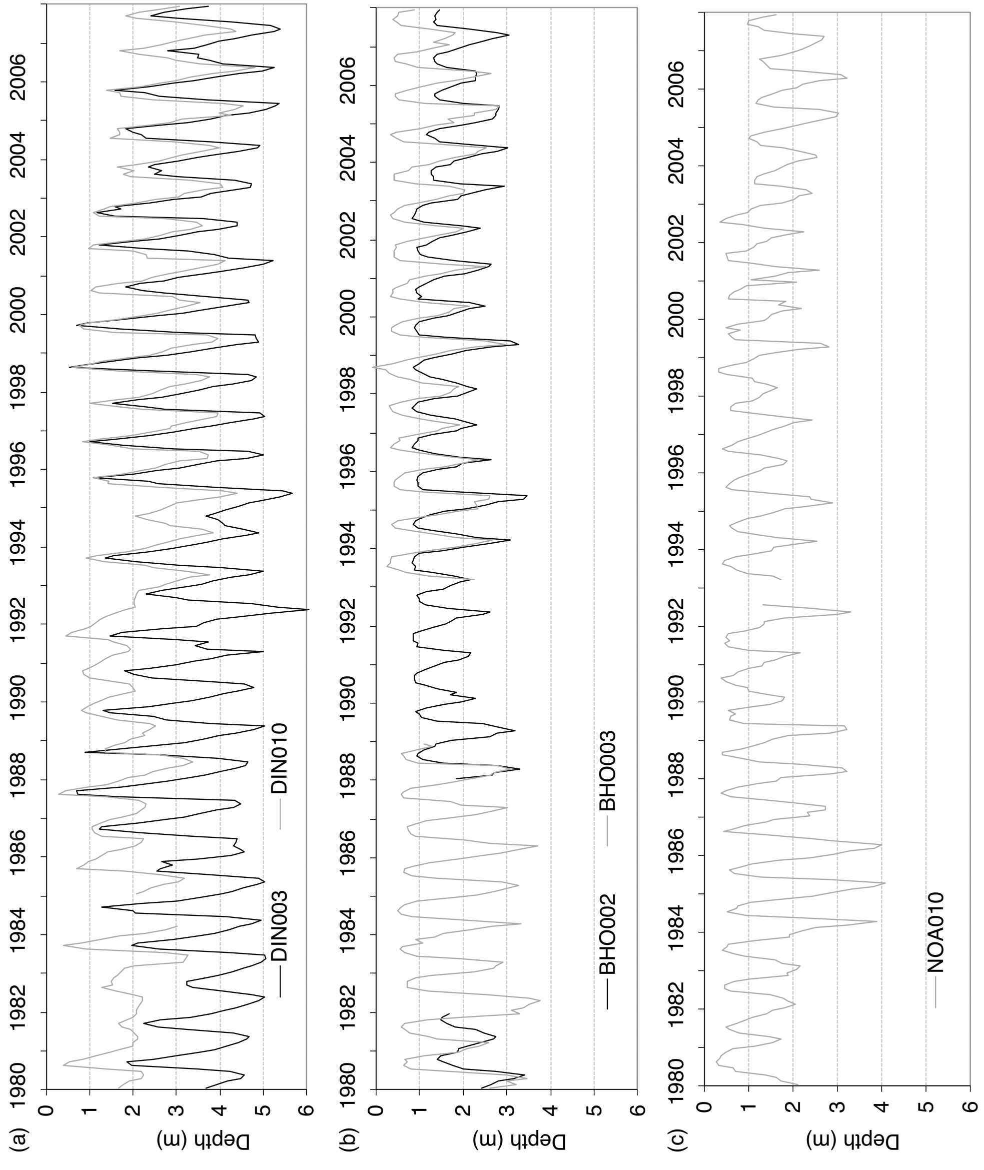


Figure 15. Fluctuation in depth to watertable from 1980 to 2007 at (a) the northern site Dinajpur (bore holes DIN003 and DIN010), and southern sites (b) Bhola (BHO002 and BHO003) and (c) Noakhali (NOA010) (Source: data supplied by Bangladesh Water Development Board)

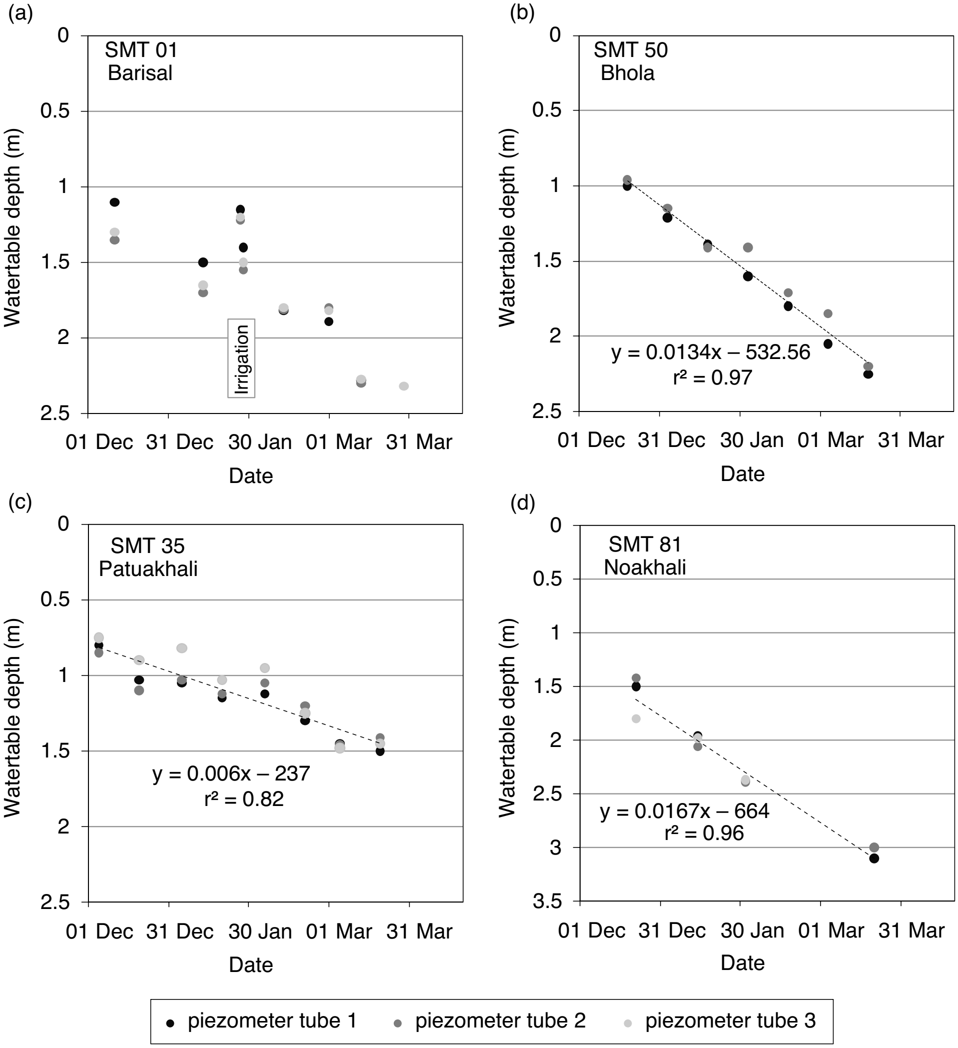


Figure 16. Change in shallow watertables during the 2008–09 Rabi season at four study sites in (a) Barisal (SMT 1), (b) Bhola (SMT 50), (c) Patuakhali (SMT 35) and (d) Noakhali (SMT 81) (data derived from measuring piezometers installed at each seed multiplication trial (SMT) site in 2008)

to impose serious stress on shallow aquifer reserves. This is a particular issue in regions bordering saline aquifers, where the potential for saltwater intrusion resulting in salinity-derived adverse environmental effects is high. Crops such as wheat or mungbean can sustainably exploit this natural cycle of shallow groundwater through the process of capillary rise, requiring one or two early irrigations when surface water is abundant and reducing the need for investment in additional irrigation infrastructure.

Is there sufficient water to meet Rabi-season crop demand?

At the start of this section, the question was asked whether there were sufficient water resources from stored soil water, rainfall, irrigation and capillary rise to sustain Rabi-season crop production, with the example given of a well-grown wheat crop requiring 233 mm of available water to achieve a yield of 3,500 kg/ha (using an assumed WUE of 15 kg/ha/mm).

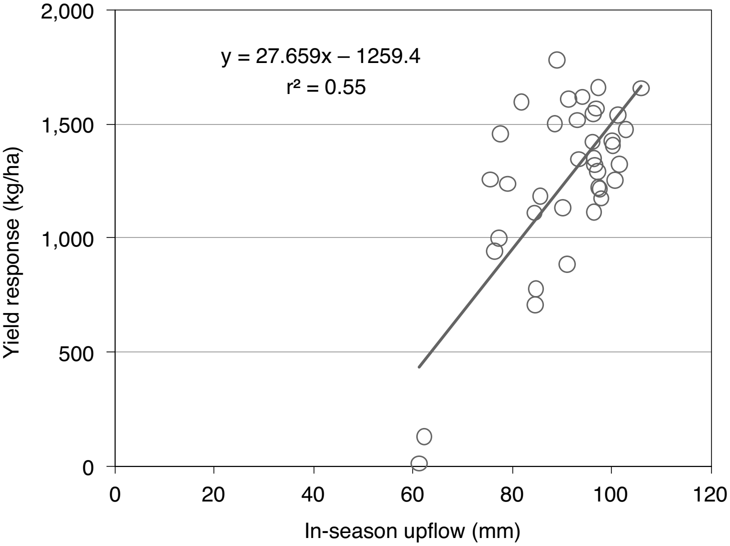


Figure 17. Simulated additional yield response in wheat at Bhola (1971–2007) from upflow of soil water as a result of capillary rise during the Rabi season, using the SWIM model of Verburg (1996)

Given that the soils in southern Bangladesh, on average, have a PAWC of 146 mm (Table 8) and are generally at field capacity at the time of wheat sowing (Figure 13b), this becomes the main water resource for the crop. Assuming some evaporative losses from the soil surface before canopy closure, it can be estimated that an additional 100 mm of water would be required to meet crop demand, this coming through rainfall, capillary rise and irrigation. As shown in Figure 17, in some years all of the additional water could be supplied through capillary rise; although in the worst-case scenario 60 mm would be contributed. While in many years there is no rainfall during the Rabi season, there is, however, still a 25% chance of receiving >35–40 mm in February and a 30% chance of >56–60 mm in March (Bhola and Barisal districts), although March rainfall may be too late to contribute to crop water supply. One irrigation 20 DAS has been found to significantly increase yields in the south, and while questions remain about the mechanism by which this is achieved, i.e. directly through improved water supply or through improved nutrient availability, the fact remains that irrigation will contribute to water supply if application rates are sufficiently high. Data collected in the 2007–08 season (Table 7) indicate that irrigation rates vary widely, between 1 mm and 92 mm with mean application rates for the districts of Bhola, Barisal and Noakhali of 39, 65 and 8 mm, respectively. Clearly the rates at the lower end of this scale will contribute little to water supply with most, if not all, the water applied being lost to evaporation.

For this hypothetical scenario, therefore, it can be seen that it is highly likely that through a combination of soil water (133 mm), capillary rise (60 mm) and rainfall and irrigation, crop demands will be met. If, however, some of the components of water supply are unable to meet crop demand, or the crop lacks sufficient nutrients, or weeds are allowed to grow to use the water and the space, then yield potential will not be reached.

Discussion

The southern Bangladesh region has significant potential to support national food security through an increased emphasis on Rabi-season cropping; in particular, the production of wheat. There are three attributes of the natural system that contribute to this potential:

1. the silt soils which have the capacity to hold significant amounts of water available for crop production and are
2. generally at or above field capacity at the time of crop sowing and
3. the significant contribution to crop water supply through capillary rise.

As a consequence of these three factors, a single irrigation of 100 mm is sufficient to achieve optimal wheat yields in most years. This compares to the traditional northern cropping system in which the soils are often below field capacity at the start of the season and the underlying aquifers too deep to contribute to water supply through capillary rise, which results in the need for three irrigations to achieve optimal crop yields. Given that irrigation infrastructure is limited in the south and the majority of water has to be sourced from above-ground storages, the attributes of the southern soils (storage capacity, available water and capillary rise) work in favour of the farmer who wants to use limited irrigation resources for boro rice production but, at the same time, utilise a proportion of their higher land for wheat production, either as an irrigated crop, if water is available, or as a dryland crop. These same soil attributes also favour those areas where tube wells have been installed and the underground aquifer overexploited, or where the aquifer is moderately saline or suffering from salt incursion, and its continuing use is contributing to rice mortality. In these areas, a crop such as wheat, with a lower requirement for irrigation, should be an attractive alternative to boro rice and may become even more so as the impacts of climate change affect groundwater availability.

While soil salinity can constrain yield in the char lands of the districts that border the Bay of Bengal, its presence should not necessarily exclude wheat from the farming system, except where observation indicates that salinity levels at the commencement of the Rabi season are already high enough to restrict plant growth. The research indicates that, more commonly, salt levels in the surface soil start at relatively low levels and rise as the season progresses, thus allowing crops to be successfully established and to grow adaptively into an increasingly saline environment, albeit with a lower yield potential than in non-saline environments.

Nutrient supply in subsistence farming systems is problematic, with research and extension organisations recommending expensive commercial levels of nutritional input designed to maximise yield and farmers ignoring their advice due to their lack of financial resources and aversion to risk. Southern Bangladesh is no different, with research indicating that fertiliser requirements to achieve high yield for crops planted at the recommended time are similar to WRC-recommended rates for the north, i.e. nitrogen at 100 kg/ha, phosphorus at 27 kg/ha, potassium at 50 kg/ha, sulfur at 20 kg/ha, boron at1 kg/ha, zinc at 4 kg/ha (in zinc-deficient soils) and calcium at 36 kg/ha. The reality, however, is that farmers will apply what they can afford, or what is available to them at the time. This will be somewhere between zero and the recommended rate, using fertilisers of either inorganic or organic origin, or a combination of the two.

While the subsistence farmers' limited finances and aversion to risk seem unlikely to change, there are ways to improve fertiliser usage and to bring application rates, and hence yields, closer to those recommended by research. Currently a 'recipe' approach to fertiliser application is used by extension services. While this 'one size fits all' model is an expedient mode of mass communication and allows the message to be 'kept simple', there is no flexibility that allows for soil type, previous cropping history, time of planting or other factors to be considered in any recommendation. An example of this occurs with the rate of fertiliser applied in response to time of sowing. Currently, the WRC recommendation is for the application of 100 kg/ha of nitrogen no matter when the crop is planted. However, southern research indicates that while this is an appropriate rate for crops planted in late November to early December, rates could be reduced to 66 kg/ha for crops planted after mid December and to 40 kg/ha for those planted at the end of December (Chapter 3.4, this volume). The promotion of variable rates of fertiliser, while more difficult than the 'one size fits all' approach, may in fact encourage farmers who are currently unwilling to invest in high rates of fertiliser to commence their use, contributing to higher and more consistent results than are currently realised by many farmers.

Appendix

The determination of the plant available water capacity (PAWC) of a soil

A modified characterisation protocol, based on Dalgliesh and Foale (1998) and Burk and Dalgliesh (2008) was used to determine PAWC. In the standard protocol, which was designed for use in dryland farming systems in Australia, the soil is wetted to saturation (SAT) by irrigation and then allowed to drain until the soil-water content reaches an equilibrium, assumed to be the drained upper limit (DUL) of the soil. Gravimetric moisture content and bulk density (BD) to depth of crop rooting are then measured through soil coring.

Using this protocol, the lower limit of water extraction by the crop (CLL) is determined at crop maturity. The sampling site is sheltered from rain from crop anthesis until maturity, when gravimetric water content of the soil profile is determined to the depth of crop rooting. The measurement of DUL, BD and CLL enables the determination of PAWC (in millimetres of available water) for the soil × crop combination (see Figure 13 of main text).

However, because soils are invariably moist at wheat sowing in southern Bangladesh, it was not considered necessary to irrigate sites for the determination of PAWC. Instead, soil cores (32 and 37 mm external diameter) taken for the routine monitoring of plant available water (PAW) before the sowing of the wheat crop and at maturity, were used to estimate DUL and CLL. Three cores were extracted, using a hand-operated driven core system (Figure 18) for each of the on-farm sites, and the cores subdivided into depth increments of 0–15, 15–30, 30–60, 60–90, 90–120 and 120–150 cm. Samples were bulked for the three cores across each sampling layer and gravimetric water content determined on oven-dried samples (dried at 105 °C).

Sampling at a particular location ceased if the watertable was intersected before reaching the planned sampling depth of 150 cm. This occurred regularly, with free water often found at approximately 1 m (Figure 13). Samples taken at wheat sowing were considered to be at DUL for the soil layers above the layer where saturated conditions were encountered. This generally resulted in direct measurement of gravimetric moisture content, assumed to be at DUL, for the depth increments of 0–15, 15–30 and 30–60 cm, although the actual number of layers at DUL varied according to geographical location and local conditions.

Because of the lack of textural change and defined soil horizons, we assumed that DULs of the saturated layers, where sampling was not possible, were similar to that measured in the non-saturated layers closer to the surface i.e. 0–15, 15–30 and 30–60 cm. The sampling at crop maturity for CLL could be undertaken at all 29 locations to a depth of 1.5 m, although in many cases the soil moisture content was still above DUL in the lower one to two soil layers (90–120 and 120–150 cm) (Figure 13).

Gravimetric soil moisture percentage was determined for samples at DUL and CLL using equation (1).

BD was measured at the time of crop maturity using a hand-operated coring device and open-ended steel rings with a volume of 50 cm^3 (2.7 cm high and 4.9 cm internal diameter) which were pushed into the undisturbed soil, removed intact, and trimmed (Burk and Dalgliesh 2008). Three replicates were taken for each of the soil layers, 0–15, 15–30 and 30–60 cm, with sampling positions located to straddle the midpoint of the particular layer. For example, in the 0–15 cm layer, the soil was excavated to a depth of 6.15 cm from the surface and the ring inserted to straddle the 7.5 cm midpoint of the layer. BDs at depths below 60 cm were estimated based on the BD of the surface layers and the assumption that BD did not change significantly at depth due to the lack of horizon or textural change. Samples were dried at 105 °C and BD calculated using equation (2).

The determination of the BD then allowed the volumetric water content of the DUL and CLL to be calculated using equation (3).

Soil saturation (SAT), required for the running of the Agricultural Production Systems Simulator (APSIM) model was calculated from total porosity (PO) and measured BD using equations (4) and (5).

PAWC for a particular soil by crop combination was then calculated using equations (6) and (7) (Figure 13).

Monitoring the plant available water (PAW)

PAW is measured using the same driven tube technology as described for determination of PAWC (Figure A1). Cores are driven to the depth of assumed rooting potential (150 cm for wheat) and gravimetric water content (equation 1) determined after the samples are oven dried at a temperature of 105 °C. Calculation of volumetric water content (equation 3) allows current crop water content to be described relative to the soil's PAWC and in the same units as shown in Figure 13b.

A short digital video is available from the authors (email: <Neal.Dalgliesh@csiro.au>) depicting the field procedures associated with the monitoring of soil water in Bangladesh.

Gravimetric water (%) = ((sample wet weight[g] – sample dry weight[g])/sample dry weight[g] – container tare[g]) × 100 (1)

BD (g/cm^3) = dry soil weight in sampling ring (g) / volume of the sampling ring (cm^3) (2)

Volumetric water (%) = gravimetric water (%) × BD (g/cm^3) (3)

PO (% volumetric) = (1 – BD/2.65) × 100 (4)

where BD/2.65 is the fraction of the soil volume occupied by solid particles and based on an assumed absolute density of 2.65 g/cm^3 for the solid matter in the soil.

SAT (% volumetric) = (PO – e) × 100 (5)

where e = % entrapped air at PO (0.05 for silty soils).

PAWC (mm) for 1 depth layer = (DUL – CLL) × depth layer thickness (cm)/10 (6)

PAWC (mm) for the full profile = sum of PAWC for each depth layer (7)


(a)
(b)
(c)

Figure A1. Soil coring: (a) driving the steel coring tube into the ground with the wooden hammer; (b) extracting the core tube using the jack; and (c) placing the extracted core into the cutting tray for cutting into depth layers and bagging

References

Adhikari C., Bronson K.F., Panuallah G.M., Regmi A.P., Saha P.K., Dobermann A., Olk D.C., Hobbs P.R. and Pasuquin E. 1999. On-farm soil N supply and N nutrition in the rice–wheat system of Nepal and Bangladesh. Field Crops Research 64(3), 273–286.

BARC (Bangladesh Agricultural Research Council) 1999. Report on project–BARC/UNDP/FAO GIS Project: BGD/95/006. Bangladesh Agricultural Research Council: Farmgate, Dhaka, Bangladesh.

Bhuiyan S.I. 1984. Groundwater use for irrigation in Bangladesh: the prospects and some emerging issues. Agricultural Administration 16(4), 181–207. Accessible at <http://www.sciencedirect.com/science/journal/0309586X>.

Buresh R.J., Reddy K.R. and van Kessel C. 2008. Nitrogen transformations in submerged soils. Pp. 401–436 in 'Nitrogen in agricultural systems', ed. by J.S. Schepers and W.R. Raun. Agronomy Monograph 49. American Society of Agronomy, Crop Science Society of America and Soil Science Society of America: Madison.

Burk L. and Dalgliesh N.P. 2008. Estimating plant available water capacity. Grains Research and Development Corporation: Canberra.

Carberry P.S., Saifuzzaman M., Rawson H.M., Sufian M.A., Hossain A.B.S. and Dalgliesh N.P. 2008. Scoping study to assess the technical and economic feasibility of wheat production in southern Bangladesh. Australian Centre for International Agricultural Research: Canberra.

Chowdhury M.A.T. 2009. Sustainability of accelerated rice production in Bangladesh: technological issues and the environment. Bangladesh Journal of Agricultural Research 34(3), 523–529.

Dalal R.C. and Mayer R.J. 1986. Long-term trends in fertility of soils under continuous cultivation and cereal cropping in southern Queensland. 2. Total organic carbon and its rate of loss from the soil profile. Australian Journal of Soil Research 24, 281–292.

Dalgliesh N.P. and Foale M.A. 1998. Soil matters: monitoring soil water and nutrients in dryland farming systems. Technical manual. Commonwealth Scientific and Industrial Research Organisation (CSIRO)/Agricultural Production Systems Research Unit: Toowoomba.

Dalgliesh N.P., Foale M.A. and McCown R.L. 2009. Re-inventing model-based decision support with Australian dryland farmers: 2. Pragmatic provision of soil information for paddock-specific simulation and for farmer decision making. Crop & Pasture Science 60, 1031–1043.

Dalgliesh N.P., Wockner G. and Peake A. 2006. Delivering soil water information to growers and consultants. In 'Proceedings of the 13th Australian Agronomy Conference'. Australian Society of Agronomy: Perth. Accessible at <http://www.regional.org.au/au/asa/2006/poster/water/4552_dalglieshn.htm#TopOfPage>.

Dang Y. 2007. Diagnosing the presence and severity of subsoil constraints. Pp. 2–7 in 'Combating subsoil constraints' (projects results book), ed. by Y. Dang, S. Buck, R. Dalal, P. Price, G. Schwenke, Z. Hochman, I. Daniells, A. Biggs, D. Freebairn, K. Watling and N. Cupples. Queensland Department of Primary Industries and Fisheries: Brisbane.

FAO (Food and Agriculture Organization of the United Nations) 1998. Production yearbook, Vol. 52. FAO: Rome.

FAO (Food and Agriculture Organization of the United Nations) 1999. Production yearbook, Vol. 53. FAO: Rome.

FAO/UNDP (Food and Agriculture Organization of the United Nations/United Nations Development Programme) 1986. Classification of the soils of Bangladesh FAO: Rome.

FAO/UNDP (Food and Agriculture Organization of the United Nations/United Nations Development Programme) 1988. Land resources appraisal of Bangladesh for agricultural development, Vol. 2: agroecological regions of Bangladesh. FAO: Rome.

Faruque H. and Alam S. 2002. State of arsenic contamination in Bangladesh. International Water Conference, Hanoi, Vietnam, 14–16 October 2002. At <http://www.bvsde.ops-oms.org/bvsacd/dialogo/shahid.pdf>, accessed 12 April 2011.

French R.J. and Schultz J.E. 1984a. Water use efficiency of wheat in a Mediterranean-type environment. I. The relation between yield, water use and climate. Australian Journal of Agricultural Research 35, 743–764.

French R.J. and Schultz J.E. 1984b. Water use efficiency of wheat in a Mediterranean-type environment. II. Some limitations to efficiency. Australian Journal of Agricultural Research 35, 765–775.

Haque S.A. 2006. Salinity problems and crop production in coastal regions of Bangladesh. Pakistan Journal of Botany 38(5), 1359–1365.

Harvey C.F., Ashfaque K.N., Yu W., Badruzzaman A.B.M., Ali M. A., Oates P.M., Michael H.A., Neumann R.B., Beckie R., Islam S. and Ahmed M.F. 2006. Groundwater dynamics and arsenic contamination in Bangladesh. Chemical Geology 228 (1–3), 112–136.

Hobbs P.R. and Morris M. 1996. Meeting south Asia's future food requirements from rice–wheat cropping systems: priority issues facing researchers in the post-green revolution era. Natural Resources Group (NRG) Paper 96-01. International Maize and Wheat Improvement Center (CIMMYT): Mexico.

Huth N.I., Thorburn P.J., Radford B.J. and Thornton C.M. 2010. Impacts of fertilisers and legumes on N_2O and CO_2 emissions from soils in subtropical agricultural systems: a simulation study. Agriculture, Ecosystems & Environment 136, 351–357.

Kahlown M.A., Ashra M. and Zia-ul-Haq 2005. Effect of shallow groundwater table on crop water requirements and crop yields. Agricultural Water Management 76, 24–35.

Keating B.A., Carberry P.S., Hammer G.L., Probert M.E., Robertson M.J., Holzworth D., Huth N.I., Hargreaves J.N.G., Meinke H., Hochman Z., McLean G., Verburg K., Snow V., Dimes J.P., Silburn M., Wang E., Brown S., Bristow K.L., Asseng S., Chapman S., McCown R.L., Freebairn D.M. and Smith C.J. 2003. An overview of APSIM, a model designed for farming systems simulation. European Journal of Agronomy 18, 267–288.

Kirschbaum M.U.F. 1995. The temperature and dependence of soil organic matter decomposition, and the effect of global warming on soil organic-C storage. Soil Biology & Biochemistry 27, 753–760.

Ministry of Agriculture 2007. Handbook of agricultural statistics, December 2007. Ministry of Agriculture, Government of the People's Republic of Bangladesh: Dhaka. At <http://www.moa.gov.bd/statistics/statistics.htm>, accessed 12 April 2011.

Poulton P.L., Rawson H.M., Dalgliesh N.P. and Carberry P.S. 2010. Inserting wheat into rice-based farming systems of southern Bangladesh. Proceedings of the Australian Society of Agronomy conference, Lincoln, New Zealand, 15–19 November 2010. At <http://www.regional.org.au/au/asa/2010/farming-systems/international/7165_poultonp.htm#TopOfPage>, accessed 12 April 2011.

Poulton P.L. and Saifuzzaman M. 2010. Assessing potential additions to crop yields from shallow water tables for smallholder farmers during the Rabi season in southern Bangladesh. Presented at The International Scientific Week around Agronomy Agro2010, 29 August to 3 September. At <http://www.agropolis.fr/agro2010/paper/s332/poulton.pdf>, accessed 12 April 2011.

Rahman M. and Bhattacharya A.K. 2006. Salinity intrusion and its management aspects in Bangladesh. Journal of Environmental Hydrology 14, Paper 14.

Rahman S.M., Khalil M.I. and Ahmed M.F. 1995. Yield–water relations and nitrogen utilization by wheat in salt-affected soils of Bangladesh. Agricultural Water Management 28, 49–56.

Rashid H.E. 1991. Geography of Bangladesh, second revised edition. The University Press: Dhaka.

Rawson H.M., Gomez-Macpherson H., Hossain A.B.S., Saifuzzaman M., Rashid H., Sufian M.A., Samad M.A., Sarker A.Z., Ahmed F., Talukder Z.I., Rahman M., Siddique M.M.A.B., Hossain I. and Amin M. 2007. On-farm wheat trials in Bangladesh: a study to reduce perceived constraints to yield in traditional wheat areas and southern lands that remain fallow during the dry season. Experimental Agriculture 43, 21–40.

QDNR (Queensland Department of Natural Resources) 1997. Salinity management handbook. QDNR: Brisbane.

Shahid S. 2010. Spatial assessment of groundwater demand in northwest Bangladesh. International Journal of Water 5(3), 267–283.

Shelley M.R. 2010. Power crisis: heart of the darkness. The Daily Star, Thursday 13 May 2010. The Daily Star: Dhaka. At <http://www.thedailystar.net/newDesign/news-details.php?nid=138178>, accessed 12 April 2011.

SRDI (Soil Resource Development Institute) 2001. Soil and water salinity in the coastal area of Bangladesh. SRDI: Dhaka.

USDA (United States Department of Agriculture) 2009. Bangladesh grain and feed annual 2009. Global Agriculture Information Network (GAIN) Report No. BG9003. USDA Foreign Agricultural Service: Washington DC. Accessible at <http://www.fas.usda.gov/gainfiles/200902/146327245.pdf>.

Verburg K. 1996. Methodology in soil water and solute balance modelling: an evaluation of the APSIM-SoilWat and SWIMv2 models. Divisional Report 131. Commonwealth Scientific and Industrial Research Organisation (CSIRO): Canberra.

Walkley A. 1947. A critical examination of a rapid method for determining organic carbon in soils: effects of variations in digestion conditions and of inorganic soil constituents. Soil Science 63, 251–264.

Walkley A. and Black I.A. 1934. An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Science 37, 29–38.

WFP (United Nations World Food Programme) 2010. Agricultural production & national food balance, Bangladesh. WFP: Rome. At <http://foodsecurityatlas.org/bgd/country/availability/agricultural-production>, accessed 12 April 2011.

Yamane Y., Hayashi T., Dewa A.M. and Akter F. 2010. Severe local convective storms in Bangladesh: part 1, climatology. Atmospheric Research 95, 400–406.

2.3 Land availability

Perry L. Poulton

Abstract

This chapter assesses how much suitable fallow land is available at the correct time in the Rabi season for wheat production. It uses published statistics from the Department of Agricultural Extension and Bangladesh Bureau of Statistics (DAE/BBS) in five separate ways to estimate the area of fallow land and adds estimates made using satellite-mapping techniques. It concludes that if farmers in the seven study areas of the Australian Centre for International Agricultural Research (ACIAR) project could be encouraged to sow an extra 215,000 ha to wheat in the south, this area representing just 25% of the estimated suitable fallow land during Rabi, they would contribute 0.62 million tonnes of grain (at 2.85 t/ha) to annual wheat production in Bangladesh.

The following methods were used to estimate total fallow and suitable fallow area for Rabi wheat cropping in the south:

- The raw DAE statistics, which up-scale land use on a few selected farms to the district level, indicated around 200,000 ha fallow plus wasteland could be available for wheat.
- Much larger estimates, averaging 818,305 ha and ranging between 1,208,068 ha and 428,543 ha were produced by working backwards from actual land use for the main cropping periods of Kharif-1, Kharif-2 and Rabi.
- A fallow total of 1,045,809 ha was estimated by summing the statistics for cropping intensity for each district.
- The final approach used the detailed land-use data for boro rice and other major and minor crops and subtracted the sum of those areas from the total cultivable area. This calculation produced values for Rabi total fallow of 1,110,809 ha for 2006–07 and 1,027,877 ha for 2007–08.

Only medium–high land and medium–low land are likely to be suitable or available for growing wheat. Applying this land class filter to the whole southern zone indicated that around 0.86 million ha of suitable land is potentially available for wheat during Rabi.

Introduction

Bangladesh is supported by a traditional agricultural economy with over 50% of the 7.3 million ha of land area currently under cultivation; of this, the southern region, which is the focal area for this analysis, accounts for approximately 38% (2.7 million ha). Situated on a river delta, comprised of 79% flood plain, the country is one of few regions that continue to grow in area, particularly along fringes of the southern coastline, due to deposition from siltation. Originally saline mudflats, these ‘char’ lands are leached annually as a result of monsoonal rains and irrigation practice, becoming progressively less saline and more suitable for agriculture over time. Evidence of these dynamic processes is readily found along the Bangladesh coastline in currently productive rice fields which, less than 15 years ago, were shown as ocean on satellite-derived maps. It is these southern regions that have attracted attention since 2003 for intensification of agriculture, with estimates of up to 800,000 ha of fallow land potentially available for cultivation during the dry (Rabi) season. A study in 2003–05 funded by the Food and Agriculture Organization of the United Nations (FAO) raised the possibility of using this southern fallow land for wheat production (Rawson et al. 2007). Later studies, funded in 2005–10 by the Australian Centre for International Agricultural Research (ACIAR), reassessed the nature, extent and realistic availability of fallow land for additional Rabi cropping and its likely suitability for cropping wheat and mungbean. This chapter describes the approaches used in the ACIAR project to identify what area of underused land can really be used for wheat expansion.

Land availability

Farmers keep their land fallow for agricultural management, environmental, social or economic reasons. The Bangladesh Bureau of Statistics (BBS) publishes extensive agricultural statistical data on land use. Six methods are used here to interpret those data in order to assess what area of fallow land is realistically available for sowing crops such as wheat or mungbean in southern Bangladesh. The last approach uses processed satellite images. Also considered is the capacity of current farming systems to take on additional cropping on any land identified as fallow. Social or local justification for choosing not to farm fallow land is discussed elsewhere (Chapter 1.2, this volume). Current land-use and cropping sequences are also considered when reaching conclusions about availability of land for intensified cultivation.

Rice-based farming systems, both rainfed and irrigated, are the most important cropping system in South Asia (Devendra and Thomas 2002), with rice representing food security for the majority of Bangladesh's 15 million farm holdings (BBS 2006). For many farmers, rice is planted in each of the three major growing seasons, Kharif-1, Kharif-2 and Rabi, with traditional cultivation occurring during the annual monsoon from June to November. Rice fields are expected to produce at least two rice crops annually in normal seasons, with early-season aus rice planted during Kharif-1 (March–April) followed by a larger planting of transplanted (T.) aman rice during the summer rains of Kharif-2. A third rice crop, boro, which is intensively irrigated, is planted during the Rabi or winter months, putting it potentially into competition for land with wheat, vegetable, pulse and fodder crops. Figure 4 in Chapter 1.1 (this volume) shows the range of planting and harvest dates for some of the main Bangladesh crops, while Figure 1 in Chapter 4.3 illustrates the months of the three seasons. Boro rice (high-yielding varieties; HYVs) has significantly increased in area and production since the early 1970s (Figure 5 in Chapter 1.1, this volume) at the expense of traditional aus plantings, accounting for over 50% of Bangladesh's cereal area of 4.2 million ha in 2007–08. Boro is currently the major contributor to total rice production although further expansion may now be limited due to increasing costs of inputs and availability of irrigation resources (Asaduzzaman et al. 2010). By comparison, the 394,000 ha sown to wheat during season 2008–09 was estimated at around 9% of the area occupied by boro.

Analysis 1: estimating fallow area using current land-use statistics

Agricultural statistical data are collected four times each year by the Department of Agricultural Extension (DAE) using both subjective and objective methodologies. Five farms consisting of large and small holdings are randomly selected at a union (parish) level and the farmers interviewed about their crops. Using those selected statistics and scaling them up produces estimates of cropping areas over the entire district. These surveys are combined with cluster plot sampling at over 9,300 sites for the entire country to estimate cropping area at a district level. The accuracy of these data relies heavily on initial farm typologies determined during farm selection and in the process of scaling up these results to over 11.6 million (1996 data) Bangladesh farm holdings. District-wise agricultural data collected by DAE are the primary source for the statistical information used in these analyses.

These data are partitioned into 20 subdistricts or upazilas (Figure 1b) to aid spatial evaluation and comparisons between locations. Using the data, the BBS estimates that fallow land totals 124,225 ha for the southern cropping region, distributed as shown in Figure 2a.

BBS additionally estimates the area of cultivable wasteland; this is not included within their estimate of areas 'under cultivation'. Using land utilisation data from 2004–05 and 2006–07, land classified as waste was estimated at about 2.5% of cultivated area; approximately 67,548 ha in the south. Combining estimates for fallow and wasteland areas suggests 191,773 ha of land (Figure 2b) is underutilised and potentially available for additional Rabi cropping (Table 1). This area is less than half that from a 2003–05 FAO-funded study (Rawson et al. 2007) that reported fallow land in southern Bangladesh as 'more than 400,000 ha'. To understand this large difference in estimates requires further analysis of the data collection process. That process may not

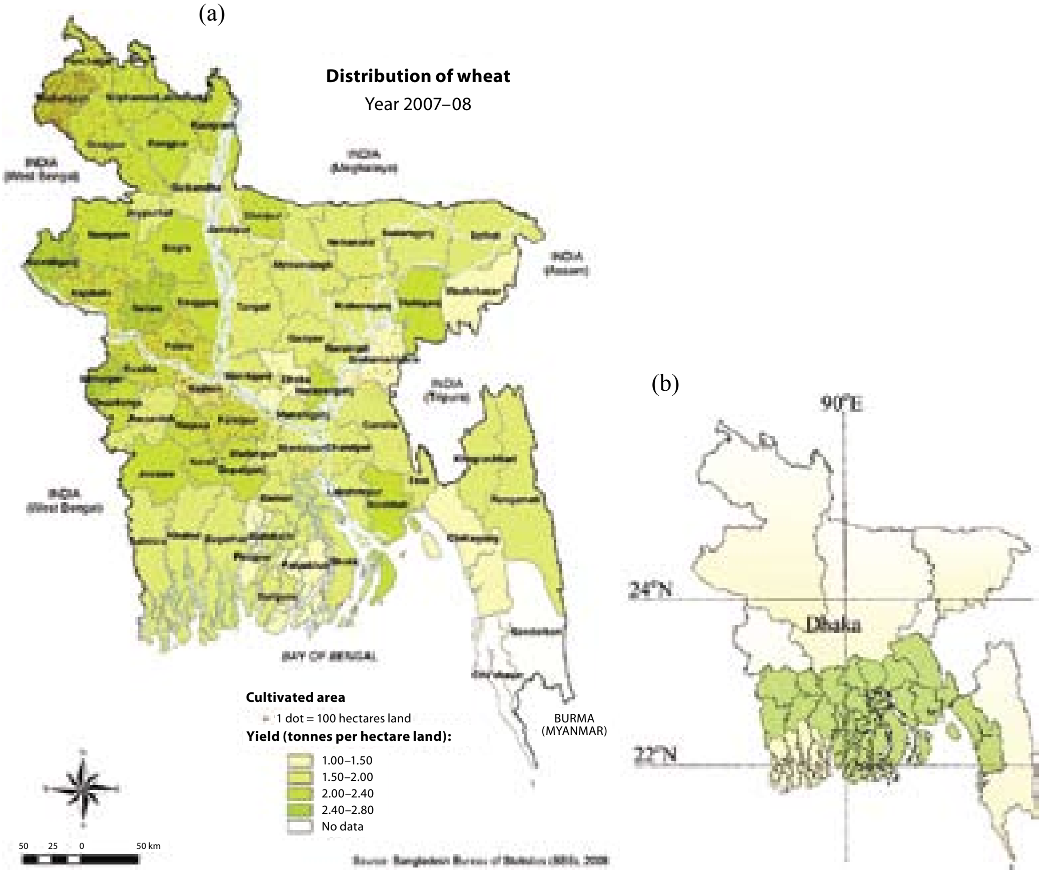


Figure 1. Maps of Bangladesh showing (a) the distribution of wheat for the 2007–08 Rabi season (Source: WFP 2010) and (b) locations of the 20 southern regions (upazilas) evaluated in this analysis—these regions account for 2.7 million ha of land currently under cultivation

account for the dynamic nature of current cropping sequences and ignore planting window opportunities within current cropping patterns. It may only consider land remaining fallow between rice plantings. The expanded analyses follow.

Analysis 2: estimating fallow area using cropping intensity (land utilisation)

Population expansion in Bangladesh is reducing the area of land that can be cultivated. Consequently, greater total crop production in Bangladesh can come only from increased cropping intensity, which is more crops on each land area in a year, and higher yields (Roy 2002). Cropping intensity is calculated from the area of land used and its frequency of cropping during the three growing seasons of Kharif-1, Kharif-2 and Rabi. Triple cropping means the same land will be cropped in all three seasons. The BBS reports the proportion of agricultural land under single, double or triple cropping at a district level (Table 2). Those data are used in Table 3 to estimate the potential area cultivated during each of the three growing seasons.

Land utilisation or cropping intensity (Figure 3) for the southern region of 176% (±24%) reflects local expectation that capacity exists for additional cultivation; it could be 200–300%. The area cultivated during both Kharif-1 and Rabi is assumed equal in area (inclusive of double- and triple-cropped area),

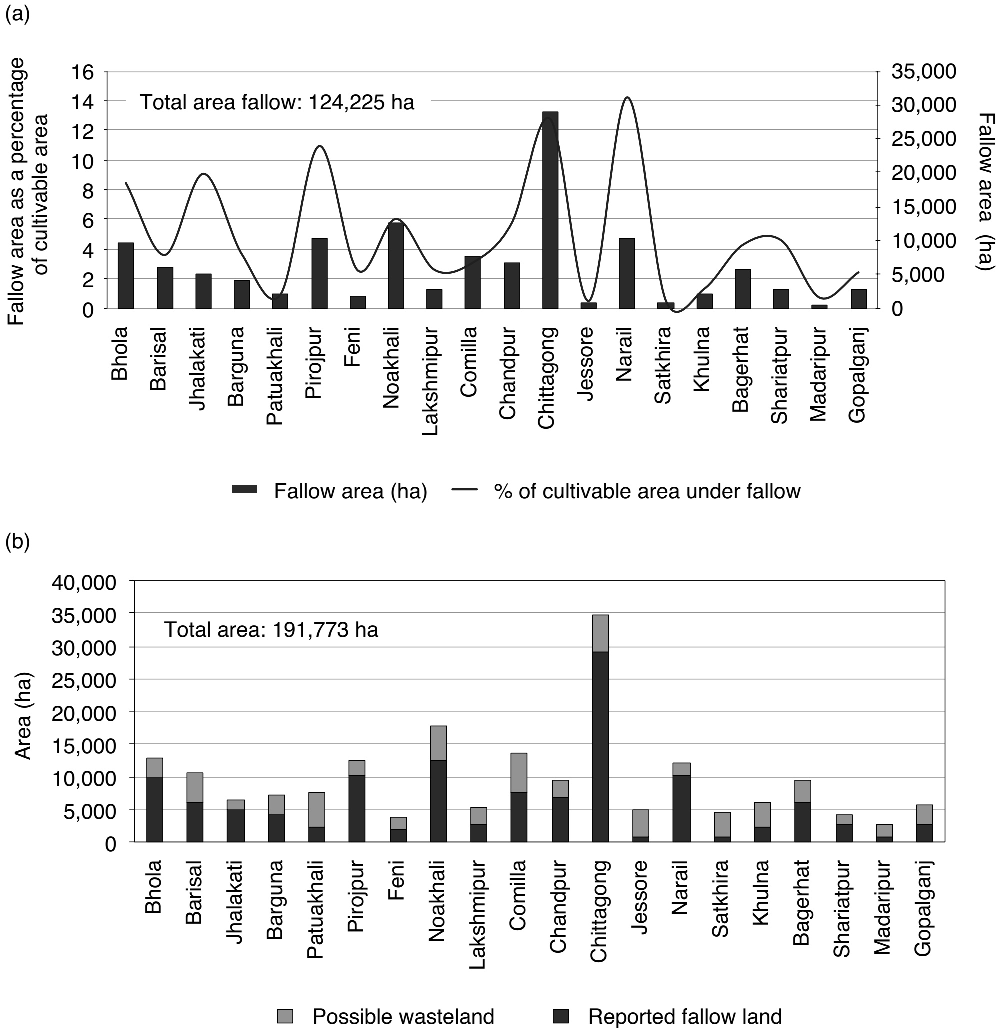


Figure 2. Area remaining under fallow during the 2005–06 season: (a) calculated values for fallow land are expressed as a percentage of the total area under cultivation for each subdistrict (upazila); (b) reported estimates of fallow land and wasteland for each area (all data sourced from the 2005 agricultural census)

while Kharif-2 includes all single-, double- and triple-cropped areas. Estimated fallow area for a particular season is the difference between total area available for cultivation (Figure 3) and current cropped area. Results in Table 3 are expressed as a range of values reflecting the level of inaccuracy associated with the statistical data and assumptions used in calculating the farm land cultivated each season.

In Table 3, the upper limit estimate (maximum) of available fallow land is the difference between total cultivable area and land currently cropped in Rabi. The lower limit (minimum) for fallow land is the difference between the total cultivable area and the land used by boro and all other crops (assuming average plantings of 53.5% for boro and 40.5% for other crops from Table 4). Land reported as currently fallow and cultivable wasteland is included with cropping.

Estimates of Rabi fallow for 2003–04 (*italics* in Table 4) range from 1.09 to 0.34 million ha of land and for 2004–05 from around 1.26 to 0.43 million ha.

This method of using cropping frequency was applied to land-utilisation data from BBS for the entire country from 2000 to 2007 (Table 4). Cultivable area for the southern region was considered to increase from 30% to 38% of total area during the 7 years and results in an average 7-year estimate of Rabi fallow land of between 1.20 and 0.43 million ha (standard deviation (SD) 0.10–0.12 million ha).

Analysis 3: estimating fallow area using knowledge of local crop sequences

The previous analyses have used BBS statistical data based on aggregated estimates of cultivated area at the district or country level. Introducing additional (new) crops into an area requires knowledge of the

Table 1. Estimated fallow area for the southern region of Bangladesh based on district-wise reports of current fallow area

Analysis	Data source	Year	Fallow area (ha)
1. Current statistics	2005–06 agricultural census	2005–06	
From BBS, collected by	Fallow area, all districts		124,225
DAE	Wasteland, all districts		67,548
Estimated total fallow area			191,773

Note: DAE = Department of Agricultural Economics
Source: Bangladesh Bureau of Statistics (BBS)

Table 2. Greater district-wise land utilisation data (×1,000 ha) for 2003–04 for selected southern districts—total cropped area is the summed area of single-, double- and triple-cropping intensity

District	All area	Forest area	N\A[a]	Waste area	Fallow area	Single crop	Double crop	Triple crop	Net area sown	All crop area
Chittagong	824	264	244	20	12	100	145	39	284	507
Comilla	672	1	169	5	12	152	261	72	485	890
Noakhali	617	184	111	12	1	101	149	59	309	576
Faridpur	698	0	199	7	16	148	247	82	477	887
Jessore	657	0	197	9	20	68	281	81	431	874
Khulna	1,239	577	306	14	32	276	113	21	410	565
Patuakhali	504	113	33	2	4	183	139	30	352	550
All south	5,211	1,139	1,259	70	97	1,027	1,335	384	2,747	4,850

[a] N/A = not available for cultivation
Source: reproduced from the Bangladesh Bureau of Statistics

Table 3. Calculated land area (×1,000 ha) cultivated (cult) and remaining fallow in the Kharif-1, Kharif-2 and Rabi seasons in 2003–04

District	Cultivable area total	Kharif-2 area cult	Rabi area cult	Kharif-1 area cult	Fallow area	Estimated Kharif-2 fallow	Estimated max Rabi fallow	Estimated min Rabi fallow
Chittagong	316	284	184	184	12	32	132	93
Comilla	502	485	333	333	12	17	169	96
Noakhali	322	309	208	208	1	13	114	55
Faridpur	500	477	329	329	16	23	171	89
Jessore	460	431	362	362	20	29	98	17
Khulna	356	410	134	134	32	(54)	222	201
Patuakhali	358	352	169	169	4	6	189	159
All south	2,813	2,747	1,719	1,719	97	67	1,094	710

Note: Area of land remaining fallow during the Kharif-2 and Rabi seasons is estimated using a cropping intensity approach to land use; total cultivable area is the difference between total district area and land planted to forest and land not available for cultivation (N\A in Table 2)
Source: based on data from the Bangladesh Bureau of Statistics (Table 2)

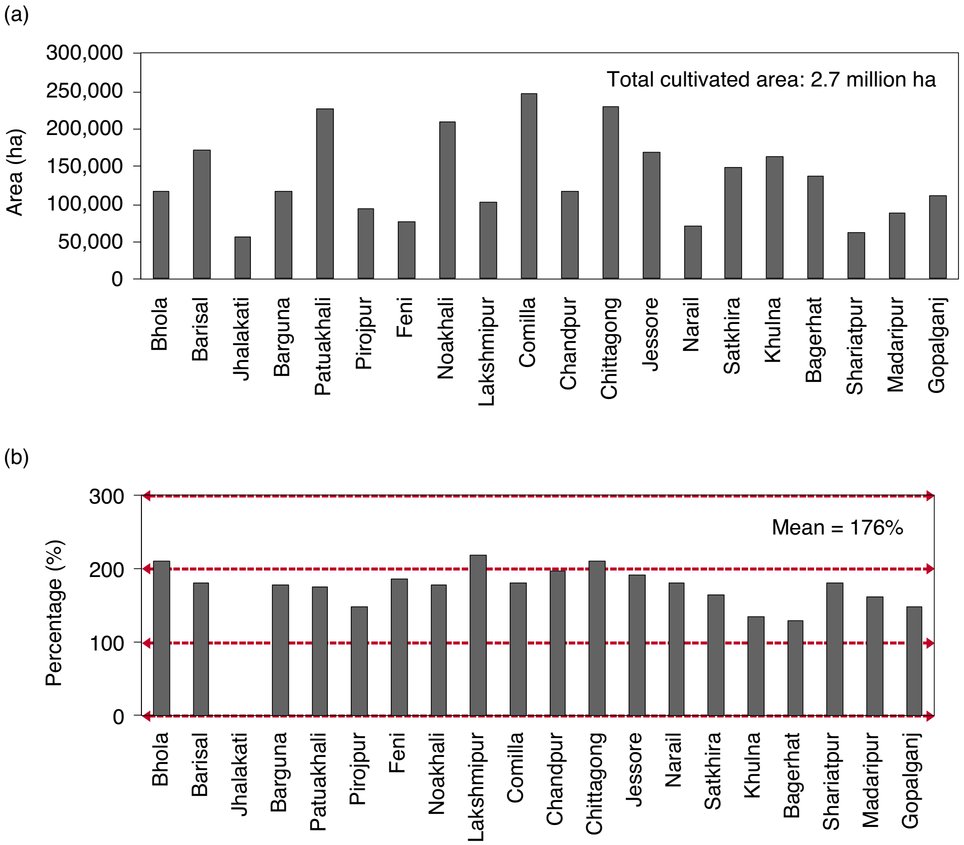


Figure 3. (a) Surveyed distribution of cultivated land in the 2005–06 season for 20 upazilas, totalling 2.7 million ha for southern Bangladesh; (b) cropping intensity for 19 of the 20 locations in southern Bangladesh—the red lines indicate 1, 2 or 3 (300%) crops/year (all data sourced from the 2005–06 agricultural census)

farming system and cropping sequence or pattern practised at the local level. Shahidullah et al. (2008) described cropping patterns as the yearly sequence and temporal and partial arrangement of crops in a given land area. A crop sequence approach assesses opportunities for timely exploitation of short fallow periods to include additional crops in the current sequence, within the growing season.

Shahidullah et al. (2008) reported 18 potential cropping patterns in the Noakhali district alone, of which eight were composed entirely of rice crops. In Rabi 2001–02, nearly 50% of the cropped area remained fallow as the result of three major cropping patterns (fallow/fallow/T. aman, fallow/broadcast (B.) aus/T. aman, and fallow/T. aus/T. aman) (Shahidullah et al. 2008). DAE survey data for 2005–06 used 10 key cropping sequences to describe the farming systems for Noakhali, Feni and Lakshmipur. In Noakhali, three cropping sequences accounted for over 70% of the cultivated area with only two, fallow/fallow/T. aman at 27%, and fallow/aus/T. aman at 7%, offering an opportunity to sow additional (new) Rabi crops. These two cropping sequences were analysed using the method described above under cropping intensity to estimate Rabi fallow for 2005–06 (Table 5) in the Noakhali district at approximately 90,932 ha or 40% of the cultivable area and Feni at approximately 37,472 ha (49%). Detailed crop sequence data cover only 290,000 ha or around 10% of the southern region, but provide a direct comparison with aggregated data on cropping intensity for the three locations (Table 5).

Table 4. Estimated fallow area (ha) for the southern region of Bangladesh based on land-utilisation statistical data

Analysis	Data source	Year	Estimated max. fallow	Estimated min. fallow	Estimated average fallow
2. Cropping intensity (regional)	Land-utililisation statistics	2000–01	1,084,023	374,956	729,490
		2001–02	1,117,521	389,416	753,468
		2002–03	1,144,238	390,739	767,489
		2003–04	1,155,392	394,216	774,804
		2004–05	1,202,052	419,902	810,977
		2005–06	1,341,214	502,255	921,734
		2006–07	1,412,033	528,314	970,173
		2003–04	*1,094,188*	*335,515*	*714,851*
		2004–05	*1,268,622*	*431,488*	*850,055*
Estimated total fallow area:		All districts	1,208,068	428,543	818,305

Source: data from Bangladesh Bureau of Statistics

Table 5. Estimated maximum, minimum and mean fallow area (ha) for selected districts based on evaluation of current cropping intensity data and crop sequence data

Analysis	Data source	Year	District	Estimated max. fallow	Estimated min. fallow	Estimated average fallow
3. District cropping pattern	Crop Intensity data	2005–06	Noakhali	108,950	77,095	93,023
		2005–06	Feni	11,503	174	5,839
		2005–06	Lakshmipur	20,505	0	10,253
	Crop sequence data	2005–06	Noakhali			90,932
		2005–06	Feni			37,472

Source: data from Department of Agricultural Extension, Noakhali

Analysis 4: estimating fallow area using cropping intensity at the district level

Statistical estimates of cropping intensity at the district level for 2004–05 (BBS) for major crops such as rice, jute, sugar and wheat are used in calculating the area under cultivation during each of the three cropping periods as detailed above. To simplify this approach, all Rabi crops other than the major four assume coverage at 23.8% of cultivable area in all districts (calculated in Table 7). That number is based on the analysis of whole-of-country crop statistics for 2000–06 (Table 6).

The area of cultivation for each season is calculated from individual crop areas in Tables 6 and 7 and produces an estimate of 1.04 million ha of potentially available fallow land in the south during the 2004–05 Rabi (Table 8). District estimates for Noakhali of 87,411 ha (Table 8) are comparable with the 90,932 ha calculated using a crop sequence analysis (Table 5), thus creating confidence in the analyses used.

Analysis 5: estimating fallow area using boro statistics

Statistical data on rice production are available at a district scale for all of Bangladesh and when combined with estimates of land used for Rabi crops provide a further approach for calculating potential fallow area. Data for boro production (local + HYV + hybrid) and cultivated area for 2006–07 and 2007–08 for the 20 southern districts were used for analysis. Boro, as a percentage of cultivable land, occupied 35.1% and 38.1% for the two seasons with other Rabi crops assumed to be 23.8% (Table 7). Using this method of difference between all cultivated area and summed areas of boro and other Rabi crops gave estimates of fallow area at 41.1% and 38.1% or 1.110 and 1.028 million ha for 2006–08 (Table 9).

Table 6. Bangladesh crop production area (×1,000 ha) for all crops (2000–06)

	Crop	2000–01	2001–02	2002–03	2003–04	2004–05	2005–06	Mean
Rice	aus	1325	1242	1243	1202	1024	1034	1178
	aman	5709	5647	5682	5677	5279	5429	5571
	boro	3761	3771	3844	3943	4063	4065	3908
Oilseed	mustard	318	330	298	279	242	217	280
	til	37	37	39	39	39	31	37
	linseed	5	5	5	4	5	14	6
	peanut	33	26	27	26	29	29	28
	coconut	31	31	31	39	5	9	24
Cereal	wheat	773	742	706	642	558	479	650
	maize	26	30	29	50	68	98	50
	barley	6	4	2	2	1	1	3
	other	73	73	42	38	36	26	48
Cash crop	jute	448.2	456.5	436.6	407.9	390.0	399.0	423
	cotton	45.2	51.2	47.6	12.8	11.7	10.2	30
	sugarcane	168.8	162.7	176.0	163.7	157.2	152.5	163
	tobacco	30.0	30.6	30.8	30.4	29.8	31.7	31
	tea	48.6	49.5	50.5	51.0	53.2	52.5	51
Pulse	gram	16.2	15.4	15.1	13.9	13.1	12.7	14
	mungbean	52.6	45.3	44.3	43.6	24.4	22.4	39
	lentil	164.4	157.0	154.1	154.8	153.9	134.7	153
	knesari	187.0	181.7	185.7	159.2	148.4	127.4	165
	mashkalai	27.1	26.3	25.5	25.0	23.2	23.4	25
	other	21.1	22.0	23.6	24.3	20.3	16.8	21
Spice-potato	chilli	174.9	170.0	170.0	162.2	154.8	142.5	162
	onion	34.0	36.8	37.6	52.0	86.4	115.6	60
	garlic	13.4	14.2	14.5	21.1	25.6	26.6	19
	ginger	7.3	7.7	7.7	7.9	7.7	8.0	8
	other	23.1	23.5	23.5	26.4	27.7	28.4	25
	potato	249.0	237.6	245.3	270.9	326.3	301.2	272
	sweetpotato	39.3	38.1	36.8	35.8	35.0	34.1	37
Vegetable	brinjal (Kharif)	22.3	22.3	22.3	22.5	21.2	19.5	22
	brinjal (Rabi)	42.1	40.9	40.6	37.5	36.5	31.2	38
	tomato	15.0	15.4	15.8	17.9	17.7	18.8	17
	cauliflower	10.9	10.9	11.2	12.5	13.2	15.1	12
	cabbage	11.7	11.7	12.1	12.7	13.6	14.8	13
	radish	22.3	22.7	22.7	23.4	24.4	24.9	23
other	summer	73.7	82.6	86.6	55.9	106.6	59.8	78
other	Rabi	36.8	37.2	52.6	7.87	7.49	7.84	25
Fruit	mango	50.6	50.6	50.8	51.0	25.1	26.0	42
	banana	42.9	44.9	45.3	49.3	53.9	56.0	49
	pineapple	14.17	14.2	14.2	16.8	18.5	17.1	16
	papaya	6.5	6.9	7.3	7.7	3.1	1.1	5
	jackfruit	26.7	27.1	27.0	27.7	7.4	9.2	21
	lychee	4.9	5.3	5.4	5.7	1.8	1.7	4
	guava	10.1	10.1	16.2	16.9	6.1	5.8	11
	melon	10.5	10.5	10.5	10.8	4.4	4.4	9

Source: reproduced from Bangladesh Bureau of Statistics data

Table 7. Total crop production area (×1,000 ha) for crops, summarised from Table 6

	2000–01	2001–02	2002–03	2003–04	2004–05	2005–06	Mean
Total area of all crops	7,214	7,189	7,189	7,102	7,098	6,924	7,119
Total area of Rabi crops	6,952	6,914	6,903	6,838	6,850	6,724	6,864
Area of all crops excluding boro, wheat, sugar, jute	1,813	1,795	1,753	1,687	1,716	1,656	1,737
Unutilised area	86	111	111	198	202	376	181
Available during Rabi	348	386	397	462	450	576	436
% area of boro rice	51.5	51.7	52.7	54.0	55.7	55.7	53.5
% area of other crops	43.7	43.1	41.9	39.7	38.2	36.4	40.5
% area of Rabi crops—no boro, wheat, sugar, jute	24.8	24.6	24.0	23.1	23.5	22.7	23.8
% area available	4.8	5.3	5.4	6.3	6.2	7.9	6.0

Table 8. Estimated fallow area (ha) for selected districts based on evaluation of cropping intensity

Analysis	Data source	Year	District	Estimated average fallow (ha)
4. Cropping intensity (district level)	Estimated fallow area	2004–05	Bhola	74,438
			Barisal	78,253
			Jhalakati	33,922
			Barguna	67,701
			Patuakhali	110,707
			Pirojpur	53,685
			Noakhali	87,411
Estimated fallow, all 20 southern districts				1,045,809

Source: data from Bangladesh Bureau of Statistics

Table 9. Estimated maximum, minimum and mean fallow area (ha) for selected districts and the southern region based on land remaining fallow after allowing for the area planted to boro rice and other Rabi crops

Analysis	Year	District	Estimated max. fallow	Estimated min. fallow	Estimated average fallow
5. After boro rice		Bhola	45,573	67,137	56,355
		Barisal	74,494	109,236	91,865
		Jhalakati	33,788	46,974	40,381
		Barguna	87,005	116,004	101,505
		Patuakhali	166,108	221,360	193,734
		Pirojpur	56,375	76,984	66,680
		Noakhali	111,980	154,135	133,057
Fallow area after Rabi-crops (and boro) excluded	2006–07	All districts			1,110,086
	2007–08	All districts			1,027,877

Source: data from Bangladesh Bureau of Statistics

Analysis 6: estimating fallow area using satellite images

Detailed survey data collected at a regional scale by DAE and reported by the BBS are the critical source of land-use information. However, the collection, processing and publication of these data can take several years. An alternative way to generate land cover and land-use data quickly is to use satellite remote sensing and analysis techniques (Rogan and Chen 2003). Poulton and Dalgliesh (2008) used this approach to estimate that 10–13% of a 1,592 ha randomly selected zone for the Noakhali region remained uncultivated between December 2006 and March 2007 (Figure 4). The analysis techniques used for satellite ground scans differentiate easily between water bodies, forests and regions of bare soil, so the method is relatively accurate for calculating areas of bare-soil fallow. To distinguish areas of individual crops automatically from scans requires calibration of

Figure 4. Satellite picture of the Noakhali region showing fallow land as pink-magenta, trees as dark green, ponds as dark purple, and crops, forage or weeds as light green (Source: Poulton and Dalgliesh 2008)

small areas on the satellite images to the same areas of actual crops on the ground ('ground-truthing'). This was not done in the Noakhali example.

Expanding the satellite mapping analysis approach from the 1,592 ha sample to the whole southern region indicated that around 0.23 million ha of bare soil fallow was potentially available during the 2006–07 Rabi for cropping (Table 10). Land covered in weeds or forage was not distinguished by this method and this would add significantly to the area likely to be fallow.

Land class filters to assess fallow as suitable or not for wheat

It is not realistic to assume that all land considered as available for cropping is suitable for Rabi crops such as wheat or mungbean, given that southern Bangladesh lies close to sea level and is flooded to varying degrees by fresh water during the monsoon. The extent, level and duration of this inundation is described under five land classes from high land (class 1) to very low land (class 5). Large tracts of very low land are completely inundated during the monsoon and because of water depth and duration of inundation are unsuitable for traditional T. aman rice, they are used instead for jute during March (Figure 5).

Very low and low lands are not normally considered for growing wheat as they drain slowly at the end of the monsoon and can remain waterlogged for extended periods and be naturally saline. Farmers prefer to use medium–high and medium–low land for wheat or mungbean cultivation. These two land classes together make up about 80.7% of the southern region. High land is only a small proportion of the available land for the majority of regions and is usually reserved for vegetable or fruit plantings close to farm houses. Figure 6a shows the wide variation in percentage distribution of land types between the 20 southern upazilas with Barguna, for example, being entirely medium–high land to Gopalganj having a large proportion of low and very low land.

Figure 6b shows how much fallow land of the type suited to wheat cultivation (medium–high and medium–low land) is likely to be available in each of the 20 upazilas. Data are from BBS estimates. Assuming the proportion of fallow land is evenly distributed across all land classes, approximately 95,272 ha of fallow land is suitable for wheat. Using

Table 10. Estimated fallow area (ha) for the southern region and selected districts during Rabi, based on interpreted land-use data from satellite imagery

Analysis	Year	District	Estimated max. fallow	Estimated min. fallow	Estimated average fallow
6. Satellite imagery to estimate bare fallow	2006–07	Bhola	15,917	12,579	14,248
		Barisal	23,456	16,417	19,936
		Jhalakati	7,618	5,296	6,457
		Barguna	15,938	9,871	12,905
		Patuakhali	30,793	16,170	23,482
		Pirojpur	12,881	9,604	11,242
		Noakhali	28,581	15,266	21,923
Total fallow area:	2006–07	All districts			226,984

Figure 5. Crop of jute (Photo: PLP)

this approach of applying land-class filters to the area of fallow land better represents local farm practice and provides an acceptably accurate picture of land most likely to be utilised for cultivation; the approach is applied to more detailed district-wise estimates reported below under ‘current practice’.

Current practice

Wheat is grown predominantly in the cooler northern regions (Figure 1) under irrigation and to a small extent in the south where, until recently, it was considered ill-matched to the climatological and technological constraints. These constraints have had little impact in some southern districts with, for example, >8,000 ha currently sown to wheat in Comilla, Jessore and Chandpur (Figure 7). These districts have a significant farmer knowledge base with capacity for adoption of new wheat cultivars and management technologies but may lack capacity for further expansion given limited availability of suitable fallow land. Agriculture proceeds on millions of small farms with no more than 1 ha (2.5 acres) of land; these smallholdings account for 88% of farms and 60% of all cultivated land (Asaduzzaman et al. 2010). Selection of experimental sites for seed multiplication trials (SMTs), demonstration and detailed agronomy trials (2007 to 2010) in the ACIAR-funded project has focused on regions with traditional rice/fallow land and on farmers with little or no exposure to wheat cultivation.

The area of wheat production (2005) for ACIAR project districts presented in Figure 7 shows significant potential for the expansion of Rabi-season

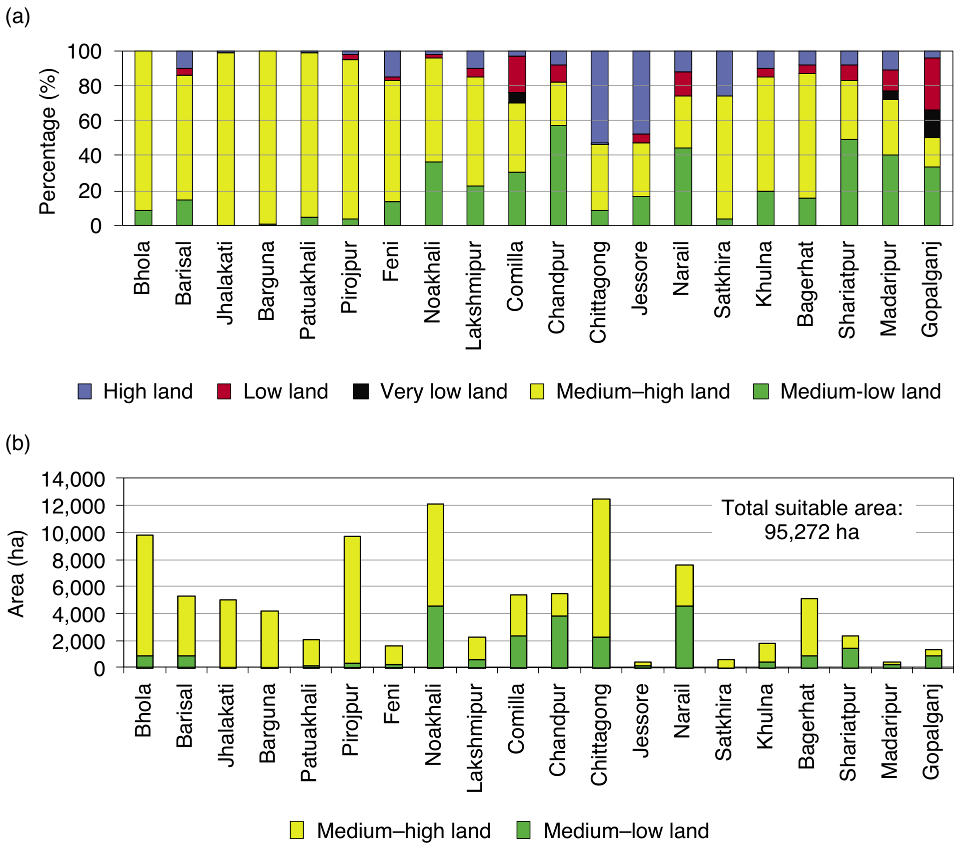


Figure 6. (a) Calculated land inundation type (land class) expressed as a percentage of the total area under cultivation for each upazila; (b) estimated area of fallow land of medium–high and medium–low inundation class types (suitable for wheat)

cropping in the south if all land currently fallow is utilised for cropping. It is estimated that the seven regions in Figure 8a could contribute an additional 487,671 ha of land of medium–high and medium–low inundation type, suitable for wheat and mungbean cultivation, if the new heat-tolerant varieties and irrigation-management strategies are used. Estimates of 0.86 million ha of land classified as medium–high and medium–low land remain fallow in southern Bangladesh (Figure 8b).

Discussion

Estimates from the BBS that fallow land in southern Bangladesh during Rabi is 0.12 million ha are at odds with earlier published figures and with results of the analyses in this chapter. Including land considered cultivable wasteland (70,000 ha) with the fallow land estimates increases the area potentially available for expanded Rabi cultivation but raises questions of what wastelands are, where they are and how appropriate they are for Rabi agriculture.

Understanding cropping sequences identifies opportunities for additional crops at a district level and leads to a more realistic approximation of underutilised land during Rabi. Crop intensity statistical data for all districts from 2000 to 2007 (0.81 million ha fallow land) and boro rice production data from 2006 to 2008 (1.06 million ha fallow land) produced estimates more closely aligned with earlier studies. Land type largely determines the crops and management systems that farmers can choose and, by

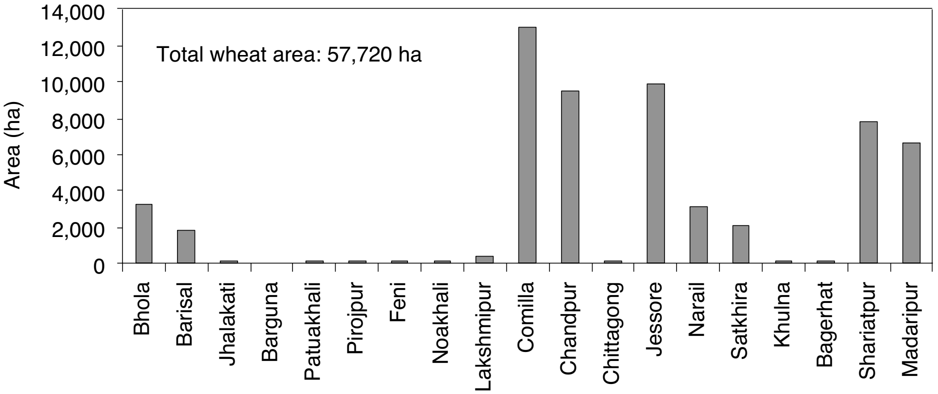


Figure 7. Area of current wheat production across the southern region in 2004–05

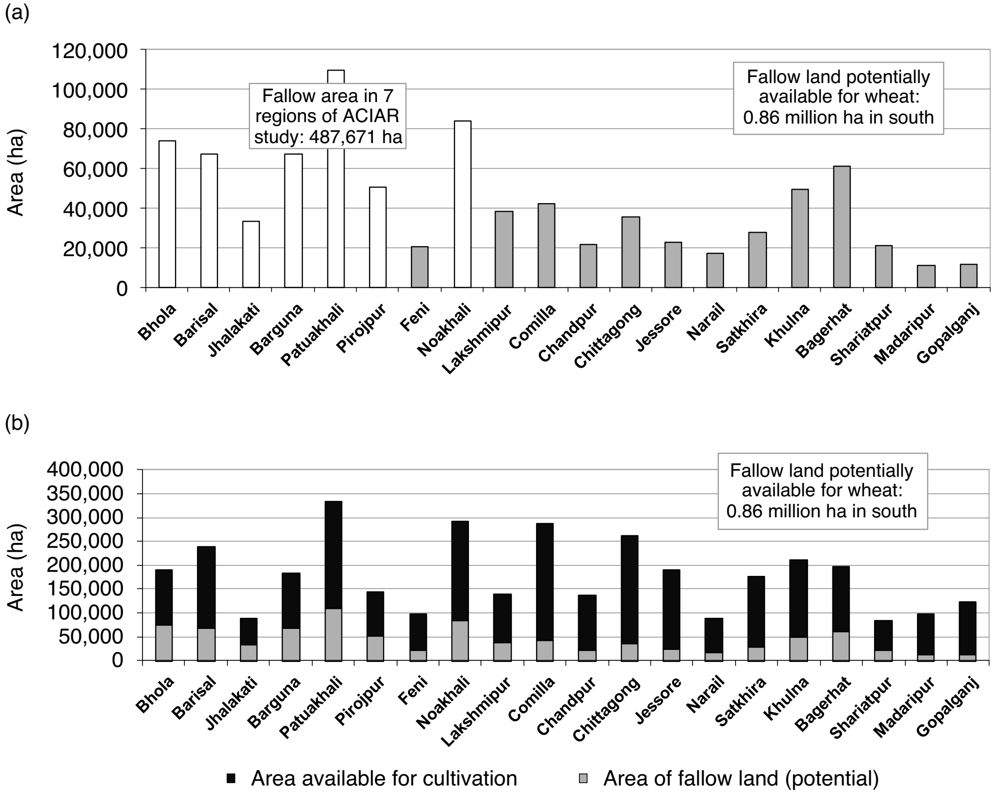


Figure 8. (a) Area suitable for wheat in each of the seven areas evaluated during the current Australian Centre for International Agricultural Research (ACIAR) project (unshaded) and Rabi fallow area in the remainder of the 20 southern upazilas (shaded); (b) estimated area of fallow land considered as medium–high and medium–low land classes shown in association with current area of cultivable land available in each of the 20 upazilas

including land inundation classification in estimating land availability in different seasons, aligns estimates of unused land with current farming practices.

The assumption that farmers are more likely to prefer medium–high and medium–low land for sowing of wheat can be used to better gauge realistically usable fallow area for the southern region. Land of these two classes represents around 0.86 million ha of potentially fallow land for the entire region and 0.56 million ha for the seven key districts of Bhola, Barisal, Jhalakati, Barguna, Patuakhali, Pirojpur and Noakhali, which are the subject of this ACIAR-funded project.

Declining land resources and competing demand for limited land is a major concern for future agriculture. New technological breakthroughs, appropriate development interventions and a robust land-use policy will be needed to address the problems (Rahman and Khan 2005). Use of satellite imagery offers a cost-effective and opportune approach for comparing land-use change at a regional scale and provides an alternative data source to complement local agency surveys.

The current technology does provide a baseline estimate of at least bare fallow land at a point in time but requires a level of ground-truthing to distinguish weedy fallow areas from that of other cultivation. Investment in more detailed crop or pasture identification utilising this technology has been successfully adopted in other countries and may provide a more robust methodology of land-use assessment in Bangladesh in the future.

The current area sown to wheat remains consistently low in comparison with boro rice and raises the question, if fallow land is available then why do farmers choose not to cultivate additional crops during the Rabi? Agriculture is dominated by rice cultivation, with limited crop diversification. Statistical data show increases in rice area from 75% (2003–04) to 84% (2008–09) with little change for the majority of other crops and indicate that crop diversification has moved only slightly since the 1980s from 0.54 to 0.60 (Deb 2008). An established practice in traditional rice/fallow systems for southern Bangladesh that cannot be ignored is that at the end of the monsoon in November large areas of rice lands not intended for boro are under-sown to forage such as grasspea (*Lathyrus sativus*) used for both human and animal consumption (Figure 9).

Initial assessment during the Rabi season describes these lands as grazed weedy fallow but in reality they should be termed as economically underutilised land rather than fallow in the traditional sense. Grasspea is highly susceptible to adverse seasonal variability but gives risk-averse farmers a low opportunity cost strategy offering reasonable economic returns. Land set aside for the purpose of grazing, such as T. aman fallow, has not been considered in this assessment of fallow potential and is suggested as a major factor in land currently left fallow. Factoring grazing in calculating fallow area will reduce those results and requires further localised evaluation of livestock management. Future changes to local economic drivers or government incentives may result in more intensive utilisation of these grazed lands for crops such as wheat or mungbean and therefore the potential for these lands cannot be ignored.

Figure 9. Grasspea being harvested in Noakhali (Photo: PLP)

Conclusion

Rice-based ecosystems of Bangladesh are complex in their nature, requiring an integrative approach by farming-system researchers in understanding smallholder farmers' decisions on a broad range of agricultural, environmental, social or economic reasons. Food security and livelihood are fundamental to the majority of farmers in managing their land, with investment in future cropping activity likely to progress slowly. Evaluation of statistical data, using the approaches described in this study, has revealed a range of possible estimates of available fallow—some as low as 191,773 ha based on use of current statistics. Use of detailed district-wide land-utilisation data has been demonstrated to result in consistent fallow estimates across statistical datasets spanning a period of up to 7 years.

This study suggests that approximately 0.86 million ha of land of medium–high and medium–low inundation type remain fallow in southern Bangladesh, although a significant proportion of this land should be considered as economically underutilised rather than unproductive fallow. Results are consistent with earlier studies and demonstrate that the research effort afforded to the last 3 years in targeting selected southern districts has been justified.

These seven study areas have significant potential for additional Rabi cropping in the future, with available fallow land estimated at around 0.49 million ha, and from planting opportunities within the current cropping sequence practised by the majority of smallholder farmers in these districts. Total land sown to wheat in Bangladesh is currently only 394,000 ha and, with significant areas of additional land suitable for additional Rabi cropping in the south, suggests excellent prospects for future expansion of wheat production in Bangladesh. A modest utilisation in the future by farmers in southern Bangladesh of only 25% of land currently fallow would see an additional 215,000 ha, or 54% of the current wheat area, sown during Rabi and contribute 0.62 million tonnes of grain (at 2.85 t/ha) to annual wheat production in Bangladesh.

References

Asaduzzaman M., Ringle C., Thurlow J. and Alam S. 2010. Investing in crop agriculture in Bangladesh for higher growth and productivity, and adaptation to climate change. Bangladesh Food Security Investment Forum, Dhaka, 26–27 May 2010. At: <http://bangladeshfoodsecurity.files.wordpress.com/2010/05/investing.pdf>, accessed 14 April 2011.

BBS (Bangladesh Bureau of Statistics) 2006. Handbook of agricultural statistics. BBS: Dhaka.

Deb U.K. 2008. Agricultural diversification in Bangladesh: progress, constraints and policy issues. Pp. 55–82 in 'Emerging issues in Bangladesh economy: a review of Bangladesh's development 2005–06', ed. by S.R. Osmani. Centre for Policy Development and The University Press Ltd: Dhaka.

Devendra C. and Thomas D. 2002. Smallholder farming systems in Asia. Agricultural Systems 71(1–2), 17–25.

Poulton P.L. and Dalgliesh N.P. 2008. Evaluating use of remote sensing for identifying management strategies: example for small plot farmers during the dry season in southern Bangladesh. In 'Global issues, paddock action', ed. by M. Unkovich. Proceedings of the 14th Agronomy Conference, Adelaide, South Australia, 21–25 September 2008. At <http://www.regional.org.au/au/asa/2008/concurrent/agronomy-abroad/5754_poultonpl.htm>, accessed 14 April 2011.

Rahman M.M. and Khan S.I. 2005. Food security in Bangladesh: food availability. In 'Food security in Bangladesh, Workshop, 19–20 October'. Islamic Development Bank (IDB) Bhaban: Dhaka.

Rawson H., Gomez-Macpherson H., Hossain A.B.S., Saifuzzaman M., Rashid H., Sufian M.A., Samad M.A., Sarker A.Z., Ahmed F., Talukder Z.I., Rahman M., Siddique M.M.A.B., Hossain I. and Amin, M. 2007. On-farm wheat trials in Bangladesh: a study to reduce perceived constraints to yield in traditional wheat areas and southern lands that remain fallow during the dry season. Experimental Agriculture 43, 21–40.

Rogan J. and Chen D.M. 2003. Remote sensing technology for mapping and monitoring land-cover and land-use change. Progress and Planning 61, 301–325.

Roy K.C. 2002. Hindrances of increasing cropping intensity: from agricultural machinery perspective. Agricultural Mechanization in Asia, Africa & Latin America 33(3), 61–64.

Shahidullah S., Talukder M., Kabir M., Khan A. and Elahi N. 2008. Cropping patterns in the south east coastal region of Bangladesh. Journal of Agriculture and Rural Development, North America, 4, 53–60.

WFP (United Nations World Food Programme) 2010. Agricultural production & national food balance, Bangladesh. WFP: Rome. At <http://foodsecurityatlas.org/bgd/country/availability/agricultural-production>, accessed 12 April 2011.

Section 3

Optimising wheat production through research

3.1 Building yield in Bangladesh wheat crops: experience from traditional wheat-producing regions

H.M. Rawson, M. Saifuzzaman, M. Abu Zaman Sarker, M. Ilias Hossain, M. Mustafa Khan, M. Abdul Khaleque, Abul Awlad Khan, M.M. Akhter and A. Hossain

Abstract

Using research crops of wheat from traditional wheat-producing areas of Bangladesh to understand how and why yields vary, this chapter identifies crop parameters and farm-management approaches that are likely to be needed in the southern and coastal zones of the Australian Centre for International Agricultural Research (ACIAR)-funded project. It defines the potential timing and width of the cropping window for wheat and describes how and why yield changes as crops are moved within that window. By comparing crops from Dinajpur in the north and Jessore in the south, it explains how temperature and radiation at different stages of crop growth can alter yield and its components and suggests that planting dates should be avoided that have a high risk of exposing the crop to low radiation or long-duration fogs during the immediate pre-anthesis phase. It sets some simple crop-development targets needed to achieve high yields.

The safest time for planting to achieve a good crop in the north is late November to early December, in part because this gives the longest crop duration to anthesis while still starting the grain-filling phase in relatively cool conditions. This gives 105–110-day crops. In the south (Jessore) this reduces to 90–95-day crops because of higher maximum temperatures in winter and because varietal heat-sum accumulations to anthesis are unchanged by location at 1,300 °Cd > 0 °Cd. This means that, from equivalent planting dates, Jessore commences grain filling earlier than in the north, resulting in grain filling proceeding over equivalent temperatures at the two locations. Grain filling heat-sums in the south were essentially unchanged by whenever grain filling occurred (780–750 °Cd > 0 °Cd), but in Dinajpur progressively later planting reduced grain-filling heat-sums from 870–650 °Cd > 0 °Cd, indicating something other than temperature is curtailing the phase. In two seasons, planting between early November and mid December in Jessore gave yields that exceeded 3 t/ha, but in Dinajpur yields well above 4 t/ha were achieved from the same period except when fogs reduced yields from the earliest plantings.

This Dinajpur/Jessore comparison indicates that the former location has the environment to out-yield the latter, implying the coastal south will never be better than the north. But the south may have less polluted air and fewer fogs, benefiting biomass production, and maximum temperatures may be more modulated by the presence of surrounding water while also producing heavier dews than any traditional sites. These would all boost yields. And with farmer training, the yield gap between most and least competent farmers of 67%, if brought towards the optimum, could potentially bring the coastal south into direct competition with the traditional wheat lands for production.

Introduction

This chapter sets the scene for wheat production in the southern region by looking first at yields and the yield-building process of wheat crops in the traditional wheat-growing areas of Bangladesh. From the analysis we might hope to guess some of the likely constraints and characteristics of crops to be grown in the south. For example, we might be able to define:

- the number of days needed to grow a crop of wheat
- how yield is changed by compressing that time window using the management approach of sowing at different dates
- the time to sow for highest yield
- the likely variation in yield between seasons and regions
- the size of the effects of weather on yield, such as impacts of high temperature and low radiation and whether these constraints have different effects at different crop stages
- changes in the components of yield such as grain numbers and grain boldness that arise from management practices.

The data used to try to answer these questions are from crops grown by wheat researchers over three sequential seasons, 2006–09. Researchers were at the Regional Agricultural Research Stations (RARSs) of the Bangladesh Agricultural Research Institute (BARI), located north to south at Dinajpur (25.62°/88.63° latitude/longitude in decimal degrees from the nearest town); Jamalpur (24.92°/89.94°); Rajshahi (24.36°/ 88.60°); Ishurdi (24.13°/89.07°); Joydebpur (23.99°/90.40°) and Jessore (23.16°/89.21°). Locations of most sites are shown on the map in Chapter 1.1 (Figure 7, this volume). The key sites for comparison in this chapter were the most northerly, Dinajpur, and the most southerly, Jessore. Jessore is the same latitude as Gaurnadi which is the most northerly farm in the Australian Centre for International Agricultural Research (ACIAR)-funded southern project.

To put these RARSs into spatial context, north to south transect distances between sites are Dinajpur 140 km to Rajshahi and a further 140 km from Rajshahi to Jessore. From Jessore to the most southerly farmer's crop in the ACIAR-funded trials is a further 160 km; the southern crops in the ACIAR-funded trials are described in Chapter 3.3 (this volume).

Matching methodologies were used at these six research centres over three seasons to grow crops of eight elite wheat varieties from eight sowing dates, 1 week apart after 7 November. Management included three irrigations and basal fertiliser plus nitrogen, top-dressed at 20 days after sowing. The sowing dates spanned the full possible time window in the Rabi (dry) season within which wheat might be grown (see Rawson et al. 2007 for details). Data presented here are the average of all varieties. Crop data were collected in three replicate measured cuts from individual plots, and yield at 12% moisture and components of yield were calculated as described earlier (Rawson et al. 2007). Cuts were from 2.4 m^2 to 3.6 m^2.

Number of days to grow a wheat crop

Depending on when these research-station crops were planted, they averaged between 110 and 95 days to complete their life cycle. As planting occurred progressively later from November through December, crops had a progressively shorter life cycle, losing days at an average of 0.35 days for every day that planting was delayed; the rate of loss accelerated with increasing delay. Consequently, a 115-day crop planted early in November lost 19 days growth if planted 55 days later in late December, (i.e. 55 × –0.35 days).

The general pattern just described for the average of the whole country held true over sequential seasons, with crop durations from particular sowing dates being altered by at most 3 days (Figure 1). These small changes are a consequence of averaging many diverse datasets. The weather data, also averaged over all locations, were also little different between the seasons. For example, during November, the 2006–07 season was 0.9 °C cooler with 2.7 MJ/d less sunshine than 2007–08 (21.9 versus (vs) 22.8 °C and 12.2 vs 14.9 MJ/d) while the 2008–09 season discussed later was warm (23.3 °C) and sunny (15.7 MJ/d). All three seasons were generally similar on average after November.

Wheat duration in different regions

Despite the average wheat life cycle following a similar pattern between years, it differed between regions. A similar rate of reduction in crop duration occurred with advance in planting date between regions, but some regions produced intrinsically shorter wheat durations. For example, Dinajpur crops in the north, with durations ranging between 115 and 95 days, took 6–9 days longer than Jessore in the south from equivalent sowing dates (Figure 2). Dinajpur crops therefore received 6–9 days more light overall than Jessore crops.

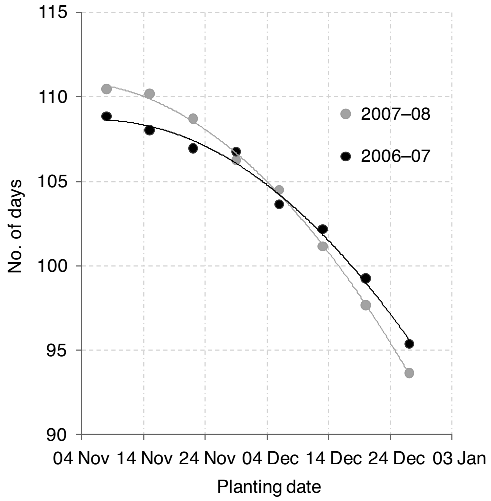


Figure 1. Days from sowing to maturity in the 2006–07 and 2007–08 seasons when crops were planted at different dates (data averaged for locations and cultivars)

From the finding that Jessore is 6–9 days earlier than Dinajpur we might predict that more southerly crops in Barisal and Bhola, areas used in the ACIAR work, would be even shorter duration, performing as 90–95-day varieties, so receiving even less sunshine days than Jessore. But this means only a narrow window is needed to fit wheat between successive rice crops.

Durations of the pre- and post-anthesis phases

In any analysis of crop yield, anthesis date is most important. It is a visual divider between the end of the vegetative stages (Figure 3), during which yield potential is accumulated by the crop, and the start of the grain-setting and grain-filling processes during which that yield potential is, or is not, realised. If the post-anthesis grain-growth period is very short, possibly because of high temperatures, grains may not have time to fill to their potential size so can be small or shrivelled. If the pre-anthesis period is short, the crop may not have sufficient growing time to accumulate enough ear-bearing shoots and enough potential grain sites on those shoots, and again yield may be small. In that way, the partitioning of crop time between pre- and post-anthesis can affect the structure of the crop. Table 1 shows how anthesis date is changed by planting date.

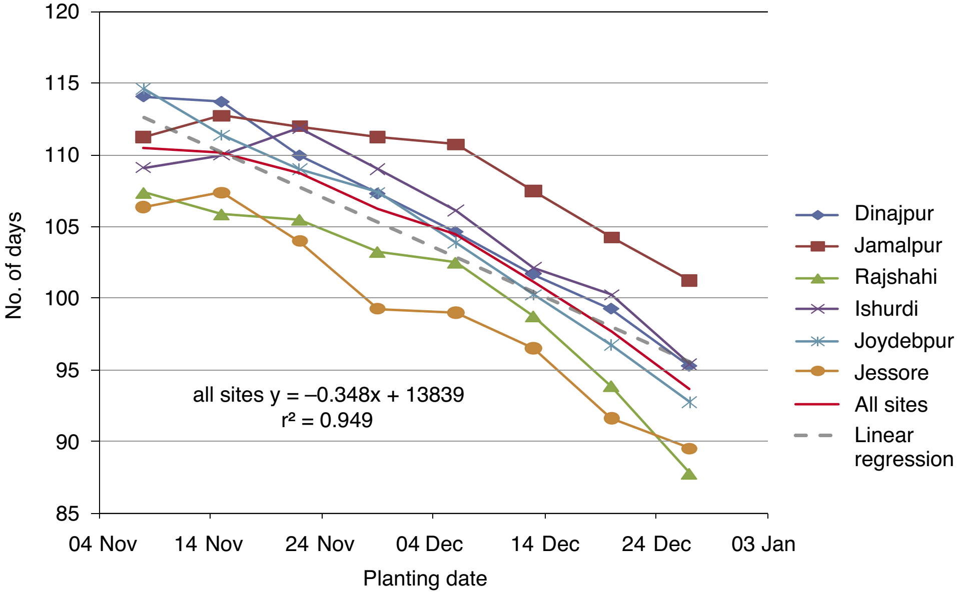


Figure 2. Days from sowing to maturity in the 2007–08 season when crops at six sites were planted at different dates (all cultivars)

Figure 3. Developmental stages of wheat: boot, heading and anthesis (Photo: HMR)

Anthesis date

Taking the average of six regions, anthesis date for any sowing date was altered between seasons by only 3–5 days (Table 1). So anthesis date could be readily estimated from experience. The southern Jessore crops took 65–67 days to anthesis regardless of planting date. By contrast, in other regions, the number of days from planting to anthesis changed with planting date.

The longest durations from planting to anthesis were from plantings around 4 December, usually considered to be within the optimum planting time, with shortest durations from the earliest plantings, which occurred during warm, pre-winter temperatures. The range was 11 days from 65 to 76 days (Figure 4). It is possible that the warmth accelerated vegetative development in these early crops, making them more responsive to the phenological development triggers of lower minimum temperatures and shorter photoperiods of 'winter' (Rawson et al. 1998). But the more likely explanation is that the varietal heat-sum requirements from planting to anthesis (Table 1) were met earlier from warm early plantings (Rawson 1993). Average heat-sums for two seasons for Dinajpur and Jessore were 1,306 ± 14 and 1,313 ± 10 °Cd > 0 °Cd, respectively. This similarity in heat-sum from two very different climates suggests that pre-anthesis durations in days for the varieties used here can be calculated for locations throughout the south from predicted temperature data. All plantings from Jessore behaved in terms of pre-anthesis duration like the earliest plantings of the north.

Advantage of early anthesis date

One advantage of reaching anthesis early, as from early plantings in the north, is that early crops can start to fill their grains in January to early February before temperatures rise significantly. Figure 5 shows grain-filling temperatures increasing linearly over 7 °C with lateness of planting. Data are for Dinajpur and Jessore.

Higher temperature shortens grain filling

In accordance with this rise in temperature, the post-anthesis phase during which the grains grow was progressively shortened by delay in planting date (Figure 6); 6 weeks delay in planting after early

Table 1. Anthesis date and thermal time accumulation as affected by planting date

Planting date	Anthesis date—all areas averaged		Days change between seasons	Heat-sum sowing to anthesis (°Cd > 0 °C)			
				Average eight varieties			
	2006–07	2007–08		Dinajpur 2006–07	Jessore 2006–07	Dinajpur 2007–08	Jessore 2007–08
8-Nov	9-Jan-07	14-Jan-08	5	1,254	1,325	1,350	1,367
15-Nov	20-Jan-07	24-Jan-08	4	1,265	1,344	1,399	1,373
22-Nov	30-Jan-07	2-Feb-08	3	1,250	1,355	1,356	1,295
29-Nov	6-Feb-07	10-Feb-08	4	1,301	1,353	1,363	1,266
6-Dec	12-Feb-07	17-Feb-08	5	1,285	1,305	1,357	1,264
13-Dec	18-Feb-07	23-Feb-08	5	1,248	1,301	1,328	1,254
20-Dec	24-Feb-07	29-Feb-08	5	1,220	1,314	1,306	1,274
27-Dec	2-Mar-07	6-Mar-08	4	1,181	1,309	No data	No data

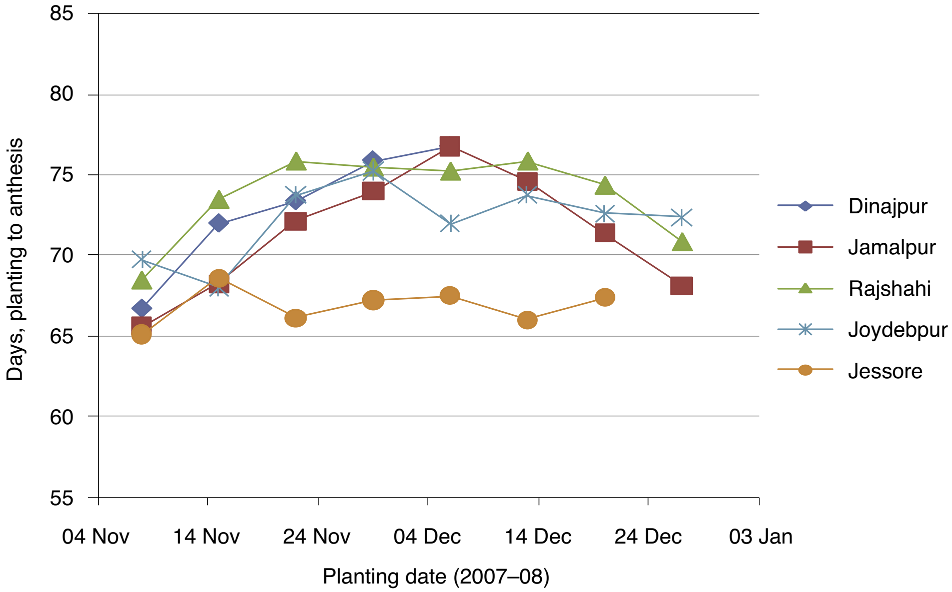


Figure 4. Change in length of the pre-anthesis phase with planting date for different locations, 2007–08

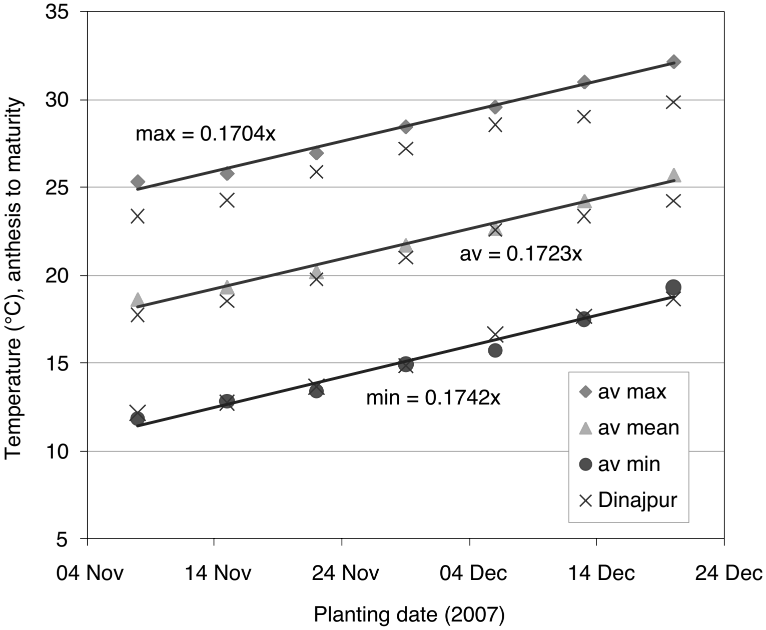


Figure 5. Grain-filling temperatures at Jessore (lines) and Dinajpur (crosses) from different planting dates in 2007

November reduced the grain phase from 40 days to 20 days on average. Differences between regions did not follow a north to south ranking but more likely a local temperature ranking.

Heat-sums during grain filling

Though number of days from anthesis to maturity followed a clear reducing trend with planting date for all locations, this was not the consistent case for heat-sums for the phase. It is generally found that rate of development during grain filling accelerates linearly with rising mean temperature, leading to similar heat-sums for the phase as temperature changes (Slafer and Rawson 1994). This is the Jessore pattern of 750–780 °Cd > 0 °Cd (Figure 7), excluding the latest planting. The contrary pattern, of rapidly reducing heat-sums with increased temperature, as found at Dinajpur (Figure 7), has previously been associated only with particular varieties (Hunt et al. 1991), not with locations. The Jessore heat-sum pattern is more likely to apply to the southern coastal regions.

Possible problems of early anthesis

Although early planting leads to grain filling occurring within lower temperatures, it could also result in exposure of these early northern crops to extended periods of fogs and low radiation in January when they are passing through the floret formative stages and pollen meiosis. During these sensitive stages between boot and anthesis (Figure 3), low radiation depresses floret production and can sterilise some of those florets, leading potentially to fewer grains (Rawson et al. 1996; Rawson and Noppakoonwong 1996). Anthesis should be timed to avoid any such negative recurring weather events (Stapper and Fischer 1990; Rawson 2003).

Yield and its components change with sowing date and season

The data are presented as averages for all eight varieties and seven locations for the three Rabi seasons (Figure 8). This allows us to see similarities and differences between seasons and the likely outcomes from planting at different times within any season.

Grain yield

The first clear outcome is that yield is sensitive to planting date and that selecting the wrong date might lose the farmer a third of potential yield. Yields are reliably highest from planting in late November to early December in the traditional zones regardless of year. Farmers who planted later than this would

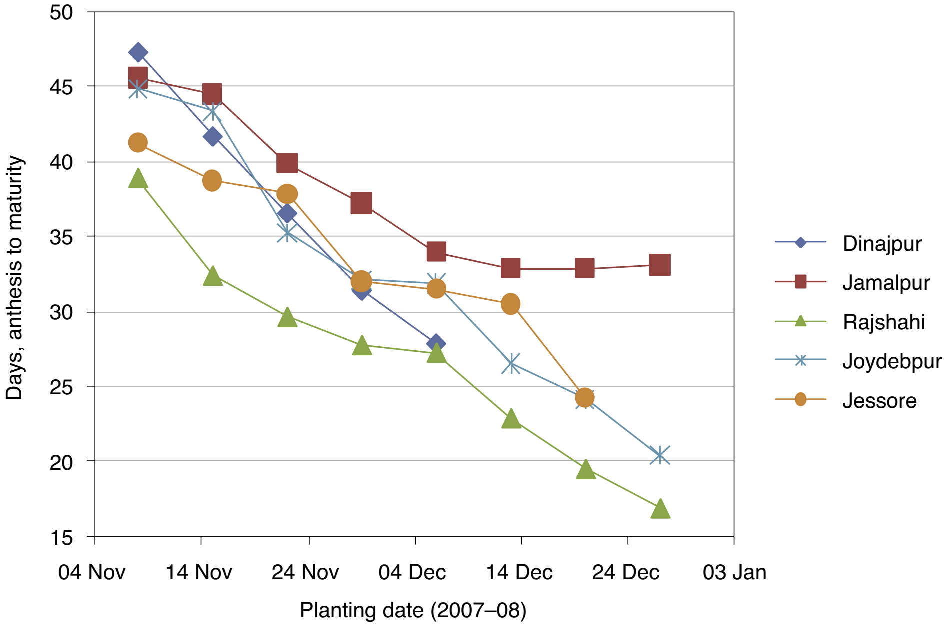


Figure 6. Change in length of the post-anthesis phase with planting date, 2007–08

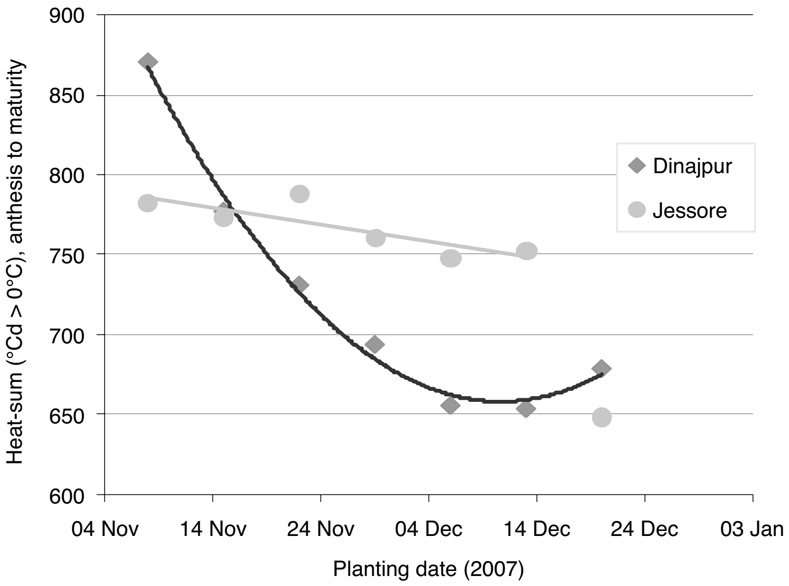


Figure 7. Heat-sum (°Cd > 0 °C), anthesis to maturity, after planting in 2007

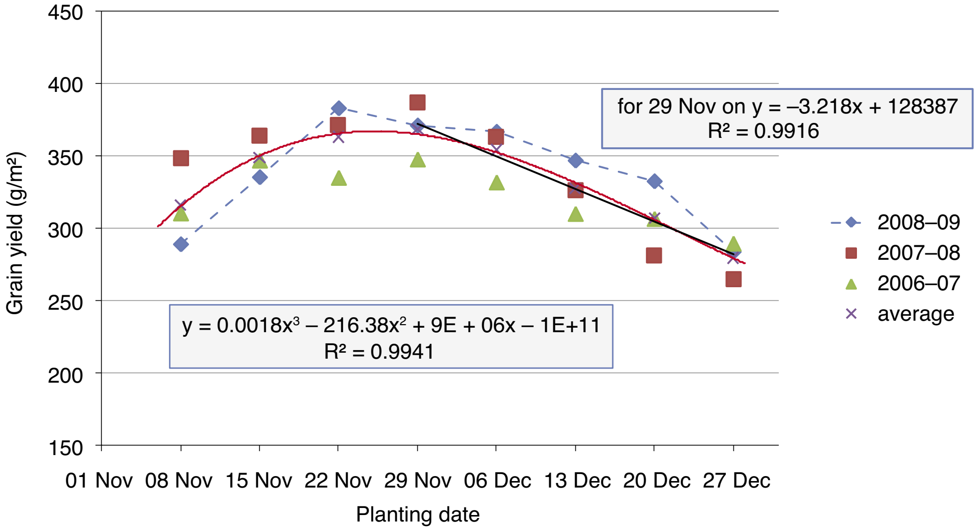


Figure 8. Grain yield as related to planting date over three seasons, 2006–09

lose around 32 kg yield per hectare per day's delay. Nevertheless, to plant as late as 20 December and harvest around 3 t/ha is still an economic proposition. The second outcome is that yield varies between years as does the relative yield achieved from different planting dates. For example, 2006–07 was a relatively poor year, with most yields between 3.0 and 3.5 t/ha, while 2007–08 produced crops of at least 3.5 t/ha from five of the eight planting dates. Season 2008–09 was also good overall, although early November plantings were poor. The reasons for poor yield from some early plantings are discussed later.

Weight per grain

This similarly reduces as planting date advances through December (Figure 9) and as the grain-filling phase is pushed into hotter conditions (Figure 5). For farmers who prefer bold (large) grains because these can carry a premium in the market, planting any time before 6 December is a guarantee of around 45 mg grains. Later planters lose 0.32 mg per grain per day delay. Grain size in Australian crops seldom reaches 40 mg so all these Bangladesh crops were outstanding in boldness. In the 2007–08 season, planting late in December carried a particularly large penalty in grain size. From the assumed relationship between increased temperature and reduced grain size, we might predict that southern crops grown under supposedly hotter conditions than in the north would have small grains. To assess the relationship between temperature and grain size, use the 2007–08 data from Figure 5 and Figure 9.

Biomass

Crops planted in late November tended to have the greatest biomass (biomass includes weight of grain and all above-ground material at harvest). This is in part because they took most days between sowing and anthesis (Figure 4) so had most days of sunlight. Early-planted crops could be light (or heavy) as could late-December crops (Figure 10a). Biomass gives an idea of how well the crop grew before anthesis. Poorly fertilised crops and crops that are unable to access nitrogen fertiliser, possibly through inadequate irrigation, are light and have relatively few ear-bearing culms per unit ground area. The rate of loss in biomass with planting date after late November averaged 500 kg/ha/day delay.

Harvest index

Harvest index (HI) describes the relative allocation of biomass between grains and non-grain material. More than 40% of biomass being grain is considered good. There was a trend for less allocation to grain as planting was delayed (Figure 10b) with HI falling from 42 to 36%. But this average trend was strongly influenced by the 2007–08 season. An average reduction in HI was 1% per day delay in planting date but in 2006–07 this did not apply. A crop with HI of 40% needs to produce 10 t/ha of biomass to yield 4 t/ha.

Culm and grain numbers

Number of culms averaged 300/m^2 which is close to optimum to produce a 4 t/ha crop, and this changed little with planting date (Figure 11a). 2006–07 produced fewer culms/m^2, particularly than season 2008–09. Numbers approaching 250/m^2 in 2006–07 could have been constraining yield as suggested by the regression (yield (g/m^2) = 1.42 × culms/m^2) in Figure 17. Culm numbers are determined by radiation and nitrogen availability during the early vegetative stages, other things being equal. Culms each bore about 28 grains and this number changed by less than 10% amongst planting dates in any season but ranged more between seasons (Figure 11b).

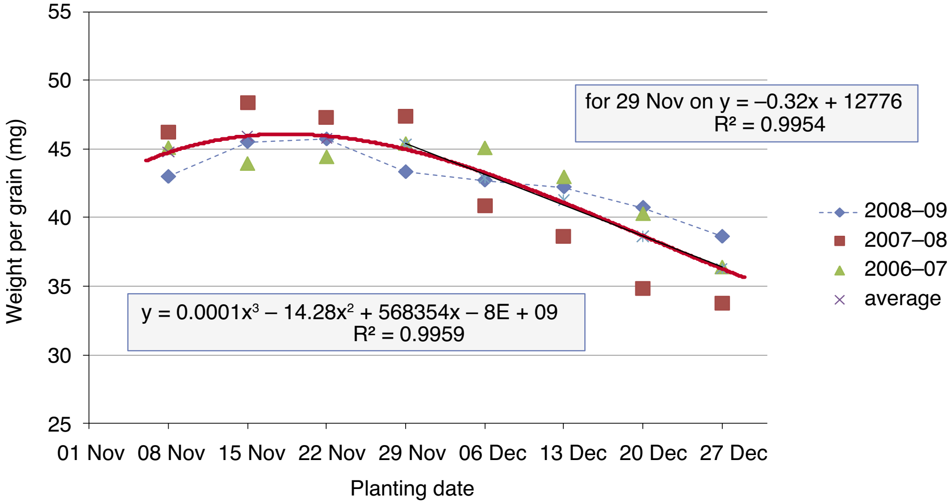


Figure 9. Weight per grain as related to planting date over three seasons, 2006–09

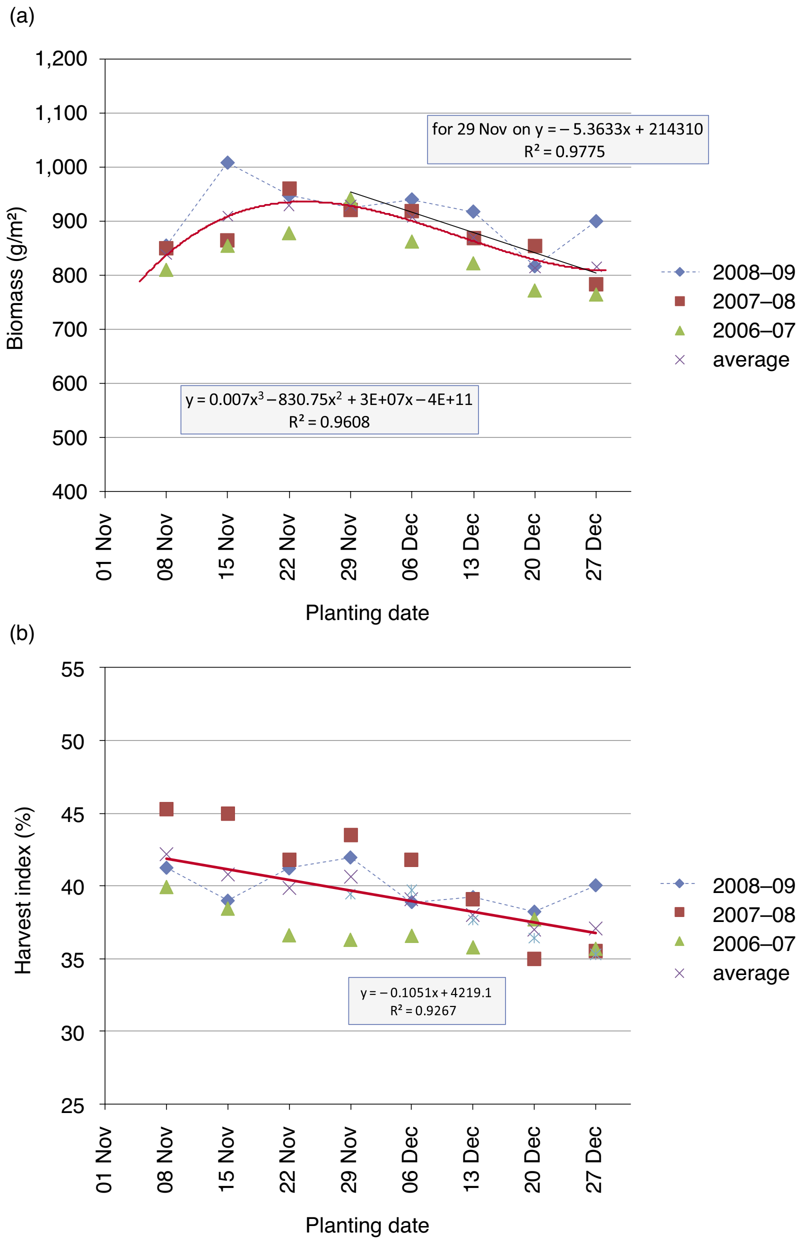
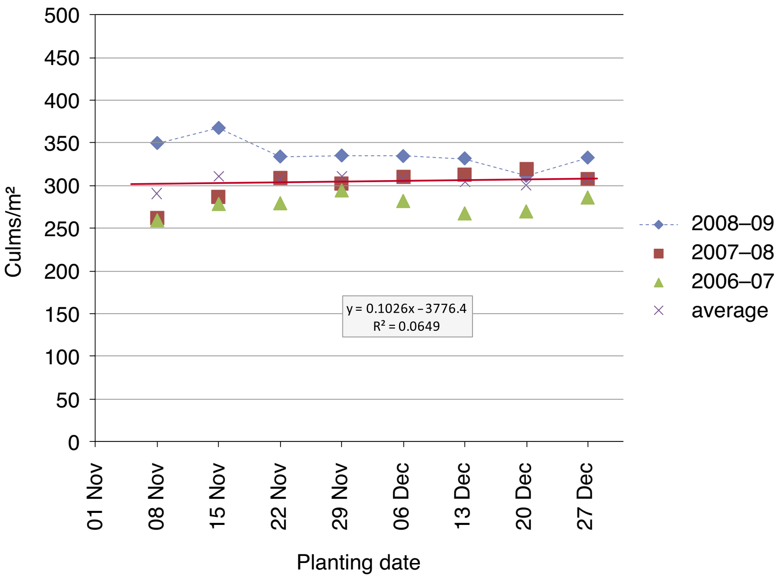


Figure 10. Biomass (a) and harvest index (b) as related to planting date over three seasons, 2006–09

(a)



(b)

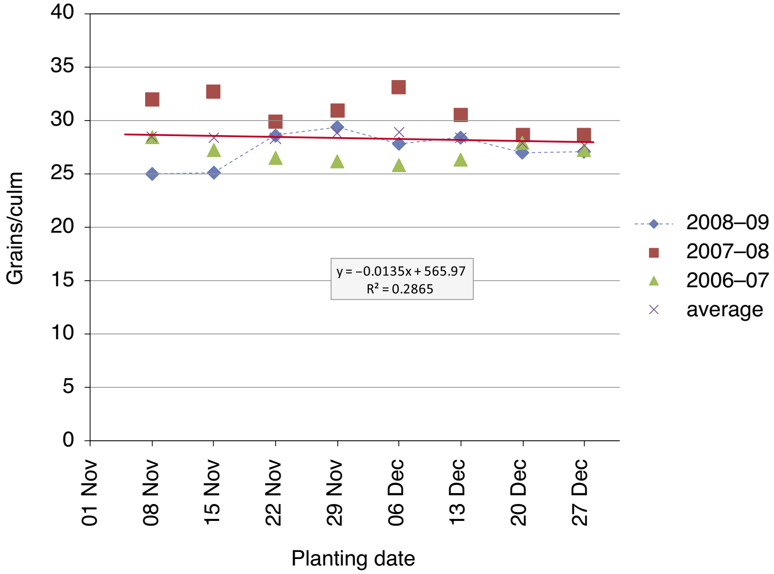


Figure 11. Culms/m² (a) and grains/culm (b) as related to planting date over three seasons, 2006–09

These overall values for yield components from the RARS crops enable us to set targets for numbers of plants, numbers of culms, numbers of grains and weight of grains depending on the yields that we want to achieve in the crops to be grown in the southern and coastal regions. Numbers can be manipulated by appropriate farm management, including by amounts and timing of fertiliser and water inputs.

The north and the south: Dinajpur and Jessore compared

In the preceding discussion, some of the regional effects on yield have been masked by presenting Bangladesh-wide averages. The following focus is on regional differences; specifically on comparing yield and biomass for Jessore and Dinajpur. Ishurdi, which is located between Dinajpur and Jessore, is included to provide confidence in the trends. The data are taken from the averaged general set that has just been described in overview. Two seasons only are compared. The questions asked are:

- Are yields always higher in the north (Dinajpur) than the south (Jessore)?
- Is the optimal planting window of late November the same in the north and south, so would we expect that this window would also apply in more southerly locations?
- Is it really hotter in Jessore than Dinajpur and, if so, what are the consequences to yield?

Average yields in 2007–08 and 2008–09 were higher in Dinajpur than Jessore (Figures 12 and 13) and in 2007–08 the optimal planting window of early to late November applied to both regions. In fact, the curves of yield versus sowing date for 2007–08 (Figure 12) were almost identical across locations, although yield was approximately 800 kg/ha lower in the south from any planting date. This result fits the generalised pattern for the traditional sites already described.

In the following season, 2008–09 (Figure 13), the optimal planting window in Jessore remained as early November to early December. In Dinajpur, the optimal planting window shifted to late November to mid December, because yields from early November plantings were severely depressed. The pattern for Ishurdi generally followed that for Dinajpur.

So why did this change in planting window between seasons occur in the north and not in Jessore? More specifically, why did early plantings in the north in 2008–09 yield below expectations?

Weather compared

The weather data show some key differences between Dinajpur and Jessore in terms of temperatures and radiation in 2008–09 Rabi season (Figure 14).

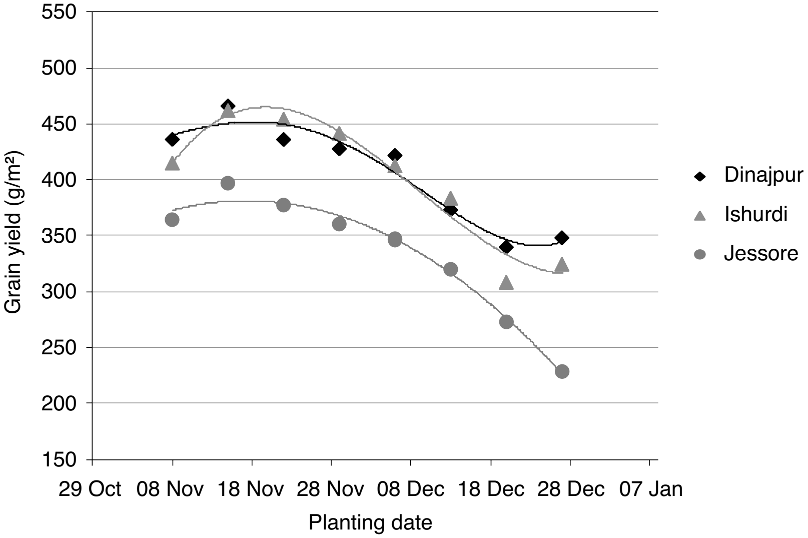


Figure 12. Grain yield and planting date at traditional wheat sites in the north and south, 2007–08

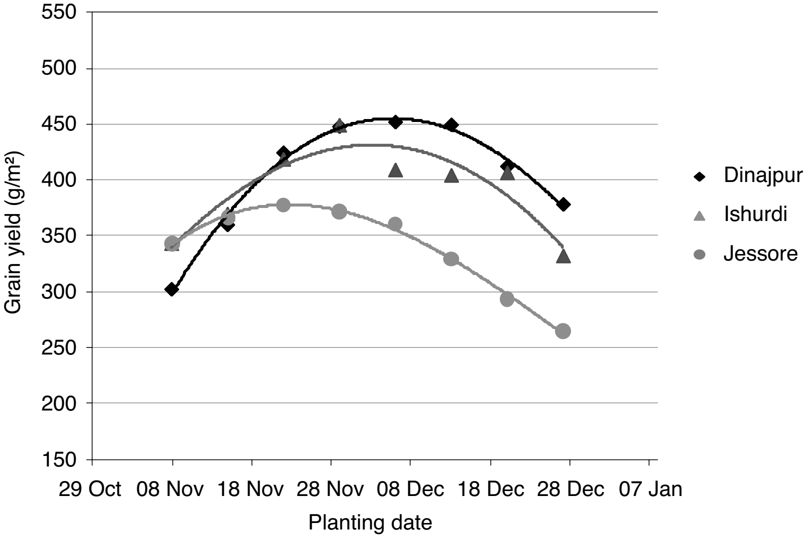


Figure 13. Grain yield and planting date at traditional wheat sites in the north and south, 2008–09

First, maximum temperatures were consistently higher in Jessore and up to 3 °C higher than Dinajpur for all except the beginning of the Rabi season. Second, minimum temperatures were very similar at Jessore and Dinajpur in all months but March when Jessore became hotter by more than 1 °C. Mean temperatures were always higher in Jessore than Dinajpur mainly because of the large differences in maximum temperature (but see Figure 5 for 2007–08-season grain-filling temperatures, which were similar between locations).

The third difference relates to radiation. While radiation at the two locations was not very different when summed over the whole of Rabi, there was a period between 11 December and 31 January when cumulative radiation was lower by 90 MJ/m² in Dinajpur than Jessore. This calendar period encompasses a stage in crop growth when biomass is accumulating quickly between early jointing and anthesis, particularly for early plantings (see anthesis dates in Table 1). Radiation drives photosynthesis and associated biomass production. Figure 15 shows how biomass was reduced by up to 3 t/ha in the early plantings of Dinajpur in 2008–09 (dashed blue line). This contrasts with 2007–08 (solid blue line) when radiation during jointing was not low. It also shows that Jessore was much less affected (c.f. dashed and solid yellow lines) as radiation in the two seasons was more similar.

These effects of radiation on biomass fed directly to yield as grain received 40% of biomass in this example regardless of the amount of biomass. Reduced radiation, whether as a consequence of fogs, particulate industrial pollution, dust or heavy cloud cover, reduces biomass production and usually yield.

Setting yield potential

The foregoing analysis may explain the differences in yield for specific planting dates at two locations in terms of radiation and associated biomass production but can similar arguments explain why Jessore produces lower yield overall than Dinajpur? Furthermore, what are the lessons to learn for the more southerly regions?

Considering optimal planting dates in late November, when Dinajpur produced up to 700 kg/ha higher yield than Jessore, the same arguments apply. As explained, Jessore has a higher mean temperature which, through its effects on accelerating phenological development, shortened the crop cycle to anthesis by 12%, equivalent to 8 days of radiation lost by the crop and equivalent reduction of biomass at anthesis.

This reduced biomass also led to fewer grains at Jessore than at Dinajpur (8,014 vs 8,701 ± 430/m², respectively) and, with equivalent HI, directly to differences in yield of 0.5 t/ha. Additionally, because the

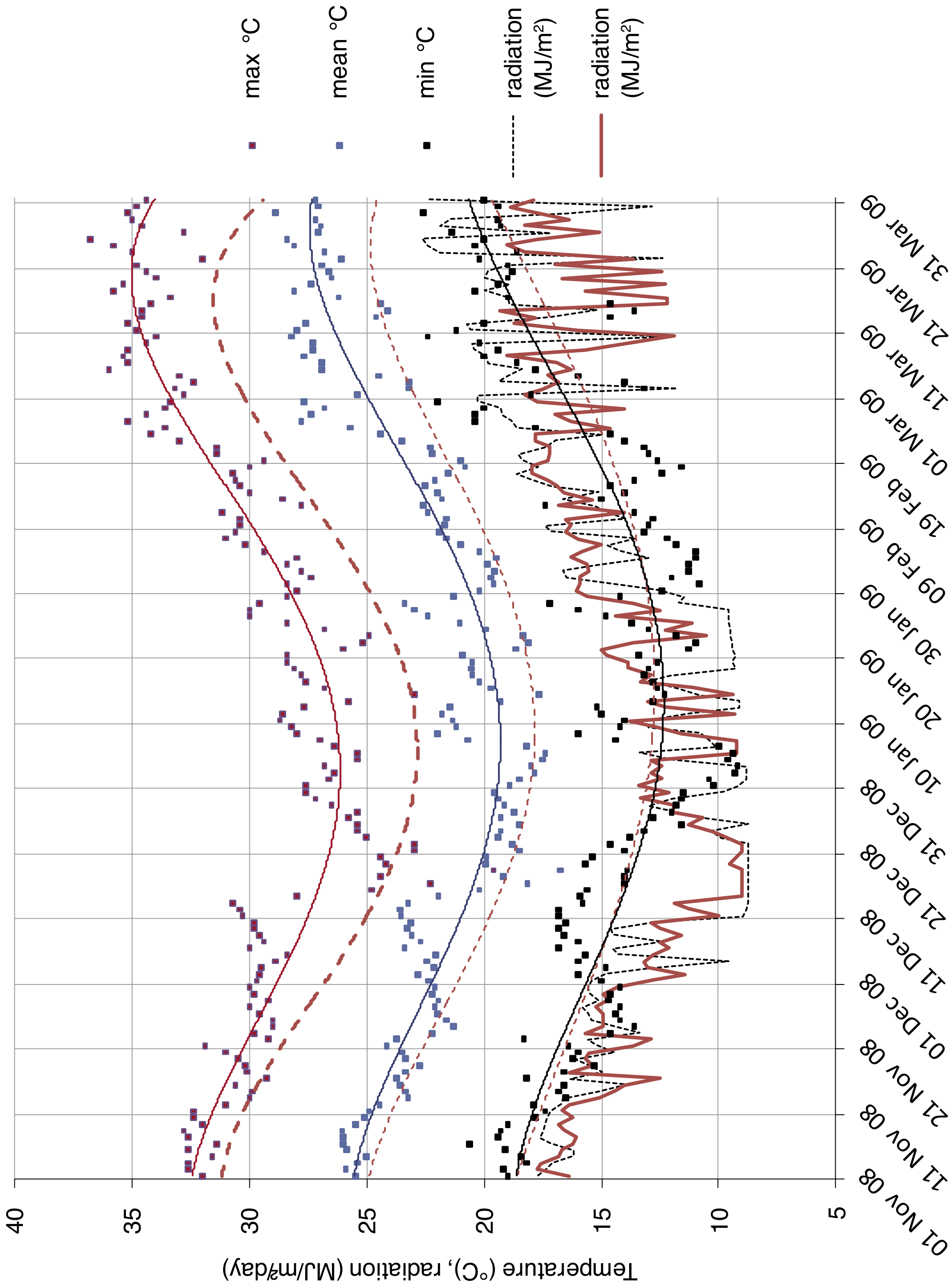


Figure 14. Temperatures and radiation in the Rabi season 2008–09 for Dinajpur (dashed lines) and Jessore (solid lines)

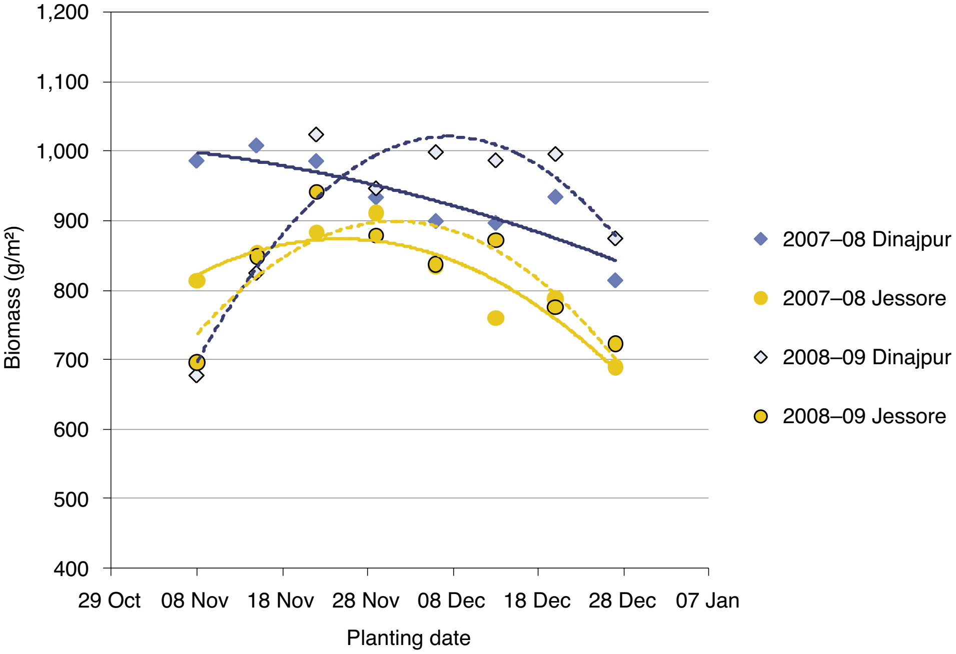


Figure 15. Changes in biomass with planting date for the 2007–08 (solid lines) and the 2008–09 (dashed lines) seasons

post-anthesis phase is hotter in Jessore than Dinajpur, grains were less well-filled (43 vs 47 ± 2 mg, respectively). In fact, as potential kernel weight is in part determined by temperature before anthesis (Bremner and Rawson 1978), potential at Jessore may have been less than at Dinajpur. Clearly, Dinajpur has more components of weather in its favour than Jessore. This augurs poorly for more southerly sites, unless the air is less polluted, the fogs less common or severe and the maximum temperatures more modulated by the presence of surrounding water. These would all boost yield.

Do farmers in the north get the best yields?

Experience from an FAO study

Figure 16 shows yields from farmers who were within a Food and Agriculture Organization of the United Nations (FAO)-funded study that provided them with training, free fertiliser and seed. Their management practices were ostensibly very similar. It included northern farmers from near Dinajpur (Vognagar and Rajuria), southern farmers from Jessore (Monirampur and Jikorgaccha), farmers from the west-central region of Rajshahi (Paba and Eusufpur) and those from the southern coastal region of Barisal (Kashipur) and two saline sites in Noakhali (Char Jublee and Hazirhat).

There was no difference overall between Dinajpur and Jessore (Monirampur) although Jikorgaccha farmers had reduced yields that season because of water constraints. Some Kashipur (Barisal) farmers, despite not having grown wheat before, overlapped in performance with Monirampur farmers, while the farmers in saline sites of Noakhali averaged only 2.5 t/ha. Paba (Rajshahi) farmers remarkably exceeded 5 t/ha and were astonished with their crops.

There are two points to make here. First, neighbouring farmers provided with the same technology vary widely in performance. Novice wheat farmers ranged by 67% in the yields they produced while traditional wheat farmers brought that range back to 26%. Second, constraints such as water limitation easily erode the benefits of growing a crop in a preferred latitude or location, or in the case of the Rajshahi farmers, some of their success that season

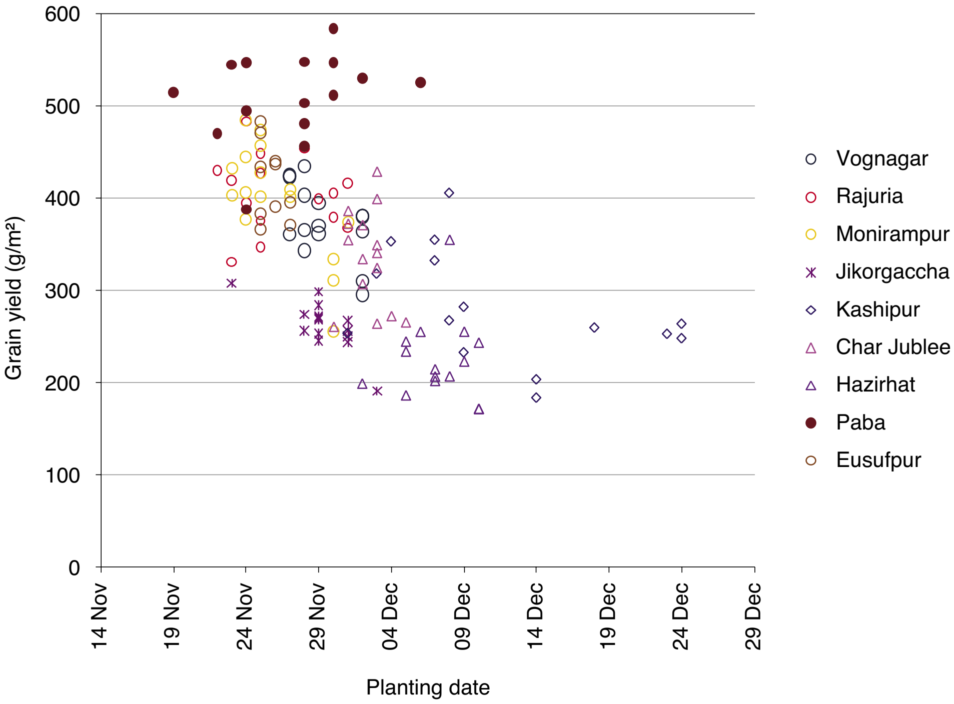


Figure 16. Grain yield of farmers' crops by planting date, throughout Bangladesh, 2004–05

was because they removed a constraint by applying boron to their crops, not done the previous year. Hazirhat farmers were and will continue to be largely constrained by salinity to 2.5–3.0 t/ha.

In essence, yields fluctuate from year to year and site to site but the aim must always be to manage the crop to take full advantage of local benefits but avoid or minimise the major constraints. Any management package needs to be continuously adapted to suit the location and any socioeconomic constraints that might be limiting in that season. And finally, good farmers will always be good, but the poor farmers must be trained to recognise and correct their mistakes as they occur or, if they are incapable of this, they should hire the machines that enable them to avoid those mistakes. An example of this is that a good farmer will produce high yields using the ancient method of broadcasting seed and fertiliser while a less-good farmer may need a power-tiller-operated seeder (PTOS) to bring their performance towards that of the good farmer. Less-good farmers sometimes delay activities until too late.

Understanding the components of the crop and how they change

This chapter has aimed to explain how weather variables and variables in the hands of farm managers, like planting date, can change the way wheat crops grow and yield. Observing components of the crop as it grows tells a story of where management is going wrong and how it can be altered. Good farmers do this automatically and in a timely fashion. Rawson and Gomez-Macpherson (2000) present in simple format a structured guide of what to look for, how to count and otherwise assess, and how to fix problems. This is also available written in Bangla for trainers (Rawson and Gomez-Macpherson 2004).

Figure 17 is an example of how a count of spikes/m² can show whether this component limits yield. Less than 200/m² may result in a 2.0 t/ha crop while 350/m² will certainly produce 3.5 t/ha towards 5.0 t/ha. Spike numbers are determined by two main factors—access to fertilisers, in particular nitrogen at around 20 days after sowing, and crop interception of radiation. But the very first step needed is to ensure

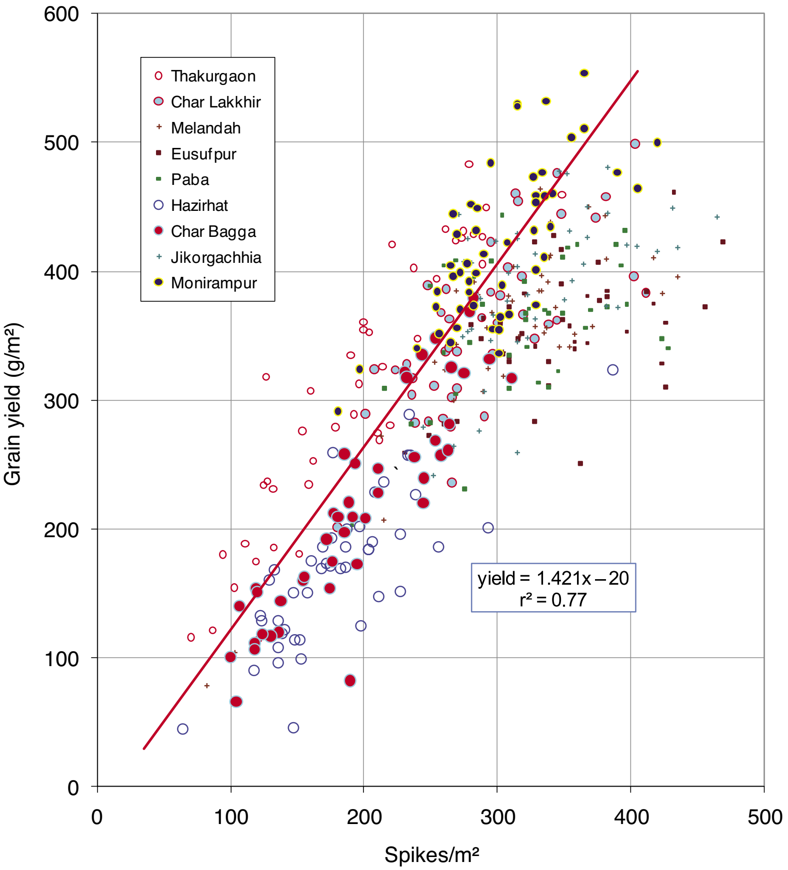


Figure 17. Grain yield and number of spike-bearing culms in 200 farmers' fields, 2004–06 (FAO project)

150 plants/m² (or 25–30 plants per m row length when row spacing is 20 cm) emerge uniformly and establish. Chapters 3.2 and 3.3 will consider all these factors and how farmers can control them.

References

Bremner P.M. and Rawson H.M. 1978. Weights of individual grains of the wheat ear in relation to their growth potential, the supply of assimilate and interaction between grains. Australian Journal of Plant Physiology 5, 61–72.

Hunt L.A., van der Poorten G. and Pararajasingham S. 1991. Post-anthesis temperature effects on duration and rate of grain filling in some winter and spring wheats. Canadian Journal of Plant Science 71, 609–617.

Rawson H.M. 1993. Prediction of heading time in wheat grown under high temperatures: effects of temperature, vernalisation and photoperiod. Indian Journal of Plant Physiology 36, 239–245.

Rawson H.M. 2003. Optimising variety and sowing date for the farm. In 'Explore on-farm: on-farm trials for adapting and adopting good agricultural practices'. Food and Agriculture Organization: Rome.

Rawson H.M. and Gomez-Macpherson H. 2000. Irrigated wheat: managing your crop. Food and Agriculture Organization of the United Nations: Rome.

Rawson H.M. and Gomez-Macpherson H. 2004. Irrigated wheat: managing your crop. Food and Agriculture Organization of the United Nations: Rome. (In Bangla)

Rawson H.M., Gomez-Macpherson H., Hossain A.B.S., Saifuzzaman M., Rashid H., Sufian M.A., Samad M.A., Sarker A.Z., Ahmed F., Talukder Z.I., Rahman M., Siddique M.M.A.B., Hossain I. and Amin M. 2007. On-farm wheat trials in Bangladesh: a study to reduce perceived constraints to yield in traditional wheat areas and southern lands that remain fallow during the dry season. Experimental Agriculture 43, 21–40.

Rawson H.M. and Noppakoonwong R.N. 1996. Effects of boron limitation in combination with changes in temperature, light and humidity on floret fertility in wheat. In ‘Sterility in wheat in subtropical Asia: extent causes and solutions’, ed. by H.M. Rawson and K.D. Subedi. ACIAR Proceedings No. 72, 85–89. Australian Centre for International Agricultural Research: Canberra.

Rawson H.M., Zajac M. and Noppakoonwong R.N. 1996. Effects of temperature, light and humidity during the phase encompassing pollen meiosis on floret fertility in wheat. In ‘Sterility in wheat in subtropical Asia: extent causes and solutions’, ed. by H.M. Rawson and K.D. Subedi. ACIAR Proceedings No. 72, 78–84. Australian Centre for International Agricultural Research: Canberra.

Rawson H.M., Zajac M. and Penrose L.D.J. 1998. Effect of seedling temperature and its duration on development of wheat cultivars differing in vernalization response. Field Crops Research 57, 289–300.

Slafer G.A. and Rawson H.M. 1994. Sensitivity of wheat phasic development to major environmental factors: a re-examination of some assumptions made by physiologists and modellers [Review]. Australian Journal of Plant Physiology 21, 393–426.

Stapper M. and Fischer R.A. 1990. Genotype, sowing date and plant spacing influence on high-yielding irrigated wheat in southern New South Wales. III. Potential yields and optimum flowering dates. Australian Journal of Agricultural Research 41, 1043–1056.

3.2 Cooperating with farmers of southern Bangladesh

A.B.S. Hossain, N.C.D. Barma, M. Saifuzzaman and M. Amin

Abstract

Farmer participatory research has become an important way to test and disseminate new technologies in farmers' fields. This applies particularly when new crop species or new varieties are being introduced into areas where farmers have no experience of the species, or where the new material is to be exposed for the first time to environmental growth limiters such as salinity, drought and heat. This chapter describes some aspects of farmers' participation in the expansion of wheat and mungbean production into southern Bangladesh. Seven southern districts were included in the project—Bhola, Noakhali, Barisal, Pirojpur, Jhalakati, Patuakhali and Barguna. Most of the research and extension activities were performed in farmers' fields with their active participation.

Farmers who took part were selected through personal contact at home, in markets and tea shops, or through recommendations within the local farming community. Selection emphasis was biased towards those considered innovative, interested in research, and likely to continue as resource farmers for technology adoption in their locality. All farmers participating had no previous direct experience of growing the introduced crops. This participatory approach has provided training and direct hands-on experience for more than 300 collaborating farmers in producing wheat as a Rabi-season crop and a proportion of them also grew mungbean. Many have continued to grow wheat and reserve a proportion of their production for subsequent planting and for sale as elite seed to their neighbours, thus ensuring continuing expansion of the newly released, well-adapted varieties. Such extension methods need to be continued but at a much greater intensity to increase and sustain future wheat production in the south.

Introduction

The aim of this research was to improve the livelihoods of farmers in southern Bangladesh by exploring the potential for the growing of Rabi-season crops such as wheat and mungbean after the harvest of the transplanted (T.) aman, monsoon (Kharif) season rice. This was undertaken through a combination of participatory on-farm and component research, demonstrating the potential for wheat and mungbean varieties, newly released by the Bangladesh Agricultural Research Institute, Wheat Research Centre (BARI-WRC) and Pulse Research Centre (BARI-PRC). Research undertaken in the 2006–07 and 2007–08 seasons in the southern districts of Barisal, Bhola and Noakhali (Figure 1) included assessment of the suitability of new wheat varieties, seed multiplication trials (SMTs) of those varieties and screening of experimental germplasm for salinity and high-temperature tolerance. Detailed agronomic experiments were also undertaken to research important components of the production system. These included determining the best time to sow wheat in the new regions and the associated best rates and times for irrigation and nitrogen applications. Importantly, what would be the consequences to yield of not meeting these optima?

The program was expanded into the districts of Jhalakati, Pirojpur, Patuakhali and Barguna in 2008–09 and 2009–10 (Figure 1). These districts were considered to have potential for increased production as the majority of land during the Rabi season either remained fallow or was used for grazing, with only small areas under existing

Figure 1. Locations of some of the almost 300 seed multiplication and block trials in seven districts of southern Bangladesh established and accumulating in number from 2007–08 (blue), through 2007–09 (pink) to 2009–10 (red). Sites for 2006–07 and several sites in Noakhali are not marked. (Source: Google maps)

production of grasspea (*Lathyrus sativus*) and chilli (*Capsicum annuum*). A short-season mungbean variety (BARI Mung 6) was introduced to farmers in the 2007–08, 2008–09 and 2009–10 seasons as a sequence crop to be grown after wheat. On-farm yields of mungbean were measured as part of the SMT program, but no detailed agronomic trials were done apart from assessing the impacts of weeding or not weeding crops.

Critical to the success of the on-farm research and for the longer term adoption of wheat and mungbean production was the focus on the SMTs, of which more than 200 were established during the 4 years of research. Not only did these trials provide research focus at the village level, they also provided particular farmers with wheat and mungbean seed for future use and sale to neighbours. The wide geographical spread of the SMT sites across seven districts and two to four seasons, depending on location, also provided an environmental comparison of the new varieties recently released by the WRC (Figure 1).

These diverse on-farm sites also provided the project with detailed data of the local environment, the soils and the water resources that together could be used to assess the suitability of the whole of the southern region for wheat and mungbean. The socioeconomic team worked in parallel to gauge the attitudes and capacities of farmers to include wheat and mungbean into their traditional crop sequences.

Selection of sites and farmers

With the exception of Bhola and Barisal, where an old wheat variety, Kanchan, had been grown spasmodically in the past, wheat was a new crop to most farmers in the south. Initially, farmers were reluctant to grow wheat for this reason and because they did not have experience in its cultivation and management. However, a few farmers were selected and offered encouragement to participate through provision of free seed, fertiliser, initial training and continuing technical support. Several criteria were considered in selecting farmers for participation. These included picking those who had sufficient land available for a trial, had some access to irrigation, were interested in collaboration and appeared motivated to be involved in research (Figure 2).

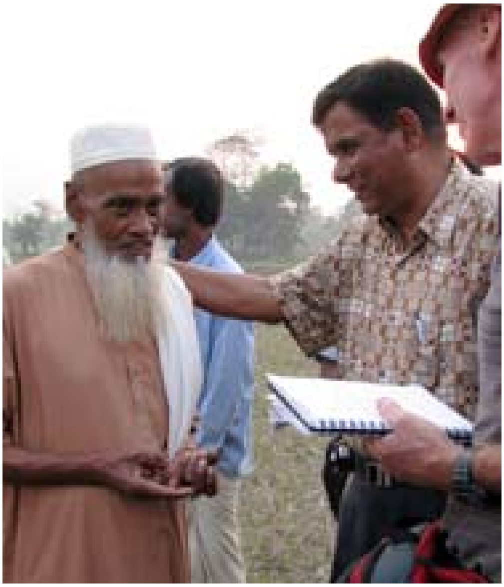


Figure 2. Noting down feedback from farmers (Photo: H.M. Rawson)

The selection process began with informal discussion to confirm that prospective collaborators really were interested in participation. This was done through personal contact at their home, in a tea shop (Figure 3) or in the marketplace. Priority was given to those who appeared actively interested, had a reputation as being innovative and were likely to act as a resource for technology adoption in the locality. The process followed was dynamic and interactive with links between farmers, researchers and extension workers used to identify appropriate collaborators. The extension personnel of the Department of Agricultural Extension (DAE) working at district, upazila and union levels were actively involved in the selection process. This was particularly the case with the Sub-Assistant Agricultural Officers (SAAOs) who work at the union level and were able to provide advice based on their almost daily contact with village farmers.

While most of the farmers selected were male, some innovative women farmers also came forward to participate. Once a group of interested farmers had been selected, discussions were arranged at the village level with the researchers and extension staff.

Discussion focused on the overall aims of the proposed activities and operational details, including land requirements, crop management and expectations of the farmers, and the level of technical support that would be available to them.

Figure 3. Interacting informally in a tea shop (Photo: H.M. Rawson)

Farmers' participation in seed multiplication trials (SMTs)

During 2006 to 2010, 211 SMT trials were conducted on farms across southern Bangladesh (Table 1). Farmers were selected for inclusion in the SMT program if they were able to provide an area of land of around 1,000 m^2 and met the criteria mentioned above. Around six sites were usually established as part of a village or union cluster. Collaborating farmers (Figure 4) were provided, free of charge, with wheat seed of the new varieties, Sourav, Sufi, Bijoy, Shatabdi and Prodip, which were to be grown under irrigation. One farmer in each cluster of six was supplied with seed of the variety Shatabdi and asked to grow it without irrigation to help gauge the impact of irrigation on yield. In 2009–10 the WRC advanced lines BAW 1059 and BAW 1064 became available and were included in the trials. These two lines, which are suitable for late planting, have since been released as BARI GOM 25 and BARI GOM 26, respectively. Fertiliser, sufficient to apply nutrients at the WRC-recommended rates of nitrogen (N) 100 kg/ha; phosphorus (P) 27 kg/ha; potassium (K) 50 kg/ha; sulfur (S) 20 kg/ha and boron (B) 1 kg/ha, was also provided to each farmer.

Preseason training was provided by WRC scientists and project consultants on modern wheat cultivation and seed preservation methods, data collection and pest control (weed, insect and rat). During the season, farmers participated in field activities and worked with project staff in the management of the trial, including irrigation application, weed and insect control and harvesting of the crops (Figure 5). Those interested in growing mungbean in sequence with wheat were provided with the seed of the short-season (55–58 days to maturity) variety BARI Mung 6 and taught how to grow it.

An important objective of the SMT program was to distribute the new wheat varieties across the south, with farmers able to choose the variety that best suited their requirements and to preserve seed for future use and sale. Besides wheat and mungbean, farmers were also provided with several of the high-yielding varieties (HYVs) of rice that were to be grown in the Kharif season as part of a rice–wheat–mungbean cropping system envisaged as suitable for the south.

Other on-farm research

Apart from the SMT program, which was by far the largest component of the on-farm research, another 51 varietal, agronomic, tillage and salinity screening trials were conducted on farms between 2006 and 2010. An additional 62 block demonstrations, similar to SMTs but where the group of farmers involved is required to provide nutritional inputs, were also conducted during the 2009–10 season (Table 1). This suite of experiments included detailed component

Figure 4. Training Noakhali farmers on their farms about wheat development (Photo: MS)

Figure 5. Seed multiplication trial farmers working with two technical staff in categorising soil core samples and labelling crop grab samples for later analysis on Abdul Motin's Noakhali farm (Photo: H.M. Rawson)

research investigating such issues as the optimal planting window for wheat in the south and the development of nitrogen and irrigation recommendations for optimal production. These trials were intentionally undertaken on-farm to ensure relevance of results to farmers who were experiencing the same conditions of climate, soils and management in their own fields. While farmers were told that the likely best sowing time was late November, this in many cases could not be achieved. So farmers planted their crops when they could. This meant that there was a spread of sowing times within localities and seasons of several weeks. Some farmers had their land ready by mid November while others could not plant until the last days of December; very late planting was common in Noakhali. This spread of planting dates, as well as being reality, was very useful to the project because it meant that in all locations the planting-date effects on yield could be assessed from the collected data. The findings are discussed in Chapter 3.3 (this volume).

Training

As the introduction of crops new to the farming community was being attempted, it was critical that farmers be trained in their management. Seasonal training was undertaken in all seven trial districts before each season. The training, which was initially at the district level, and later at the union level, was targeted at the collaborating farmers and their technical support, which included DAE, WRC and project staff employed by the non-government organisations (NGOs) PROSHIKA and Forum for Regenerative Agricultural Movement (FoRAM). The 1-day training course was provided by WRC research scientists and consultants employed by the project.

Social research suggested that whole-of-family training (WFT), undertaken at the village or union level, would contribute to better understanding of Rabi-season cropping and adoption of the technology. Consequently, in 2009–10 WFT was provided to the collaborating farmers with one male and one female adult from each family attending a session (Figure 6). The training-module approach was highly participatory, gender unbiased and easily understandable for all educational levels. Participants were encouraged to ask questions and share their knowledge and experiences. In each WFT batch, 16 families (32 participants) were trained. Discussions concentrated on wheat production technology, seed preservation methods, agronomic requirements and management of the trials.

Project technicians were also trained on the technical aspects of the field research including data recording, how to use field books, soil sampling and

Table 1. Number and locations of on-farm research trials conducted between 2006 and 2010

Location	2006–07	2007–08	2008–09	2009–10	Total
Seed multiplication trials (SMTs)					
Bhola		13	20	15	48
Barisal		13	14	15	42
Noakhali		13	20	15	48
Patuakhali/ Barguna			16	20	36
Jhalakati/ Pirojpur			17	20	37
Block demonstrations					
Bhola				20	20
Barisal				30	30
Jhalakati				6	6
Noakhali				6	6
Salinity, variety, other trials					
Noakhali, Barguna, Patuakhali	7	16	14	14	51
Total	*7*	*55*	*101*	*161*	*324*

Figure 6. Whole-of-family training: collecting donated seed bins to store wheat seed free from pests and disease

crop analysis methods and the use of a handheld GPS (global positioning system) to spatially locate research sites (data used to generate Figure 1). As the techniques being recommended for sampling the soils for water and nutrient content were new to Bangladesh, a short video of the process was produced to enable continuing training of the staff. Approximately 745 participants attended the training between 2006 and 2010. These included 473 farmers, 185 DAE personnel and 87 NGO and BARI scientists, including project staff. In addition, 90 farmers were provided with training on mungbean production in 2008–09 (Table 2).

Participation of farmers in field days

Nine field days were held just before crop harvest between 2007 and 2010 across the districts of Barisal, Bhola, Noakhali, Jhalakati and Patuakhali, with approximately 150 participants attending each event (Figure 7; Table 3).

Table 2. Participants in 1-day wheat production and seed preservation training

Year	Barisal	Bhola	Jhalakati and Pirojpur	Patuakhali and Barguna	Noakhali	Total
2006–07	20	18	–	–	22	60
2007–08	36	45	–	–	38	121
2008–09	30	45	26	37	37	175
	90[a]					90
2009–10	89	83	58	56	103	389
Total						835

[a] These farmers were trained in mungbean production

Figure 7. Commenting on a local seed multiplication trial crop at a field day in Barisal (Photo: H.M. Rawson)

The participants were mostly local farmers, DAE and NGO personnel, scientists of BARI and the Bangladesh Rice Research Institute (BRRI), the local administrative chairman and media personnel from press and television channels. The participants visited trials to see firsthand the potential of the crops being recommended, to compare what they saw with their own crops, and to learn more about production methodologies. Media articles focusing on the advantages and potential for wheat production in the south were broadcast on several television channels and also published in daily newspapers.

Farmer feedback

In October 2008 ad hoc discussions, coordinated by N.P. Dalgliesh, were held with a small subset of individual farmers in the Barisal and Noakhali districts who had participated in the SMT work during the preceding season (2007–08). While it is understood that these were impromptu discussions and are not meant to be representative of the total group of collaborators in all districts, the results do provide some insight into the thinking of farmers and their actions in terms of the use of the wheat and mungbean that they produced and their thoughts on the future production of these crops. Further detailed feedback

Table 3. Number and location of wheat-harvest field days between 2007 and 2009

Year	Barisal	Bhola	Jhalakati and Pirojpur	Patuakhali and Barguna	Noakhali	Total
2006–07	1					1
2007–08	1	1			1	3
2008–09	1	1	1	1	1	5
Total						9

collected by the socioeconomic team of the project is in Chapters 1.2, 1.3, 5.1 and 5.2, this volume.

Nasima Begum: Babuganj, Barisal

Nasima Begum produced a 3.63 t/ha crop of wheat in the Rabi season (Figures 8 and 9) followed immediately by mungbean. She grew wheat on 25 decimals (1,000 m^2) of land and sold the grain (360 kg) to her neighbours at the time of harvest for Tk35/kg (approx. A$0.60/kg in 2007–08).

The area was then planted to mungbean which yielded 1.44 t/ha (weeded) and 0.99 t/ha (unweeded). Assuming that the majority of the area had weeds present, this represents production of 100 kg which was sold at Tk40/kg. In the subsequent season, the farmer indicated that she would double her area to 40 decimals (1,600 m^2), with the neighbours who had purchased seed from her planning to plant 60 decimals (2,400 m^2). As a result of her experience and success, Nasima Begum was considered by her neighbours as the local expert in wheat and mungbean production and they came to her for advice.

Sirazul Islam: Babuganj, Barisal

In 2007–08 Sirazul Islam harvested a wheat yield of 2.89 t/ha (286 kg production) from 25 decimals (1,000 m^2). He sold 25 kg of seed at Tk30/kg to neighbours and retained the rest for home consumption and next season's planting. Mungbean was planted on 28 March 2008, 12 days after wheat harvest, and yielded 0.85 t/ha (85 kg production) in 87 days. At the time of discussion in October 2008, the farmer had given 25 kg of mungbean to his neighbours and intended selling the remaining 60 kg

Figure 8. Local expert farmer on wheat and mungbean with her wheat crop and son (Photo: N.P. Dalgliesh)

Figure 9. Nasima Begum's wheat crop, marked with a pink map pin and showing green in a background of mainly grey-brown Rabi fallow land (Source: Google maps)

as seed. Due to the late planting of T. aman rice in the 2008 Kharif season, and concerns that the land would not be sufficiently dry to allow the timely planting of wheat, Sirazul Islam decided to forgo wheat production in 2008–09 and instead to grow mungbean on 100 decimals of land as soon as it was sufficiently dry to plant.

Abdul Kalek: Senbagh, Noakhali

Abdul Kalek harvested 1.8 t/ha (180 kg of production) of wheat from 25 decimals (1,000 m^2) in 2007–08. The majority of the harvest was used for either family consumption or sold in the local market as 'Gorma Lanu' (Figure 10). He stored 35 kg as seed, some of which he plans to use to plant 20 decimals of his own land, with the remainder sold at a price of around Tk36–40/kg. Mungbean planted in March 2008 failed due to poor establishment; a result of inadequate land preparation.

Monsur Ahmed: Senbagh, Noakhali

Monsur Ahmed, a tenant farmer, grew 24 decimals (960 m^2) of wheat in 2007–08 which yielded 2.3 t/ha (220 kg). He kept 60 kg and sold the remainder at Tk40/kg. While the 60 kg he retained would have been sufficient to plant 120 decimals (4,800 m^2), poor storage in a rusty container resulted in weevil infestation and almost total loss of the seed (Figure 11).

Jakir Hossain: West Narayanpur, Barisal

The 930 m^2 of wheat planted in 2007–08 yielded 4.47 t/ha (417 kg harvested). Of this, 367 kg was consumed by the family, 20 kg kept for seed and 30 kg was intended for sale to neighbours. While mungbean planted after the wheat yielded 1,000 kg/ha (93 kg production) the seed was spoiled through rain at harvest and was immediately boiled and sold at the market.

Nural Jahangir and his wife: Noakhali

Nurul Jahangir has public commitments as a local government representative. His wife does most of the farming. In 2007–08 she planted 25 decimals (1,000 m^2) of wheat, achieving a yield of 3.5 t/ha (350 kg production). They sold 100 kg for Tk40/kg at harvest and kept 45 kg for seed. The remainder was used for family consumption or given to relatives. For 2008–09 they had plans to plant 54 decimals (2,160 m^2) to wheat using 27 kg of their seed (Figure 12). At the time of interview in October 2008 they had

Figure 10. Farmer's wheat sold at market as tasty 'Gorma Lanu'—an example of value-adding (Photo: N.P. Dalgliesh)

Figure 11. Seed stored inadequately using moth balls and camphor leaves in unsealed drums (Photo: N.P. Dalgliesh)

already sold 10 kg of the remaining seed to neighbours at a price of Tk50/kg. Their seed preservation technique correctly followed training methods and there was no spoilage.

Sah Alam: West Narayanpur, Barisal

Sah Alam grew 45 decimals (1,800 m^2) of wheat which yielded 4.38 t/ha (788 kg harvested) in the 2007–08 season. While the majority was sold, 22 kg was kept for planting and 28 kg for sale before planting in early 2009, with the expectation being that he would be able to achieve a premium price of Tk60/kg. Mungbean was planted on 25 decimals of the land in March 2008 with unweeded areas yielding 887 kg/ha (89 kg) and the weeded test areas 1.2 t/ha. They kept 12 kg for seed and sold the remainder at the market.

Figure 12. Farmer and husband with some correctly stored seed of their 3.5 t/ha wheat crop (Photo: N.P. Dalgliesh)

Conclusion

The participatory approach to extension has created awareness amongst farmers and regionally based extension personnel of the potential for wheat and, to a lesser degree mungbean, in the south. Collaborating farmers (Figure 13) have the technical know-how to produce wheat, control pests and preserve seed for future use, with the more entrepreneurial selling seed to their neighbours. While the research has been able to show that increased Rabi cropping is feasible, it now requires a concerted effort on the part of policy, research and extension staff to ensure that farmers across the south are made aware of the potential and supported in their endeavours through provision of high-quality seed and the necessary production and marketing infrastructure.

Figure 13. Farming couple at Gaurnadi, Barisal, in their 3.5 t/ha wheat crop. This is the fourth crop grown by this family who started growing wheat as seed multiplication trial–trained farmers in the Australian Centre for International Agricultural Research scoping study in 2005–06. All their neighbours now also grow wheat. (Photo: N.P. Dalgliesh)

3.3 Best time window for southern farmers to grow wheat

M. Saifuzzaman, H.M. Rawson, A.B.S. Hossain, N.C.D. Barma, M. Ihsanul Huq, M. Manirul Islam, M. Farhad, M. Helal Uddin, M. Sydur Rahman and M. Enamul Haque

Abstract

Cooperating farmers in the south were trained then provided with wheat seed and fertilisers and asked to grow a crop, fitting it when they could into their standard crop sequence with the only mandatory requirement being that they should irrigate at 20 days after sowing along with their nitrogen top-dressing. The project began in 2007–08 with farmers in Noakhali, Barisal and Bhola, but over the following two seasons spread throughout the south into Jhalakati, Pirojpur, Patuakhali and Barguna, finally including almost 300 farmers. The study was called the seed multiplication trial (SMT) because it used the widely distributed farmers to grow the new and elite varieties of wheat and sell the seed they produced to their neighbours for further wheat expansion.

The initial concern was that farmers would harvest their transplanted (T.) aman rice so late that the following wheat crop would be pushed into the hottest part of the Rabi season, so would yield poorly. Farmers grew many types of T. aman varieties including local lines and some used a bullock-powered country plough to prepare their farms for the wheat crop, but despite expected delays, almost all farmers planted wheat before mid December. There was no convincing evidence that delaying planting until mid December had any effect on yield, either positive or negative. So from that viewpoint, wheat fitted satisfactorily into the natural Rabi time window, often left fallow, within a rice–rice rotation.

Yields varied considerably between locations and farmers with an underlying year effect. Overall, Bhola farmers consistently harvested 3.0–3.5 t/ha crops, Barisal ranged between 2.5 and 4.0 t/ha but averaged around 3.0 t/ha while Noakhali farmers averaged 2.5 t/ha, although again the range was wide, in part due to the inclusion of saline areas. The other regions similarly ranged around 2.5 t/ha. Varieties did not differ in yield in any consistent manner.

A small with- or without-irrigation farm treatment was included in all regions. This indicated the relatively small positive effects of irrigation, its role being taken over by shallow watertables directly accessible by roots or through capillary rise (Chapter 2.2, this volume).

Considering that cooperating farmers were spread widely from the north of Barisal, including char areas, right down to the sea beach at Kuakata, and from the saline and non-saline areas of Noakhali in the east to Pirojpur and Barguna in the west, with yields frequently in excess of 2.5 t/ha, it is concluded that wheat can be grown successfully throughout southern Bangladesh.

Introduction

The optimal window for sowing wheat in the traditional wheat areas of Bangladesh revolves around the end of November to early December. The reasons for this are discussed in Chapter 3.1 (this volume). The south is considered to have several constraints that might preclude these early dates. Two restrictions commonly mentioned are the late harvesting of transplanted (T.) aman rice and the extended period required for the land to dry sufficiently for cultivation and planting of wheat after the rice harvest. And it is automatically assumed that when planting is significantly delayed beyond late November, yields will decline because a greater proportion of the crop life cycle will be pushed into conditions that are too hot for wheat. Chapter 2.1 (this volume) has described the climatic conditions in the south which indeed are hotter than the north by around 2 °C in any week of the Rabi (dry) season. The current chapter recounts what the farmers cooperating in the Australian Centre for International Agricultural Research (ACIAR)-funded trials did with their wheat crops: when they were able to plant so that the wheat crop fitted their standard rice or other rotations; how these planting dates altered yield; and how they varied their approaches in different regions of the south.

All farmers in the project were trained how to grow wheat by the Bangladesh Agricultural Research Institute, Wheat Research Centre (BARI-WRC) teams (Chapter 3.2, this volume, gives details). They were told to plant as early as they could but not to unduly disrupt their standard rotation methods. They were each provided with seed of one of the suite of elite cultivars and with appropriate fertilisers and instructed to use a light cultivation with their hand-tractor before broadcasting seed and fertilisers, followed by another light incorporating cultivation. Farmers who had no tractor used a country plough (Figure 1) and laddering techniques and a few farmers used direct row sowing with a power-tiller-operated seeder (PTOS). One farmer sowed in rows by hand. Mandatory was an irrigation at 20 days after sowing (DAS) or thereabouts and this was associated with a nitrogen top-dressing. Farmers who were asked to not irrigate applied all their fertiliser at sowing. Farmers were all left to decide whether they would apply more than the 20-day irrigation. Many did not have water available for more than the 20-day soaking which, it was explained, is necessary to move the basal fertiliser down into the soil zone of the extending roots. Surface water remaining over from the monsoon in channels or ponds is usually still available at 20 days. Later, that source has often evaporated or is required for farming fish or for hand-watering more important crops like chilli.

When farmers planted their wheat

All cooperating farmers in Bhola, Noakhali, Patuakhali, Barguna, Jhalakati and Pirojpur grew rice before sowing their wheat crop. Similarly in Barisal, most farmers grew rice although there were three in Gaurnadi and one in Banaripara who preceded their wheat with jute. Figure 13 in Chapter 3.2 (this volume) pictures two jute–wheat farmers and Figure 5 in Chapter 2.3 (this volume) shows a jute crop growing. The rices and jute were the farmers' choice and rices included high-yielding varieties (HYVs), hybrid and local lines. Despite the almost universal use of rice (Figure 2) and expected delays in wheat sowings due to waiting for the rice to be harvested and removed from the fields, average wheat-sowing dates for each region were surprisingly early, often being close to assumed optimum for the north. Only Patuakhali/Barguna was later, in mid December. And even there some farmers planted early December after harvesting BR 11 and BR 22 rice varieties. Local varieties Dudkolom and Kuti Agni forced wheat planting into the second half of December. In Barisal, Noakhali and Bhola, farmers could easily achieve wheat plantings from late November through to mid December using BR 11, BR 23 and BR 30 and BRRI Dhan 31, 32, 40,

Figure 1. Country plough at work in Noakhali (Photo: HMR)

41 and 44. Even some local varieties—Agonishile in Noakhali and Kuti Aghrani in Bhola—allowed wheat to be planted in early December. So, in general, late harvest of T. aman and slow dry-down of the land were not constraints to early wheat planting. Wheat planting dates for all individual farms throughout the years of the ACIAR study can be read from Figures 3–8 and 10 and in all cases the average planting date for the figure appears as a large yellow symbol.

The conclusion was that many farmers throughout the south could grow T. aman rice and plant their wheat by mid December, unless they were using some local late varieties of rice. But the critical question was—could they plant early over several seasons in this part of the country and achieve commercially viable yields of wheat?

Yields and planting dates in the south

The 2007–08 season

Sites were selected in Barisal, Bhola and Noakhali that were relatively convenient to manage by the local teams travelling by bicycle and bus from local centres. This season was to develop methodologies and test out some research ideas that will be described in other chapters. Results from the farmers' trials, called the seed multiplication trials (SMTs), were as follows. Thirty-six farmers, 12 in each region, produced crops that had the mandatory irrigation while one farmer in each region grew variety Shatabdi without irrigation (rainfed). Figure 3 identifies the three rainfed farms with round symbols. The three yellow symbols are the average irrigated yield by average planting date for the regions.

Farmers varied in the date they could plant from 1 December to 30 December. The three latest plantings were at Hazirhat, a saline site in Noakhali; their neighbours planted on 19 December and harvested 1.8 and 2.5 t/ha. Barisal farmers planted early in December and all but one Bhola farmer planted by mid December. So it confirmed the conclusion from 2008 that most farmers have the opportunity within their rice-based sequence to plant wheat by mid-December.

Farm yields were estimated from three 2-m^2 quadrat cuts taken by the project researchers who also used them to determine yield components. The first of the three cuts was chosen by eye as the best part of the

Figure 2. Farm that included a rice–wheat–rice sequence, showing a rice crop being transplanted while the wheat was being harvested in March (Photo: HMR)

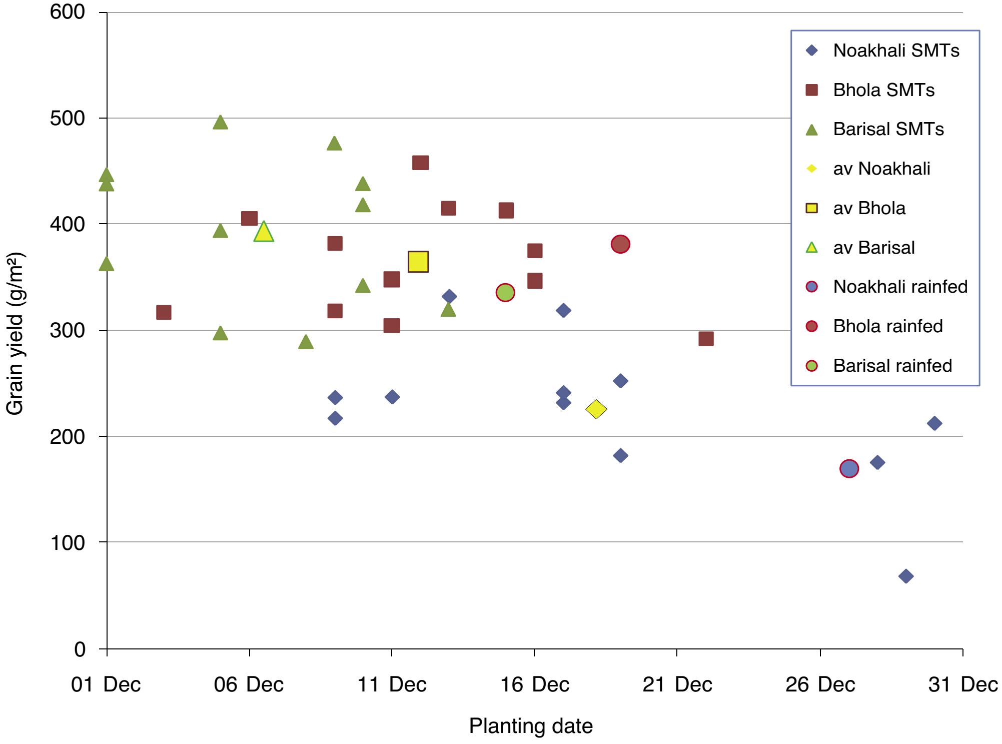


Figure 3. Seed multiplication trial (SMT) farmers' planting dates and yields in 2007–08 for Noakhali, Barisal and Bhola

farmer's crop, while the following two cuts were chosen as average. The reason for this method of choice is that the chooser makes a conscious effort to really assess the whole crop and does not subconsciously take the easy option of cutting whatever is closest to where they stand. The best-cut data also provided an estimate of potential in the farmer's field and showed the degree of variability in saline fields.

Different farmers produced very different yields despite ostensibly using similar methods. Average yield for Barisal was close to 4.0 t/ha but that included crops of 2.9 to 5.0 t/ha, both incidentally planted using PTOSs. Bhola farmers averaged 3.7 t/ha and similarly varied widely from 2.9 to 4.6 t/ha. All Bhola farmers broadcast their seed and fertiliser and 7 of the 12 farmers prepared their land initially with two passes of a bullock-powered country plough, although five of the seven completed their cultivation with a power tiller. The farmer who used only a country plough (four passes) for cultivation managed to plant by 6 December and harvested over 4 t/ha. This yield was achieved from 180 established seedlings/m^2, slightly lower than the 230/m^2 that other farmers realised by finishing cultivations with a power tiller. This difference was irrelevant to yield. Similar numbers of established seedlings came from Barisal and Noakhali farmers.

Noakhali farmers averaged only 2.3 t/ha, ranging between 0.7 and 3.3 t/ha. The former farmer produced a good crop of weeds and was generally uninterested in wheat (see Chapter 1.2, this volume, for some farmer comments).

A surprising finding was the performance of the rainfed Shatabdi crops. Compared with the irrigated Shatabdi plantings, yield in Barisal was reduced by 15%, Bhola by 1% and Noakhali by 44%. These were based only on one comparison in each region but the effects were much smaller than expected.

It was also expected that yield would decline sharply with lateness of planting as can occur in the traditional wheat-growing zones (Chapter 3.1, this volume). According to linear regressions fitted through the data, there was no evidence of this in Bhola and Barisal crops. In Noakhali, only the three plantings at the end of December, plus the rainfed trial, forced the overall data into a declining yield trend with planting date ($r^2 = 0.37$).

Three conclusions 2007–08

Farmers generally can fit wheat into their rice-based rotations, even when they use a country plough for cultivations; irrigation does not have the large impact on yield usually observed in the north; and planting date, as long as it is within the first half of December, has no major impact on yield. These were all findings supporting expansion of wheat in the south. The unknowns were whether the findings would be duplicated over the next two seasons of the project and in the new regions planned for expansion.

The 2008–09 season

In this season there were many more cooperating farmers and additional regions to compare so the data are presented separately for regions. The varieties (Prodip, Sourav, Sufi, Bijoy and Shatabdi, irrigated and rainfed) are identified on the graphs by different symbols and the upazilas are named by their first four letters. This allows more visual comparisons to be made. All yield data are expressed against the date that the crops were planted, to assess the expectation that delayed planting might reduce yield. Farmers in this season, as in 2007–08, were provided with training, seed and fertilisers and required to irrigate at 20 DAS with their nitrogen top-dressing, but otherwise were free to select their preferred planting dates and other management approaches.

Noakhali

For this season, there were no effects of planting date on yield. The average yield was around 2.5 t/ha (the round yellow marker in Figure 4) from an average planting date of 5 December. There was no conclusive evidence for a need to irrigate, comparing Shatabdi with or without irrigation, or for consistent differences in yield between varieties.

Bhola

As for Noakhali, late planting did not reduce yield at least up to mid December, although two late plantings that used the country plough (CP) for land preparation had poor yield. This was no reflection on the CP as another CP site yielded 3.8 t/ha. Average yield for Bhola farmers was around 3.4 t/ha (yellow circle in Figure 5).

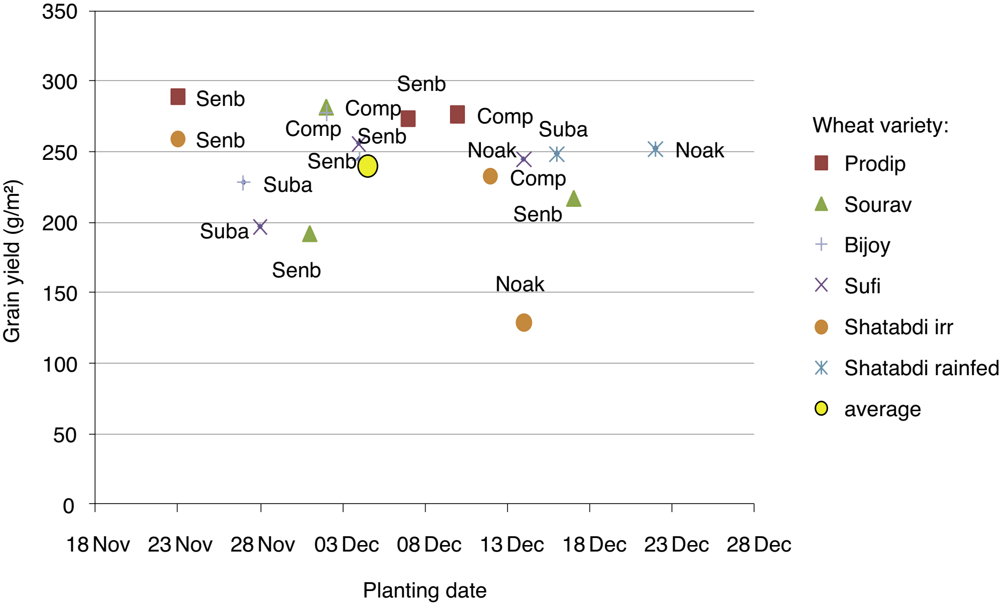


Figure 4. Noakhali planting dates and yields in 2008–09 for upazilas Noakhali Sadar, Subarnachar, Senbag and Companigonj

Barisal

This was a poor season for Barisal (Figure 6) with yields averaging only 2.8 t/ha due in part to inclusion of Banaripara sites with their production being only around 2.0 t/ha. Gaurnadi and Uzipur farms produced between 3.0 and 3.5 t/ha. All farmers planted early. Also included in Figure 6 are 2004–05 data from the Food and Agriculture Organization of the United Nations (FAO)-funded study in Kashipur (Barisal Sadar) with a much wider spread of planting dates, but showing a similar range of yields.

Jhalakati/Pirojpur

This region showed a reduction in yield with delayed planting date of 85 kg lost per day delay, driven largely by the data points after 15 December plantings (Figure 7); without these data, the regression would be flat. Yields from plantings up to and including 15 December averaged 3.0 t/ha while overall average yield was only 2.4 t/ha. Absence of irrigation reduced yield by 15% here.

Patuakhali/Barguna

Like Jhalakati/Pirojpur, there was a marked decline in yield in this season with delayed planting after 15 December, with 74 kg yield lost per day delay. Crops sown before 15 December averaged 3.3 t/ha while those sown later averaged only 2.2 t/ha. Overall yield for the region (yellow symbol in Figure 8) was 2.7 t/ha. There was no indication here that irrigation improved yield as Shatabdi crops that were irrigated all produced less yield than Shatabdi rainfed crops.

Three conclusions 2008–09

These are as for 2007–08 even although yield was lower this season. Why yield was lower is a question for later in this chapter.

The 2009–10 season

Further SMT farms were added in 2009 (red circles in Figure 9) while many from the previous season were retained for continuity of data. Figure 9 is available free on Google maps at <http://maps.google.com/maps/ms?ie=UTF8&msa=33&msid=106289035230357558981.0004865c70c964ee24e9f&abauth=4beb5cd0xLcgigdlvtZoXMczumNapkC9ffE>. In Google

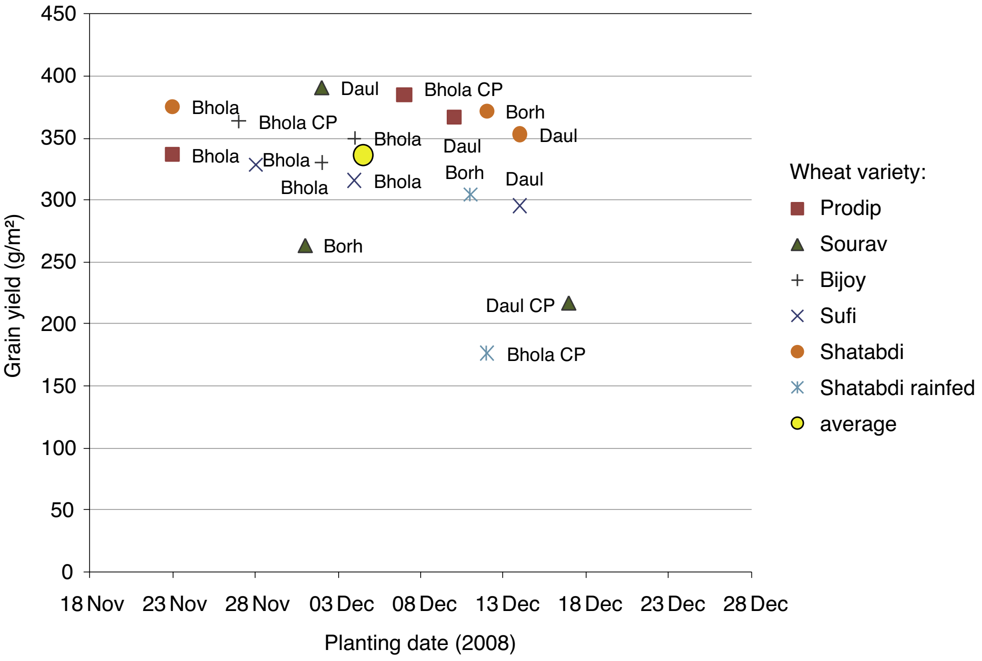


Figure 5. Bhola planting dates and yield in 2008–09 for upazilas Bhola Sadar, Borhanuddin and Daulatkhan (CP = country plough)

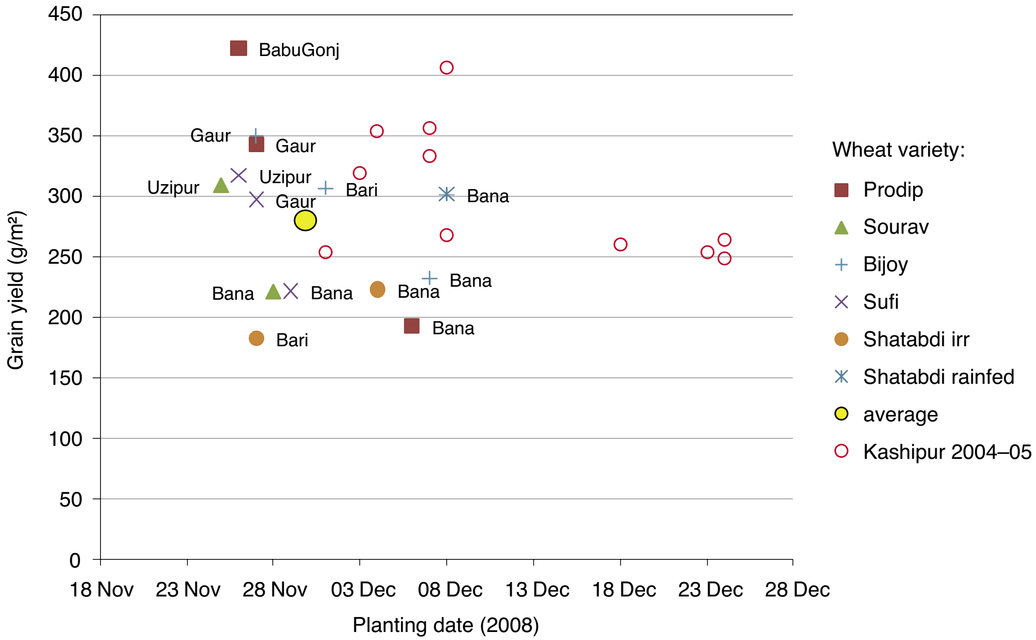


Figure 6. Barisal planting dates and yields in 2008–09 for upazilas Barisal Sadar, Uzipur, Babuganj, Gaurnadi and Banaripara, and for Kashipur in 2004–05

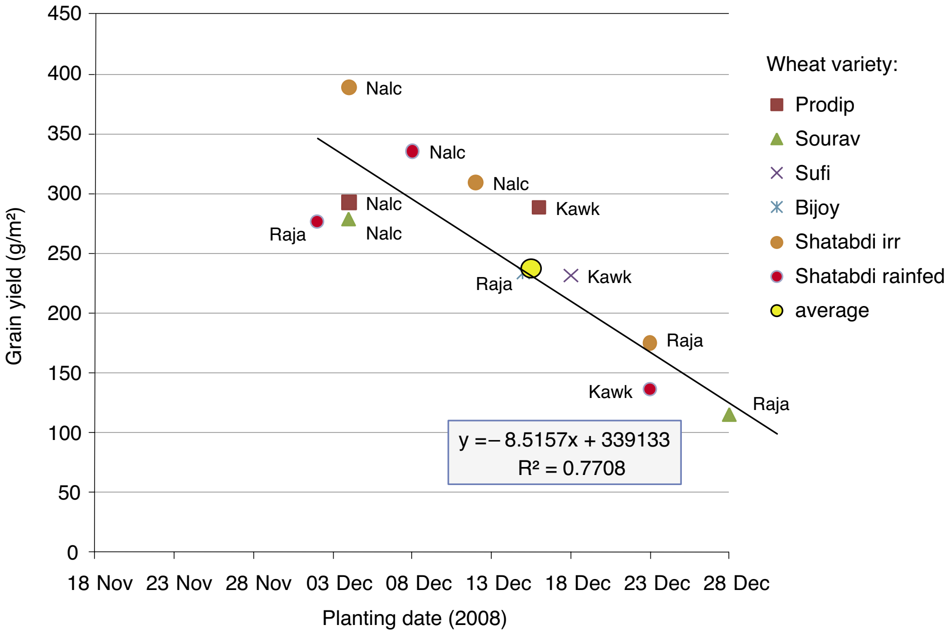


Figure 7. Jhalakati/Pirojpur planting dates and yields in 2008–09 for upazilas Nalchiti, Rajapur and Kawkhali

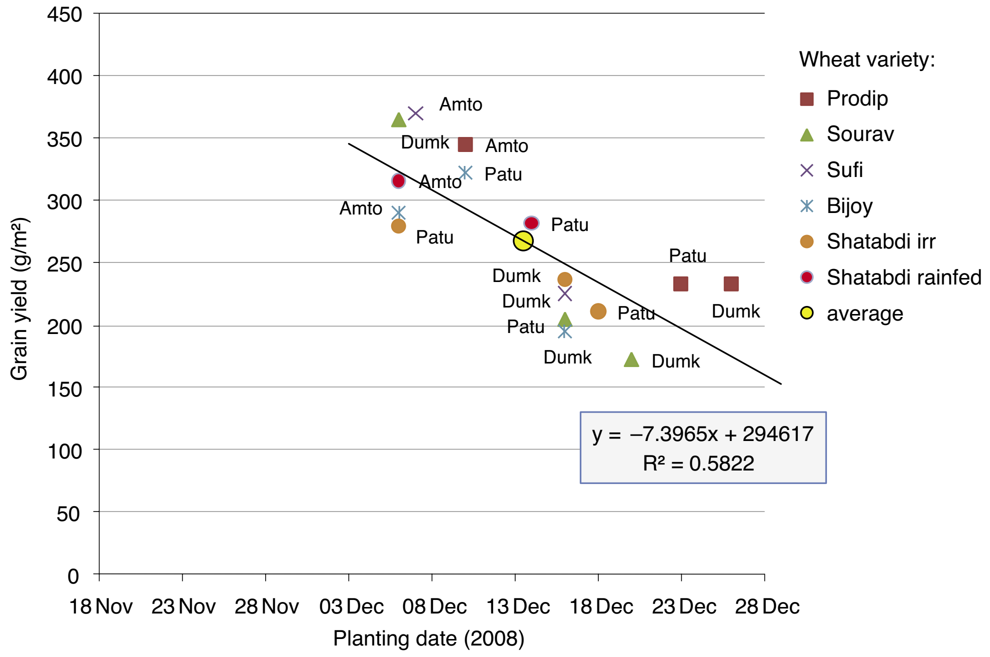


Figure 8. Patuakhali/Barguna planting dates and yields in 2008–09 for upazilas Patuakhali Sadar, Dumki and Amtoli

maps, click on any map marker to see the address, wheat planting date for the farm, variety used and the yield, and zoom in to field level to examine the farm and its locality, including ponds and waterways.

For this third season, the main conclusions were confirmed that yield is not modified by planting date as long as it is before mid December and that the main within-season yield variation is due to differences between locations and individual farmers in a locality (Figure 10). Concern in 2008–09 that yield fell rapidly in Patuakhali/Barguna where planting was delayed beyond 15 December was not supported in the 2009–10 Barguna data, where all plantings were in Amtoli upazila. There, early and late December plantings were not greatly different in yield (Figure 10f). Similarly, in Patuakhali Sadar upazila (Figure 10e), early December and 20 December sowings showed no yield reduction. Overall, yields ranked Bhola > Barisal = Barguna > Noakhali > Jhalakati > Patuakhali and all mean yields exceeded 2.5 t/ha.

Comparison of seasons

Table 1 shows average yields achieved by farmers for the regions studied. This is indicative of trends rather than being a statistical dataset as each number is the mean of very different numbers of farms. Considering only Bhola and Barisal, 2008–09 was the worst year for yield with 2007–08 being possibly the best. But 2.5–3.0 t/ha mean yields were assured for Barisal and in excess of 3.0 t/ha assured for Bhola. Noakhali yields of 2.0–2.5 t/ha were assured; the size of the average depended on the greater or lesser inclusion of saline sites such as Hazirhat.

The season yield rankings inversely fit the rankings for Rabi average temperature (Chapter 2.1, this volume) and, in the warmest regions of Jhalakati to Patuakhali, crop durations from sowing to maturity in the hottest season (2008–09) averaged only 85 days compared with 87 in Noakhali and around 90 days in Bhola. This is the only season for which accurate comparative phenology data were collected on SMT crops.

Figure 9. Locations of cooperating farmers' seed multiplication trials (SMTs) in Bhola (centre), Noakhali (top right), Barisal (top left), Patuakhali/Barguna (centre-bottom left) and Jhalakati/Pirojpur. Blue symbols represent 2007–08 (Noakhali sites not shown), magenta pins sites added in 2008–09, red circles sites added in 2009–10, orange F-flags indicate two Food and Agriculture Organization of the United Nations (FAO) sites (Source: Google maps)

Discussion

The outstanding finding from this study was that 2.5 t/ha crops of wheat could be produced almost anywhere that farmers were interested to grow them. The locations were extremely diverse, from the Charlands (Figure 11, see Figure 9 for the farm location at Char Hesamaddi shown by a pair of red markers due north of Barisal), to the vicinity of the mangrove swamps of Kuakata, to Dasmina (Figure 12) and throughout the island of Bhola. And, in most cases, the farmers had never grown wheat before or even seen it growing. Furthermore, their crops were frequently growing as oases in fallow land (Figure 12). Farmers were often surprised at what they had achieved. They had not been aware of their opportunity.

The second surprising finding was that wheat could be grown throughout the south without irrigation infrastructure such as deep or shallow tube wells and that in the few comparisons made, crops could be grown without any irrigation. However, as surface water was invariably available in ponds, canals or other waterways for some period after the monsoon rice crop was harvested, a single irrigation at 20 DAS was made mandatory. It was hypothesised that this was necessary to leach the surface-broadcast fertilisers into the root zone (Chapter 3.4, this volume). This finding of an apparent low water requirement for wheat

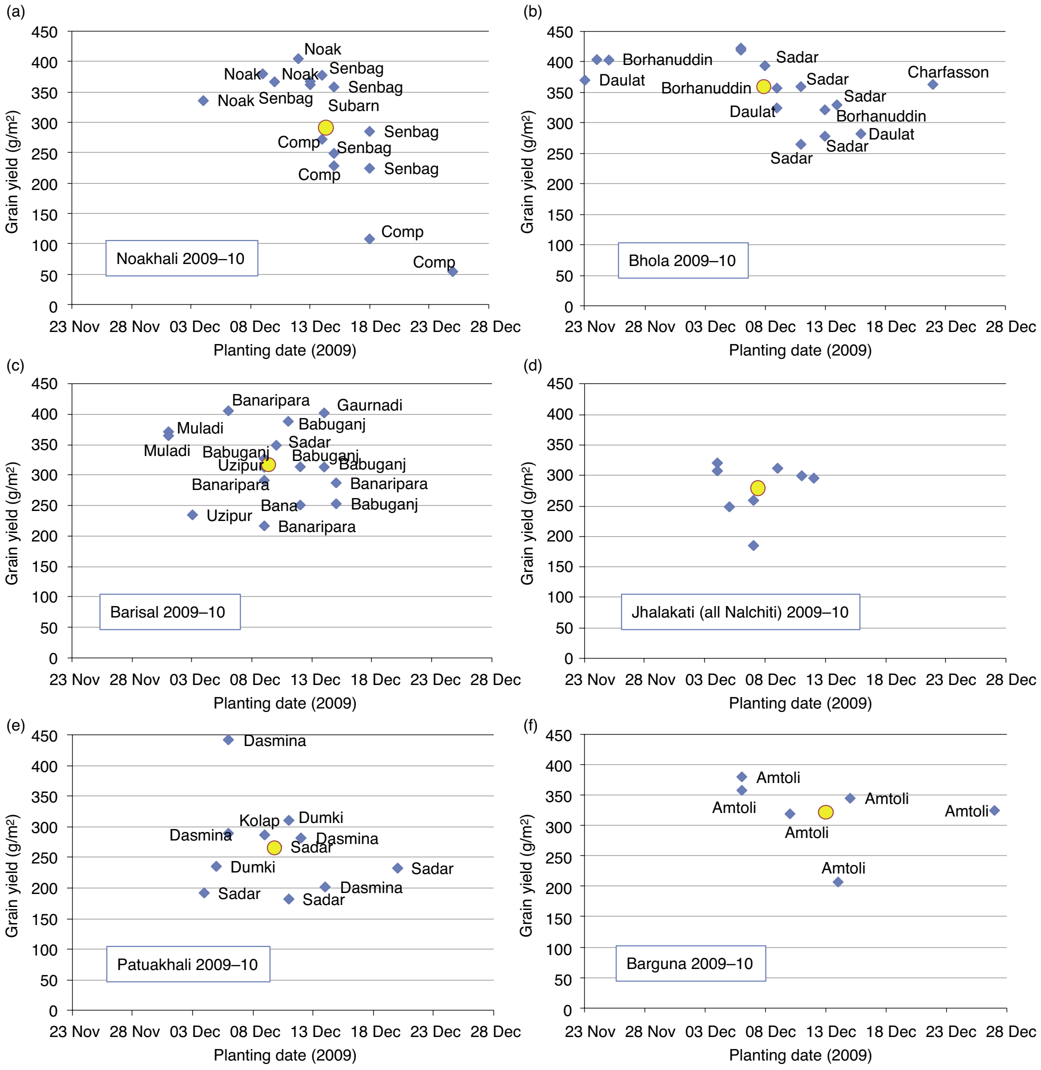


Figure 10. Yield (g/m²) and planting date (2009–10) for seed multiplication trial (SMT) farmers in: (a) Noakhali (upazilas Noakhali Sadar, Subarnachar, Senbag and Companigonj); (b) Bhola (Bhola Sadar, Borhanuddin and Daulatkhan); (c) Barisal (Barisal Sadar, Gaurnadi, Babuganj, Uzipur, Banaripara and Muladi); (d) Jhalakati (all Nalchiti); (e) Patuakhali (Patuakhali Sadar, Dumki, Dasmina and Kolap); and (f) Barguna (all Amtoli). Varieties are not identified as by this stage it was established that varietal yield differences were insignificant. The yellow circle shows mean yield at mean planting date for each graph.

Table 1. Grain yield (g/m^2) for wheat crops in southern regions over three seasons

Season	Noakhali	Bhola	Barisal	Jhalakati	Patuakhali	Barguna	Average, only Noakhali Bhola, Barisal	Average, all regions
2007–08	226	365	393				328	328
2008–09	240	336	280	216	263		285	267
2009–10	291	359	317	279	265	322	322	306
Average	252	353	330	248	264	322	312	300

Note: there are different numbers of farms in each grouping so comparisons can only be indicative

Figure 11. Yield of 3.6 t/ha on Muladi Charlands in the north of Barisal (Photo: HMR; Source for inset: Google maps)

Figure 12. Seed multiplication trial (SMT) farmer's wheat crop of 4.4 t/ha in fallow lands in Dasmina, Patuakhali (Source: Google maps)

was contrary to expectations and observations from crops grown in the north of Bangladesh (see Chapter 3.1, this volume). The difference in the south is that watertables are close to the surface so can be tapped by the wheat roots (Chapter 2.2, this volume).

The third and essential finding was that farmers could plant, grow and harvest wheat within the time window available after they harvested their T. aman crop and before they planted their next rice crop. There was no need to leave their land fallow during Rabi.

Together these findings open up the realistic opportunity for good wheat crops throughout the south and, now knowing the large extent of fallow Rabi land (Chapter 2.3, this volume), there is an opportunity to produce a large amount of wheat in the region. *(Editor's note: the 2010–11 SMT harvests were taken, processed and analysed after the closure of the project. The results from the 90 farmers involved were excellent, with average yields in g/m^2 from the regions being Noakhali 339, Bhola 366, Barisal 383, Jhalakati 349, Patuakhali 386, Barguna 392 (compare with Table 1 data). Average yields from Bhola and Barisal were among the best since the project began, but particularly encouraging were the high yields of around 3.5 t/ha from other regions. Sowing dates averaged mid December, with no farmers opting for November or early December. Jhalakati farmers achieved their 3.5 t/ha yields from 20 December plantings. Poorly performing farmers were very rare and the best farmers achieved yields over 5 t/ha. The indication overall was that farmers were following their training and treating their wheat crops as a significant asset.)*

3.4 Fertiliser and water requirements for southern wheat crops

**M. Saifuzzaman, H.M. Rawson, A.B.S. Hossain,
M. Amin, M. Abu Zaman Sarker, M.H. Ullah, M. Farhad,
M. Farhad Hossain and Kakali Roy**

Abstract

The Wheat Research Centre's (WRC's) fertiliser package was formulated for wheat in the northern and central regions of Bangladesh. Fertilisers are applied basally apart from nitrogen (N) that is split 66:33 between a basal application and one at 20 days after sowing (DAS) when three leaves are fully unfolded, the first tiller emerges and crown roots initiate. This is accompanied with irrigation, other irrigations being recommended for awn peep and watery-ripe grain stages. The questions asked here are: are the amounts and times of application of fertilisers and irrigation appropriate in this hotter southern region with shorter crop duration; and should the package be modified for different varieties, planting dates and locations?

The seven wheat varieties used all yielded similarly, with WRC-recommended procedures achieving almost 3 t/ha at Bhola and Barisal sites with only half the recommended fertiliser applications. This increased to 4.0 t/ha (Bhola) and 3.2 t/ha (Barisal) with full fertiliser applications raising speculation that a delayed first irrigation and N top-dressing to 30 DAS at Barisal might have contributed to the difference. Shatabdi variety tested how much yield declined without irrigation, averaging 19% and 2% reductions in two seasons, much less than in the north, and indicating the importance of shallow southern watertables to yield.

Studies assessed the best times for irrigation and response to N. At a high basal fertility site in Noakhali, there was no response in yield to more than 33 kg N if the 20 DAS irrigation was absent or delayed to 30 or 40 DAS. Extra N was, in effect, wasted. The 20 DAS irrigation, whether given alone or supplemented with irrigations at 50 and 70 DAS, resulted in a yield response to more N, up to 100 kg N in the single 20 DAS irrigation which yielded best at 4.5 t/ha. At low fertility sites, there was a response to increments of N up to 100 kg N.

The recommendation is to irrigate at 20 DAS. Apply up to 100 kg N/ha if planting is in early to mid December. If no irrigation water is available and planting is very late, reduce to 33 kg N because even although there is a response to N, the yield plateau is so low that the benefit does not justify the cost.

Contrary to crops in the north, late-planted wheat in Barisal reached ceiling yield at 66% of all fertilisers in the WRC package although biomass did increase with the 100% applications. The recommendation is to apply 100% for mid-December-planted crops but reduce applications to 66% for late-December sowings.

Preliminary studies with mixtures of organic and inorganic fertilisers demonstrated the primary importance of the inorganic component for high yield.

Introduction

Wheat has been grown in northern and central Bangladesh for four decades (Chapter 1.1, this volume). Recommendations to farmers about how they should grow wheat are based on research station and on-farm trials conducted over many years by the Wheat Research Centre (WRC) of the Bangladesh Agricultural Research Institute (BARI), located near Dinajpur in northern Bangladesh (Chapter 1.1, this volume, shows a location map). Although these recommendations had been developed for the cooler Rabi conditions of the north, it was decided in the Australian Centre for International Agricultural

Research (ACIAR)-funded project to follow all the WRC fertiliser and irrigation guidelines when expanding wheat into the southern regions, at least initially. The plan was to adapt the guidelines where necessary after completion of targeted studies in the south.

The WRC recommendations for fertiliser to be used at sowing were 147 kg urea/ha, 120 kg triple superphosphate, 100 kg muriate of potash, 110 kg gypsum and 1 kg boron/ha if the region was considered boron-deficient (see boron map of Bangladesh; Bodruzzaman et al. 2005). At the three-leaf stage (Z1.3, Z2.1), when the first tiller is appearing and nodal roots are starting to extend, a top-dressing of 73 kg urea/ha was recommended to be applied with an irrigation of 100 mm. In the south this crop stage occurred around 20 days after sowing (DAS). Second and third irrigations were scheduled for awn peep (Z5.0) and watery-ripe grain (Z7.1). Wheat developmental stages (Z stages) are described in the Bangladesh booklet 'Irrigated wheat: managing your crop' (Rawson and Gomez-Macpherson 2000, 2004) and 'Wheat doctor' which takes its stages from that booklet (CIMMYT 2011).

These WRC guidelines produced high-yielding crops of around 5 t/ha in the north in good seasons but some farmers used half recommendations because they could not afford the inputs (Rawson et al. 2007 and see ICAR 1998 for a similar situation in India). It was also hypothesised in discussions early in the ACIAR project that in the hotter conditions of the south with a shorter growing season (Chapter 3.1, this volume), and particularly when planting was very late, there may not be sufficient days for a crop to incorporate all that fertiliser into biomass. Excess may be leached or otherwise lost. There was also the complication of top-dressings of urea that may not be required in short-duration crops, particularly when there was no irrigation water to carry the fertiliser into the root profile.

This chapter aims to explore these questions through describing experiments conducted mainly on farms. It questions whether full fertiliser applications can be reduced without major loss in yield and under what circumstances. It assesses how much nitrogen can be efficiently used by southern crops and to what degree nitrogen and water applications might interact. As an addendum and in response to farmer interest, it explores the extent to which inorganic fertilisers can be replaced by organics. Farmers raised this last question because of the common use of water hyacinth, removed from flooded fields (Figure 1), as compost. It decays within a few days of spreading on the soil. They queried whether this might be mixed with inorganics or with cow manure to boost yield.

Using the WRC fertiliser package at 100% or 50% of recommended levels

The first studies that assessed crop response to fertiliser (2006–07) included several of the new varieties of wheat. It was not known whether they would all respond the same or indeed whether they would yield differently in southern regions. Table 1 compares five varieties all provided with 100% fertiliser in

Figure 1. Piles of water hyacinth fertiliser along the roadside, between fields of boro rice, collected as part of a government initiative to employ unemployed farmers at Tk100/day for 100 days (Photo: HMR)

two villages in each of Barisal, Bhola and Noakhali. Shatabdi is the oldest of the new varieties and was used in the Food and Agriculture Organization of the United Nations (FAO)-funded studies (Chapter 1.1). Overall, Shatabdi did yield best but the overriding conclusion was that varieties differed minimally in performance averaged over locations (3.46 ± 0.09 t/ha). Yield at the saline Hazirhat site was poorest overall (2.8 t/ha) and it was here that Shatabdi did poorly (2.35 t/ha), significantly worse than the variety BAW 1059, which might have some salinity tolerance (Chapter 3.6, this volume).

This study was also designed to assess how much yield might be reduced if crops were not irrigated. The expectation was that yields would drop to at least half, judging by the northern experience. Shatabdi alone was tested. Overall, yield declined by only 19% without irrigation in this season but the results across sites were variable (–3 to 44%, Table 1). In 2007–08, varieties Sufi and BAW 1064 were added and sites were reduced to two: South Balia in Bhola (as in 2006–07) and West Narayanpur in Barisal (Figure 2). Yield again differed little between varieties at either site but all varieties performed better at the Bhola location. Irrigation had no significant effect on increasing Shatabdi yield at either site (Table 2), with South Balia having an 8% effect as against 11% in the previous season.

The 2007–08 trial also included a 50% fertiliser treatment in which all fertilisers, including the nitrogen top-dressing, were halved. Data are in Figure 3. On average across varieties, yields at the two sites for the 50% WRC treatment were the same at 2.85 and 2.93 t/ha (Bhola and Barisal, respectively, Figure 3). But the response to doubling fertiliser to 100% WRC raised yield at Bhola to 141% and in Barisal to only 110%; a 10% increase in yield for double fertiliser is very poor and suggests that something is either preventing the extra fertiliser getting to the Barisal crop or preventing the crop from utilising it in growth. Crop biomass likewise did not respond to the doubling of fertiliser in Barisal (10% higher yield) and tiller number was only 10% more. Tillering is particularly dependent on nitrogen availability at the three-to-four leaf stage when nodal roots are initiating. This lack of response was apparent in all varieties.

What might have caused such a small response to a doubling of fertiliser in Barisal?

- The additional fertiliser was not applied.
- The irrigation intended to take the fertiliser (basal and top-dress) from the surface into the root profile was too late at 30 DAS to be effective (Bhola was 24 DAS).
- Irrigations were so heavy they leached the nutrients out of the profile.

None of these explanations are credible but all were tested later (see next subsection).

The Bhola and Barisal responses have implications for how much fertiliser farmers should apply. If the Barisal situation is real, there is no point applying more than 50% WRC levels as the cost of extra fertiliser is not fully recouped in grain production. If the Bhola situation is more normal, farmers who apply the 100% WRC recommendations will return five times the cost of their extra 50 to 100% applied fertiliser in yield profits (Table 3). In short, this study

Table 1. Grain yield (g/m²) of five wheat varieties at six sites provided with Wheat Research Centre full recommendations for fertiliser (basal and top-dress) and irrigation, and for Shatabdi without irrigation (all fertiliser as basal), 2006–07

Wheat variety	Average without Noakhali	Barisal, Sanuhar	Barisal, Babuganj	Bhola, South Balia	Bhola, North Joynagar	Noakhali, Bariopur	Noakhali, Hazirhat	Average all sites
Shatabdi	386	402	355	374	412	403	235	363
Bijoy	354	334	316	371	394	311	277	334
BAW 1059	380	375	394	362	387	360	330	368
Prodip	336	310	341	304	387	292	272	318
Sourav	356	356	366	318	382	357	294	346
Average irrigated	362 ±9	355 ±16	354 ±13	346 ±14	393 ±5	345 ±20	282 ±16	346 ±9
Shatabdi, no irrigation	291	296	307	332	230	367	242	296
Shatabdi, no irrigation, yield reduction	25%	26%	13%	11%	44%	9%	–3%	19%

gave no overwhelming reason to change WRC recommendations, but did suggest more work should be done to clarify the results.

Interaction between nitrogen and irrigation

An on-farm experiment in Noakhali in 2007–08 posed three questions:

1. As most farmers in the south have only enough water for a single irrigation during early Rabi, when should that be applied for maximum yield?
2. Top-dressing with nitrogen is part of the WRC recommendation; how much is appropriate for southern crops and when should it be applied?
3. Do water and nitrogen interact in their effects?

In relation to 3., it was hypothesised that surface irrigation may be needed to move fertiliser into the root zone once tillering has started: the water may not be needed directly by the crop for growth but rather as a mechanical fertiliser spreader. At the time of crown root initiation, when the first tiller has emerged with its associated new root primordia, the soil profile still has adequate water for optimal

Table 2. Grain yield (g/m²) of seven wheat varieties at two sites provided with Wheat Research Centre full recommendations for fertiliser (basal and top-dress) and irrigation, and for Shatabdi without irrigation (all fertiliser as basal), 2007–08

Wheat variety	Bhola/Barisal average	Barisal, West Narayanpur	Bhola, South Balia
Shatabdi	366	320	413
Bijoy	382	342	421
BAW 1059	391	357	425
Prodip	310	276	344
Sourav	335	274	396
Sufi	367	311	423
BAW 1064	390	383	396
Average irrigated	362 ±11	323 ±15	403 ±11
Shatabdi, no irrigation	359	336	382
Shatabdi, no irrigation, yield reduction	2%	–5%	8%

Figure 2. Part of the West Narayanpur, Barisal, multi-variety site with 100% Wheat Research Centre (WRC)-recommended fertiliser applications on the left and 50% WRC on the right, nitrogen (N) top-dressed at 30 days after sowing (DAS), all sown 15 December 2007 and average anthesis 22 February 2008—corresponding Bhola trial was sown 18 December, N top-dress 24 DAS and reached anthesis 28 February (Photo: HMR)

growth remaining over from the wet-season soaking (Chapter 2.2, this volume).

The experiment was planted on 19 December in three blocks, block 1 containing all the unirrigated (rainfed) treatments. Irrigation treatments in blocks 2 and 3 were a single application either at 20 DAS, 30 DAS or 40 DAS, or three applications, 20, 50 and 70 DAS; the last is the WRC recommendation for traditional wheat-growing areas. There were four nitrogen (N) treatments of 0, 33, 66 or 100 kg N/ha, with each total amount split between a basal application at sowing (66%) and a top-dress application (33%). The top-dressing was applied with the irrigation at 0, 20, 30 or 40 DAS and at 20 DAS for the 20, 50 and 70 DAS treatment. Because the N split was a percentage of the total N applied, actual amounts differed between N treatments, as shown in Table 4.

Overall effects of nitrogen

Biomass and yield both increased with N at 18 kg dry matter/kg N and 10 kg grain/kg N, respectively, with yield increasing through increments in weight per grain (0.038 mg/kg N) and grains per head (0.08 grains/kg N). But there were interactions between irrigation treatments and N as can be seen in Figure 4.

No irrigation

In this set of treatments, the soil profile at planting was not dry and this was a fertile site estimated to contain towards 100 kg equivalents of mineralisable N, so yield even without irrigation or added N was around 2.7 t/ha. But without added water, yield reached a ceiling at 33 kg/ha of applied N. In effect, addition of more than 33 kg/ha was money wasted. But to achieve a 3.3 t/ha yield with so few inputs in Noakhali is remarkable.

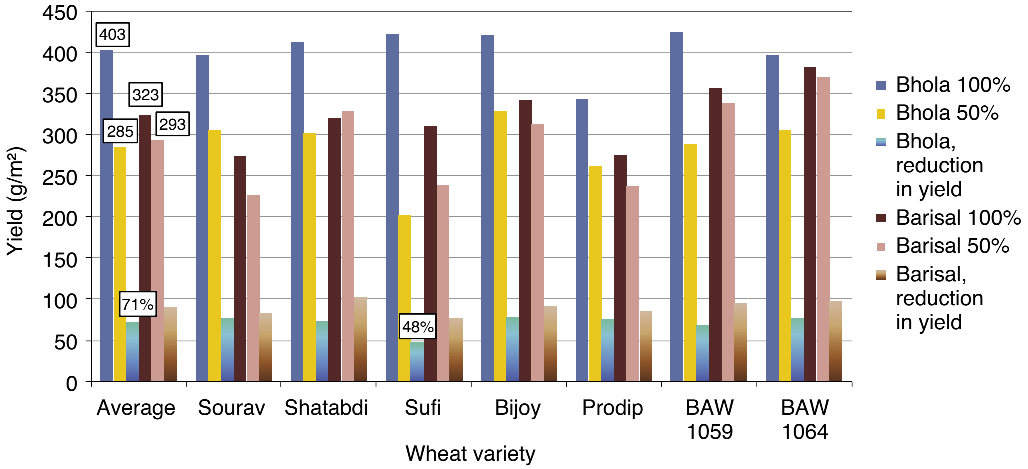


Figure 3. Effect on grain yield of 100% and 50% Wheat Research Centre (WRC)-recommended fertiliser applications at sites in Bhola and Barisal for different wheat varieties (the first group of histograms is the average response). Data are from 3 × 2 m^2 cuts from each plot. Note the poor performance by Prodip, the best variety in the north. This was traced to an inferior seed batch used here.

Table 3. Fertiliser costs and yield benefits for using full and half Wheat Research Centre (WRC) fertiliser recommendations on Bhola crops

WRC recommended fertilisers	Yield (t/ha)	Crop value (Tk/ha) at 30 Tk/kg	Fertiliser cost: all chemicals (Tk/ha)	Crop value/fertiliser cost
50% WRC	2.850	94,180	7,215	13×
100% WRC	4.030	133,173	14,430	9×
Difference	1.180	38,993	7,215	5×

Table 4. Experiment to test the interaction between irrigation and nitrogen, Noakhali, 2007–08: timing of irrigation (days after sowing, DAS), nitrogen (N) application rates including percentage splits and actual amounts of N applied

Irrigate at	Total N applied	Total N split between		N top-dress
	Four treatments of N (kg/ha)	N at sowing (%)	N at top-dress (%)	Applied at DAS
0 DAS	0, 33,66,100	66	33	20
20 DAS	0, 33,66,100	66	33	20
30 DAS	0, 33,66,100	66	33	30
40 DAS	0, 33,66,100	66	33	40
20, 50, 70 DAS	0, 33,66,100	66	33	20

Total N applied (kg/ha)	Total N split between	
	Sowing (kg/ha)	Top-dress (kg/ha)
0	0	0
33	22	11
66	44	22
100	66	33

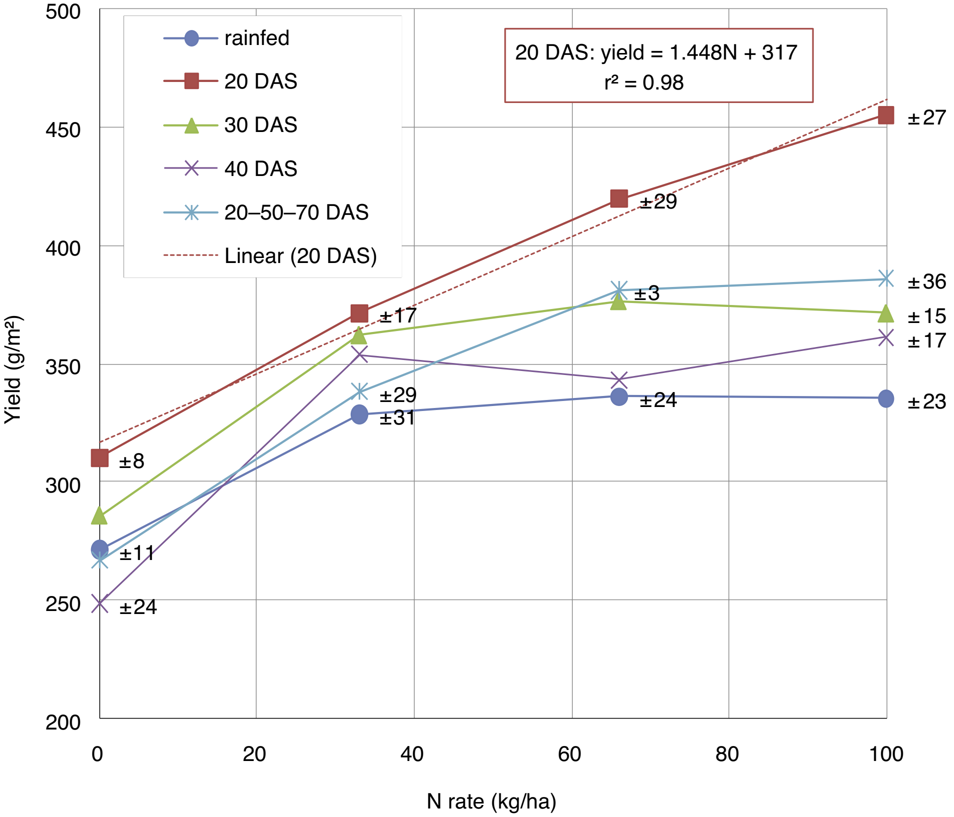


Figure 4. Grain yield as affected by nitrogen (N) rate and irrigation—days after sowing (DAS) and frequency; sowing date was 19 December 2007, anthesis was 26 February 2008 and harvest was 23 March 2008, 95 days after sowing

Irrigation at 20 DAS

In this treatment, crops responded linearly to N up to 100 kg/ha, and clearly would have responded to even higher applications. A yield of 4.5 t/ha was reached with an average response of 14.5 kg grain/kg N added. There was also an indication that the single irrigation at 20 DAS either released mineralised soil N or made basal fertilisers more available to the crop, as yield without added N was almost 400 kg/ha higher than in the rainfed treatment (Figure 4).

Irrigation at 30 DAS or at 40 DAS

Yield reached a ceiling at 33 kg N/ha as in the rainfed treatment, but for the 30 DAS irrigation, possibly from a higher base (Figure 4). So delaying irrigation beyond 20 DAS at this site meant a loss in yield of between 600 and 900 kg/ha in the 100 kg/ha N treatment.

Three irrigations—20, 50 and 70 DAS

This treatment was surprising. Despite having one irrigation at 20 DAS it responded to each level of applied N less than the single 20 DAS irrigation treatment, and reached ceiling yield at 66 kg N/ha (Figure 4). Yields at equivalent N applications for the three-times irrigation plots were approaching 500 kg/ha less than for the single 20 DAS irrigation. It may be that three irrigations in a region with relatively high watertables cause N leaching or soil waterlogging. These ideas were not tested.

The conclusion

For this trial at Noakhali at a fertile site (Figure 5), the irrigation plus N top-dressing at 20 DAS was critical for good yield. It should not be delayed even 10 days. Furthermore, too much irrigation may reduce yield. If irrigation has to be delayed beyond 20 DAS, application of more than 66 kg/ha N is money wasted. Delay to 30 DAS resulted in a yield loss of 700 kg/ha. Referring back to the Barisal variety trial (Figure 3) where there was only a small yield response to doubling fertiliser applications, it is possible that the poor fertiliser response was due to the first irrigation being delayed to 30 DAS.

The study needed to be duplicated in other areas to confirm or reject the unexpected findings and particularly at a less fertile site that might respond to higher levels of applied N. This was attempted in a parallel study at Barisal but was uninterpretable due to randomly distributed wind damage.

The second nitrogen by irrigation study (2008–09)

Two low fertility fields were chosen, one at the same farm used above in Hazirhat and one at West Narayanpur, Barisal, in the area used for the varietal trial of Figure 2. The experimental design used above (Table 4) was retained with nitrogen treatments of 0, 33, 66, and 100 kg N/ha split between 66% as basal and

Figure 5. Nitrogen by irrigation study in Noakhali, 2007–08 (Photo: HMR)

33% as top-dressing and with irrigations being none, at 20 DAS, or at 30 DAS, accompanying top-dressing. The 40 DAS and multiple irrigation treatments were not included. There was no rain in this season.

The Barisal, West Narayanpur, two-bucket study

This study is put into context by the following note in the 2008–09 annual report to ACIAR by the project leader. A visit to the site during grain filling was '…a disappointment with responses to irrigation (0, 20 DAS, 30 DAS) negligible. It transpired that the farmer had sold his pond water rights to a fisherman and only applied 2 buckets of water to each plot of 8 m^2 (*Editor's note: about 20 litres, or 2.5 mm rain equivalents*). He was however, able to find water for his seed multiplication trial (SMT) field (from which he was making a profit)'.

Remarkably, the two buckets of water had some effect on biomass and yield, but only significantly so at the highest rate of N where the ranking was: 20 DAS irrigation best, 30 DAS irrigation next best, and rainfed worst (Figure 6a, b). However, both irrigated treatments responded to N through to 100 kg/ha, unlike at the high nutrition site described above; the rainfed treatment did not respond to N beyond 66 kg/ha. Yields and biomass were all low compared with the previous study. The conclusion is that the small amount of water applied had a small positive effect on increasing the amount of N available for plant growth at high N. The farmer produced 3.3 t/ha in his own field some 50 m from the study site.

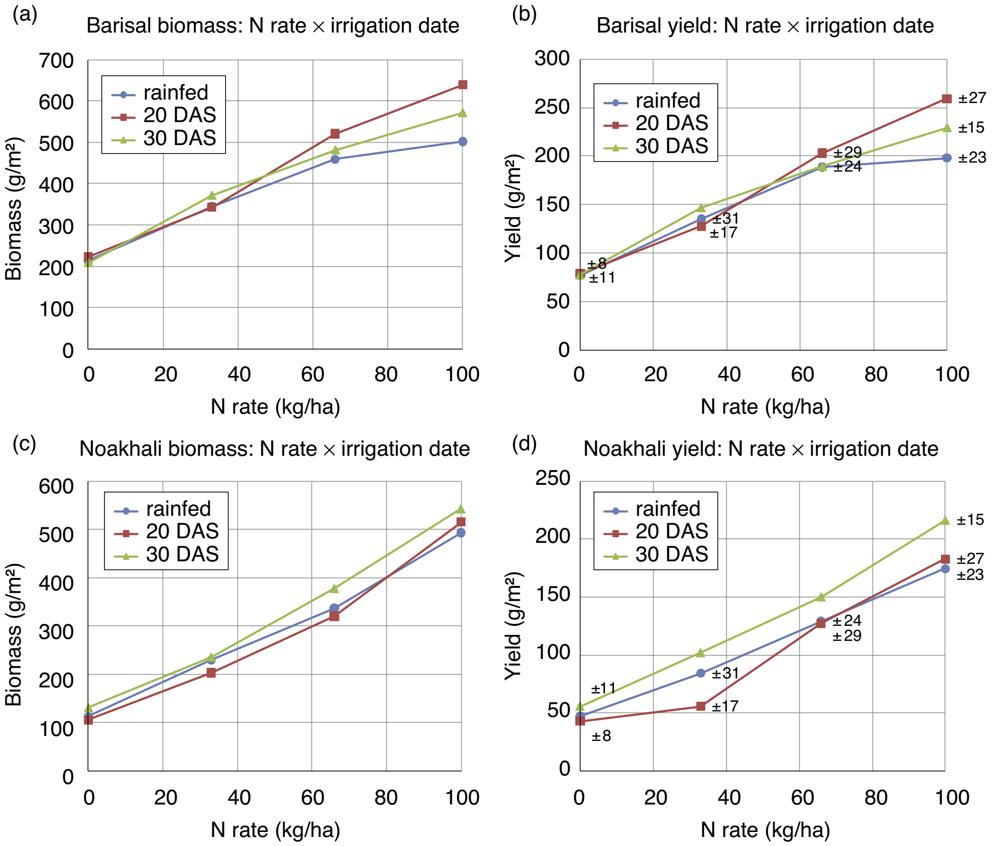


Figure 6. Effects of nitrogen (N) rate and irrigation date (days after sowing; DAS) on biomass and yield in studies in West Narayanpur, Barisal (a and b), and Hazirhat, Noakhali (c and d)—planting dates were 25 November and 31 December 2008, respectively

Noakhali, Hazirhat

The Hazirhat field selected for its low nutrition status was sown very late on 31 December because the field was too wet to enter until this date, so the crop was constrained by length of season as well as by nutrition. Yield reflected this by being around 0.5 t/ha at zero nitrogen application and without irrigation (Figure 6d). This contrasts with almost 3 t/ha from the no-irrigation, no-N treatment at the same farm in 2007–08. But, as in the two-bucket study, there was a progressive response to more N, even without water application. In this case, although applying irrigation at 20 DAS was no different from no irrigation, delaying irrigation to 30 DAS was the best treatment, although effects were not significant.

Conclusions from the nitrogen by irrigation studies

For safety, farmers should irrigate at 20 DAS. Apply up to 100 kg N/ha if planting is in early to mid December and if irrigation water is available at 20 DAS. If no irrigation is available and planting is very late in December or into early January, reduce to 33 kg N because even although there is a response to N, the yield plateau is so low that the benefit does not justify the cost.

How nitrogen alters the crop; it impacts primarily through grain number

At the two low fertility sites just described, each applied unit of N added 27–29 more grains/m² in the West Narayanpur and Hazirhat unirrigated treatments and 39–40 more grains in the irrigated treatments with increments being above a base of 1,400 grains to 1,750 grains/m² in the zero N treatment. The pattern is shown in Figure 7 for Noakhali. The commonality of response across sites is surprising.

At the high fertility Hazirhat site used in 2007–08 responses of grain number to N were different. First, the base grain number without added N was 6,000 grains/m², close to the 100 kg N application in Figure 7. Additionally, all N treatments, apart from those irrigated at 20 DAS, reached maximum grain number at 33 units of N. The 20 DAS irrigation produced a progressive rise in grain number at 22 grains/m²/kg N up to 100 units of N.

Combining data on grain number versus N from the high and low fertility studies and using only values from the 20 or 30 DAS irrigation treatments, and assuming that the 2007–08 study had 110 kg available mineralised N additional to that applied as fertiliser, produces the trend of Figure 8.

These disparate data combine convincingly and point to the critical importance of N for setting grain number per unit land area. N management linked with water is the key tool the farmer can use to control yield through grain number. Radiation receipt, particularly in the period between terminal spikelet initiation and heading, is an equally powerful variable that also correlates with increased fertile tiller number and through that with grain number (e.g. Rawson and Bagga 1979). But radiation receipt cannot be managed by the farmer.

Do late-planted crops require less fertiliser?

Following up on the idea that late-sown, reduced-duration crops might not be able to use as much N as those planted earlier when conditions are cooler and the potential growing season is long, an experiment was planted with treatments being sowing date and fertiliser amount. In this case, all WRC-recommended fertilisers were allocated as 0, 33%, 66% or 100% rate. Fertiliser ingredients in the WRC package are

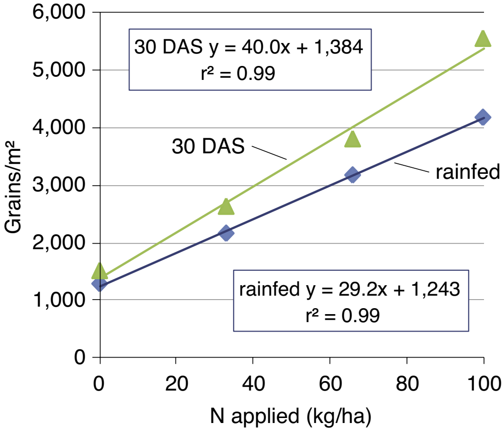


Figure 7. Relationship between grains/m² and applied nitrogen (N) in rainfed and 30 days after sowing (DAS) irrigated treatment at a low fertility site at Hazirhat, Noakhali, 2008–09

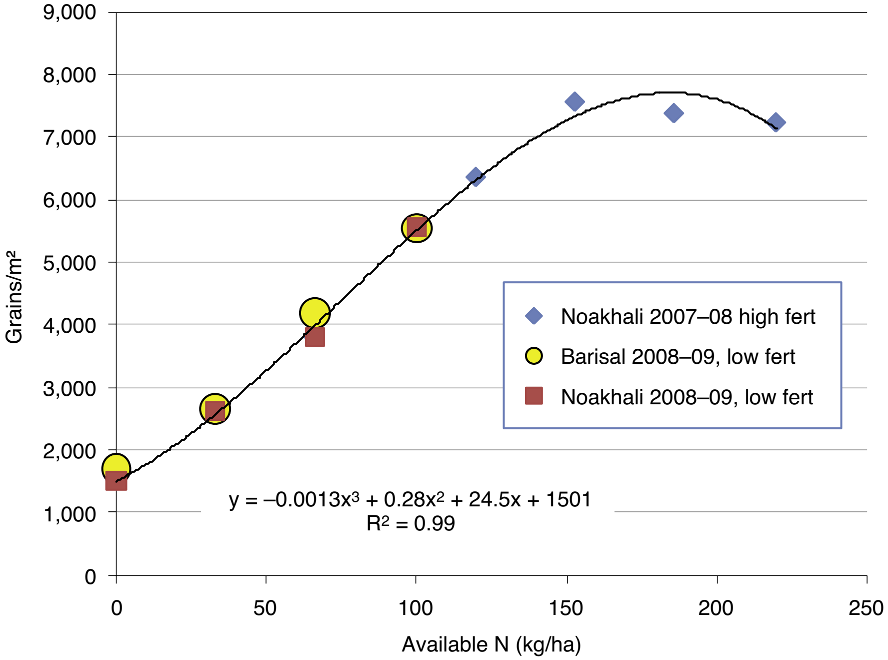


Figure 8. Relationship between grains/m² and available nitrogen (N) from two low and one high fertility sites in Noakhali and Barisal. Basal available N at the high fertility site was estimated from the yield achieved without applied nitrogen.

detailed at the beginning of this chapter. Irrigation and appropriate N top-dressing were supplied at 20 DAS. The experiment was conducted at the Barisal Regional Agricultural Research Station (RARS), and independently by one of the Barisal SMT farmers. To check whether the response to fertiliser was as expected for the traditional wheat-growing areas, the experiment was also run at Dinajpur in the north.

Crops in Barisal

Yield at Barisal RARS was, as expected, highly responsive to fertiliser, rising progressively with fertiliser amount to 4 t/ha in the 26 November and 10 December 2009 sowing date treatments (Figure 9a). Responses were not significantly different between those dates. Yields without added fertiliser were above 2 t/ha indicating the moderately high fertility status of soils at the research station.

The late planting on 24 December reached a yield plateau of 3 t/ha at 66% WRC-recommendations with no yield response to more fertiliser. Biomass did increase in all four replicate plots between the 66% and 100% fertiliser applications (760 to 830 g/m²) but because harvest index (HI) declined (40 to 36%) and the crops had smaller grains (41 versus 38 mg), the biomass increment did not convert into yield.

The Barisal farmer's crops showed the same progressive responses to increased fertiliser from the 10 December sowing date, but the early and late crops both reached a yield plateau at 66% WRC-recommendations (Figure 9b). The reasons were as at Barisal RARS; grain number responded positively to more fertiliser, but those grains were slightly smaller (44 to 42 mg) from the late sowing and HI was very much reduced in both early and late crops (51 to 43%). So again, applying more fertiliser from 66–100% WRC increased biomass, particularly from the early planting (500 to 640 g/m²), but there was no associated increase in yield. Maybe these crops were short of water during grain filling.

One point of difference between the RARS and farmer crops was the basal yields of 1 and 2 t/ha, demonstrating the absolute reliance of farmer yield on fertiliser application and the reminder that on-farm trials should always be run in parallel with research station trials to gauge realistic farm outcomes.

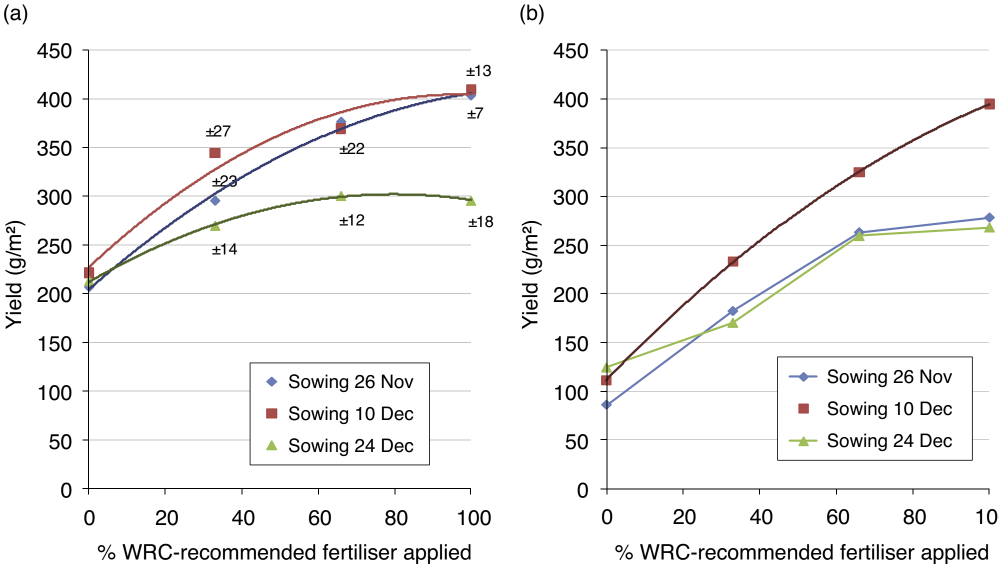


Figure 9. Grain yield in Barisal as related to proportion (%) of Wheat Research Centre (WRC)-recommended fertiliser applied and sowing date at (a) the Regional Agricultural Research Station (RARS) and (b) a local farm

Crops in Dinajpur, a traditional wheat area

The response to added fertiliser was very strong at Dinajpur, rising from low basal yields of 1.5 t/ha (Figure 10). It was linear from the earliest planting with only slight reduction in response to the late planting of 24 December.

The conclusion from these Dinajpur data is that the fertiliser (and planting date) recommendations are correct for the area. So, unlike the situation in Barisal, there is no argument here for reducing fertiliser applications to 66% of WRC recommendations when planting late. In Barisal, the farmer who plants late has to decide whether to pay around Tk5,000 to raise fertiliser application from 66 to 100% WRC recommendation in the hope that this will produce at least 250 kg grain/ha more, enough to cover the cost of the fertiliser increment (2009–10 prices). Most farmers will prefer not to take that risk.

Assessing organic fertilisers and yield

This study was done at Barisal RARS to check whether the high cost of the inorganic fertiliser package recommended for wheat by WRC could be reduced without loss in yield by supplementing a proportion of the inorganic chemicals with locally available organic materials. The basic design was to provide 100, 66, 33 and 0% of the WRC recipe mixed with either 5 t/ha of cow dung or composted water hyacinth (Figure 11).

Yield reflected the proportion of the WRC inorganic fertilisers included in the fertiliser mix and showed no positive or negative effect of the organics (Figure 12). Neither cow dung nor water hyacinth alone raised yield significantly above the level achieved with no added fertiliser (1.5 t/ha). Any immediate benefits of the organics could not be seen but such studies have to be run for many years to show impacts.

Conclusions

These fertiliser studies have produced no standard guidelines for how to grow wheat in the southern regions of Bangladesh. This is not surprising because localities and fields differ in their basic fertility so require different amounts of fertilisers to achieve target yields. This is shown in the comparison of the Noakhali site that produced 2.7 t/ha wheat without any additives (Figure 13), an adjacent field that achieved only 600 kg/ha, a farmer's field in Barisal that produced 1 t/ha without additives, to Barisal RARS that could produce 2 t/ha without added fertiliser. Then there is the variability introduced by planting early or planting late which impacts on the time that crops have to utilise fertiliser in making yield. The fertiliser may generate biomass but that may not convert into grain, in which case the fertiliser is wasted. And then there is the weather in the particular season that may be hotter or cooler to shorten or extend the crop, wetter or drier to make added fertiliser more or less available by distributing it through the soil profile to the roots, or with higher radiation stimulating potential growth and increasing the ability of the crop to utilise fertiliser in yield.

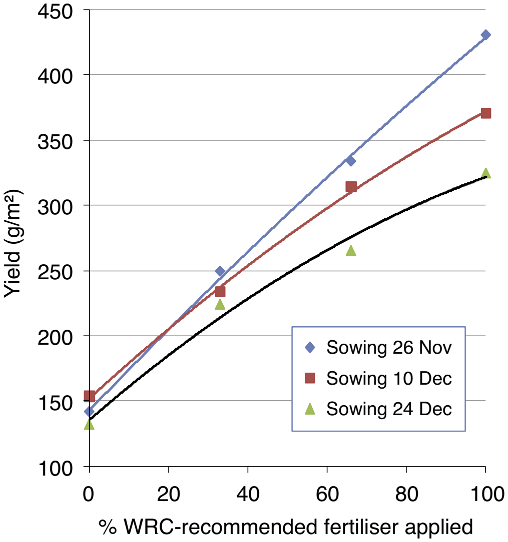


Figure 10. Yield at the Wheat Research Centre (WRC) in Dinajpur as related to % WRC-recommended fertiliser applied and sowing date

So any conclusions reached here must be surrounded by modifiers. In general, however, it seems that to minimise risk and increase the chance of harvesting a good crop, irrigation at 20 DAS is important, possibly because it makes basal and top-dressed fertiliser more available to the crop. A possible explanation for how availability is increased is the idea of the irrigation distributing the basal and top-dressed fertiliser down the profile into the root zone. Also, because the newly developing nodal roots at 20 DAS are quicker and more effective than the few deep seminal roots at taking up nitrate particularly (Brady et al. 1995), that will feed forward to production of more strong tillers and more associated nodal roots that will further explore the soil profile for nutrients. Delay of the 20 DAS treatment will delay this compound interest growth effect with large absolute consequences in this short-duration crop. If sowing is done before 15 December, it is worth using

Figure 11. Water hyacinth uprooted in flooded fields and stacked ready for spreading as an organic fertiliser (Photo: MS)

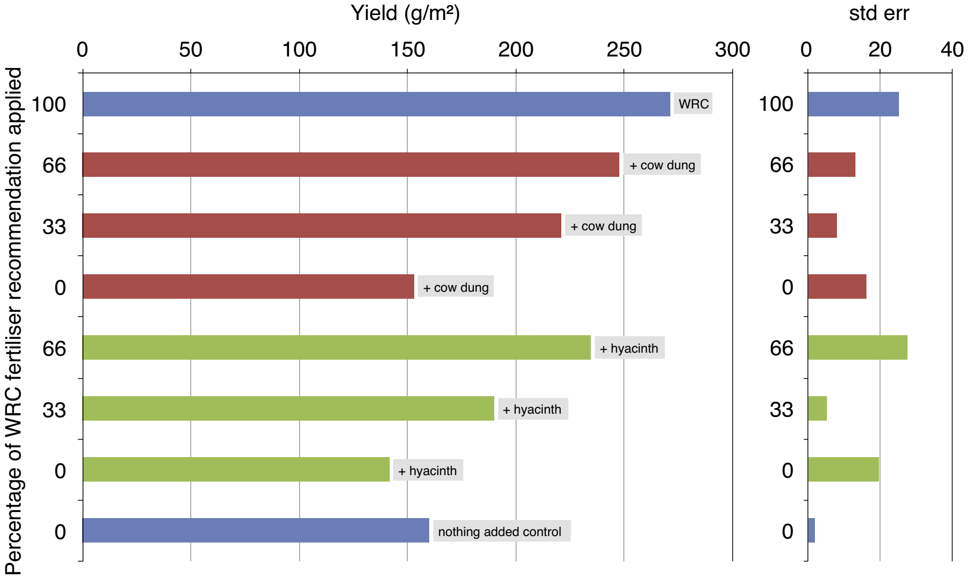


Figure 12. Effect of using 0, 33, 66 or 100% of the Wheat Research Centre (WRC)-recommended fertiliser amount mixed with 5 t/ha cow dung or 5 t/ha water hyacinth and the standard error mean for each treatment—study done at Barisal Regional Agricultural Research Station

Figure 13. Wheat crop in picturesque Noakhali (Photo: HMR)

the full WRC recommendations for fertiliser, although not the recommended three irrigations unless it is an extremely dry and hot Rabi season. There seems little advantage in using high fertiliser inputs if planting is at the end of December because potential yield then is likely to be limited to 2.5 t/ha and there is insufficient crop time to generate the biomass to use that fertiliser. Then it is always necessary to balance the costs of fertiliser against the amount and value of the crop likely to be grown. The fertiliser applied and not used by the crop will not necessarily be available to the next crop in the sequence.

The optimal management for the circumstances of here and now will always have to be best-guessed by the farmer and the local agricultural adviser.

References

Bodruzzaman M., Meisner C.A., Sufian M.A., Samad M.A., Saifuzzaman M. and Sadat M.A. 2005. Addressing wheat sterility through nutrient management. International Maize and Wheat Improvement Center (CIMMYT). Bangladesh: Dhaka.

Brady D.J., Wenzel C.L., Fillery I.R.P. and Gregory P.J. 1995. Root growth and nitrate uptake by wheat (*Triticum aestivum* L.) following wetting of dry surface soil. Journal of Experimental Botany 46, 557–564.

CIMMYT (International Maize and Wheat Improvement Center) 2011. Wheat doctor. CIMMYT: Mexico DF. At <http://wheatdoctor.cimmyt.org>, accessed 3 May 2011.

ICAR (Indian Council of Agricultural Research) 1998. Decline in crop productivity in Haryana and Punjab: myth or reality? Report of the Fact Finding Committee, ed. by R.P. Sharma. ICAR: New Delhi.

Rawson H.M. and Bagga A.K. 1979. Influence of temperature between floral initiation and flag leaf emergence on grain number in wheat. Australian Journal of Plant Physiology 6, 391–400.

Rawson H.M. and Gomez-Macpherson H. 2000. Irrigated wheat: managing your crop. Food and Agriculture Organization of the United Nations: Rome.

Rawson H.M. and Gomez-Macpherson H. 2004. Irrigated wheat: managing your crop. Food and Agriculture Organization of the United Nations: Rome. (In Bangla)

Rawson H.M., Gomez-Macpherson H., Hossain A.B.S., Saifuzzaman M., Rashid H., Sufian M.A., Samad M.A., Sarker A.Z., Ahmed F., Talukder Z.I., Rahman M., Siddique M.M.A.B., Hossain I. and Amin M. 2007. On-farm wheat trials in Bangladesh: a study to reduce perceived constraints to yield in traditional wheat areas and southern lands that remain fallow during the dry season. Experimental Agriculture 43, 21–40.

3.5 Beds or flat-planting for southern wheat crops

M. Saifuzzaman, H.M. Rawson, M. Amin, M. Farhad, M. Helal Uddin, M. Sydur Rahman, M. Farhad Hossain and M. Enamul Haque

Abstract

This chapter examines the notion that planting wheat on temporary formed beds might result in higher yielding crops than the traditional method of flat-land plantings done either in 20 cm rows or using broadcasting. Despite comparative trials over several seasons and locations in the south, there was no evidence to indicate one method is superior to the other or that the extra costs associated with beds are returned in yield. The hope that beds might result in yield increases in saline areas was not supported.

Introduction

Conservation tillage, which aims to minimise disturbance of the soil before planting, has become commonplace in the past two decades, particularly in irrigated agriculture (Hobbs and Sayre 2002). It reaches its peak of management in permanent beds that once they are raised need only a light restructure of the shoulders each season before seeds are direct drilled at the tops of the ridges. This results in minimal disturbance of microfauna over the seasons. For planting and other cultural activities, machines are used that place their wheels only in the furrows, and even then not in every furrow, so that soil compaction is minor and soil aeration remains high (see Boulal and Gomez-Macpherson 2010 for extensive literature). Crop matter that is not harvested remains as mulch in all parts of the field apart from the ridge tops where the crops are planted. This minimises weed establishment and can sequester 20–40 t/ha of carbon annually to fields; the amount depending on productivity of the crops grown. By mulching and structuring initial field landscape to the contours, beds can be used to control soil erosion. The question asked here is whether they might have an application in the southern areas of Bangladesh.

Beds, along with several other conservation tillage methods, were used in a study funded by the Food and Agriculture Organization of the United Nations (FAO) in 2003–05 with a few sites located in Barisal and Noakhali (Rawson et al. 2007). The rationale for their use was:

- Beds allow faster application of irrigation as the water runs quickly along the furrows, and less water is used because only the furrow bottom is wetted, leaving the ridge top dry.
- In the south, efficient water use, as occurs with beds, is important as irrigation infrastructure for wheat crops in the region is minimal.
- The ridge top where the crop is sown remains oxygenated during irrigation avoiding short-term root waterlogging and accompanying cessation of carbon fixation and growth; this can save 1–2 days growth per irrigation cycle compared to flat-land flood irrigation.
- Because the ridge top remains dry during irrigation and excess water drains along the furrows, there is less likelihood of crop lodging during windy weather and after heavy rain.
- In saline areas such as in Noakhali, Patuakhali and Satkhira, where salt rises through capillarity in wet soil, plants on ridges will be less exposed to salt

than on flat land; there, water pooling in low-lying areas after irrigation and light rains creates salt slicks and associated plant death.

The FAO-funded studies showed that temporary (one season) beds did not result in better yields, at least over the two seasons tested. This was the case even in saline areas with and without mulching to ostensibly reduce soil-surface water evaporation and wicking of salt; it was in saline soils that the effects were expected to be most positive (Rawson et al. 2007).

There were some positive effects in the FAO studies, but they were observed effects that were not scientifically tested. The farmers observed that rats seemed reluctant to cross bare furrows and as a consequence crop damage close to harvest was much reduced. Rats can devastate yield if they establish their network of burrows in a wheat field. Farmers also commented on the convenience and lack of crop damage caused when walking along straight furrows (Figure 1), particularly in contrast to broadcast crops with their randomly distributed plants. Associated with that was the relative ease of weeding beds. The final positive effect was that seed costs were less. The recommendation for flat-planting in line is 120 kg seed/ha and this is reduced to 80 kg/ha with ridge-planting because rows are more widely spaced (20 cm rows to 30 cm beds on average).

The rationale for retesting beds against flat-planting in the current Australian Centre for International Agricultural Research (ACIAR)-funded trials was that machines are now available that attach to a power tiller and form a ridge and plant two rows and apply fertiliser in one pass. The previous machines were cumbersome, needing several passes to complete bed forming and planting processes, and because they did not sufficiently compact the beds, the structure could collapse during irrigation. These new machines (Figure 2) provide adjustable ridge centre spacing to much less than 60 cm, which is appropriate for wheat; they cut the soil rather than pushing it during the ridge-forming process, thus using less fuel; and the bed is compacted during the final shaping. Furthermore, these machines are multipurpose rather than bed-dedicated, being adaptable to flat-planting in rows, and can be used for several crop species.

Figure 1. Standing in the furrow of Shatabdi beds in Rajshahi, Food and Agriculture Organization of the United Nations–funded studies 2004 (Photo: HMR)

Figure 2. New bed former-planter attached to a power tiller being demonstrated. Bed compaction is sufficient to support the weight of a person on the ridge. This is a single-pass operation from untilled to seeding (Photo: E.M. Haque)

Design of studies

In 2008–09, beds and flat-plantings were compared on 100-m² fields at four on-farm locations in Barisal (Gaurnadi and Banaripara) and at four sites in Noakhali, all in Hazirhat. Planting dates were 27 and 28 November in Barisal and 1 month later in Noakhali (20 December for Shatabdi and 28 December for other varieties). Several varieties were assessed as some can perform better than others in beds, largely because they use the extra plant-to-plant space to produce yield, possibly through more ear-bearing tillers with larger ears. Varieties were Bijoy, Sourav, Sufi, Prodip and Shatabdi. Nutrition and irrigation practices were the same at each site and were as described for other on-farm sites (Chapter 3.3, this volume).

Yields on beds and on the flat (2008–09)

Apart from a poor crop of Sourav, yields generally exceeded 3 t/ha at Barisal and there were no significant differences between beds and flat-planting for any of the varieties (Figure 3).

The same conclusion of no significant effects of planting methodology also applied at Hazirhat (Figure 4) and, as is normal for these saline sites and extremely late planting, yields were around 2 t/ha or less. It should be mentioned that each harvested area was measured as the crop-cut area plus half the distance to adjacent uncut rows. The cuts included two beds within their full width. Harvest area approximated 2 m² for all cuts, with three replicate cuts taken for each treatment to provide the mean shown in the graphs.

Averaged data from beds versus flat-plantings from all locations showed no method was superior, at least in these trials. There was also no evidence that beds produced more and larger grains on fewer although stronger shoots, although visual comparisons during grain filling suggested a difference. Such differences are often reported. Weight per grain was 32–33 ± 2 mg at Noakhali and 40–41 ± 3 mg at Barisal. Harvest index (HI) was also the same between cultivation treatments being 37 ± 1 at Noakhali and 44 ± 3 at Barisal.

Yields on beds and on the flat (2009–10)

Despite conclusive evidence that beds and flat-plantings do not differ in yield, the feeling continued among the involved researchers that beds should be better. So the comparisons continued at more

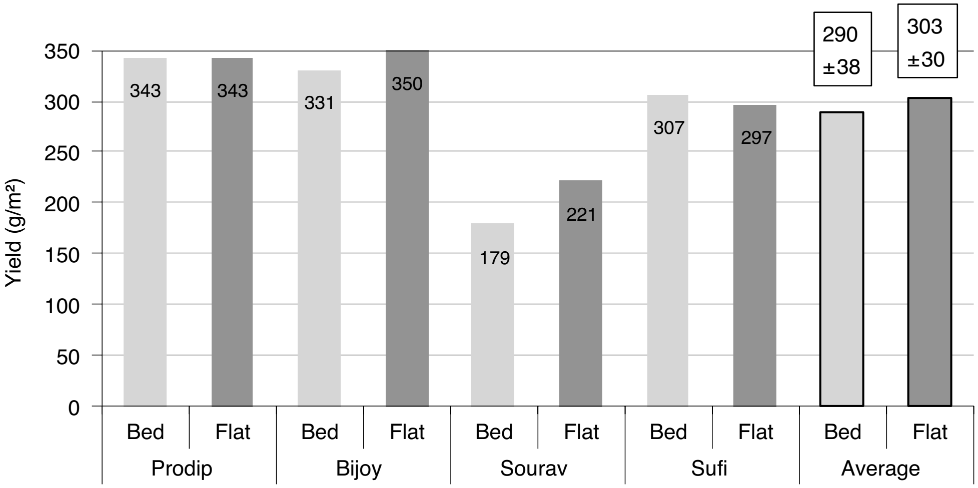


Figure 3. Grain yields of four wheat varieties planted on beds or on the flat in Barisal—the final pair is the averaged data ± standard error for Barisal

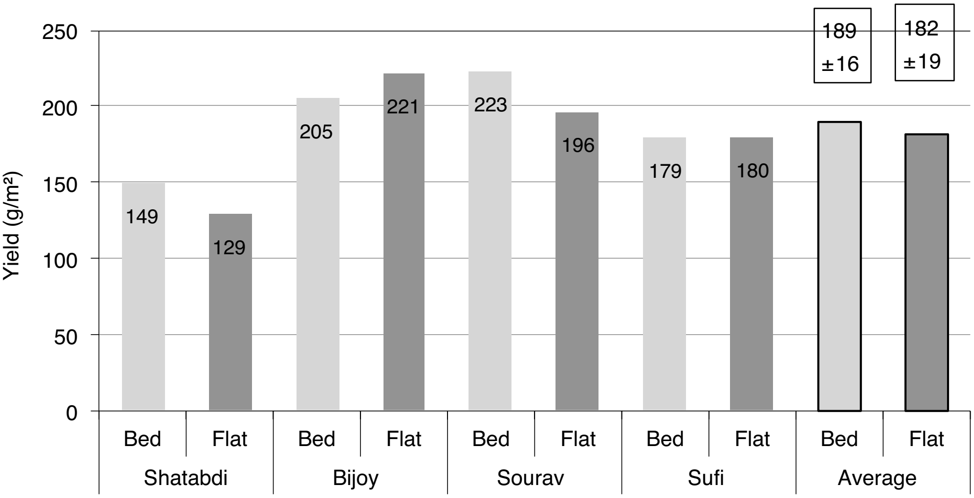


Figure 4. Grain yields of four wheat varieties planted on beds or on the flat in Hazirhat, Noakhali—the final pair is the averaged data ± standard error for Noakhali

locations in 2009–10. Four farmers were involved in each of four regions Barisal (Khanjapur), Barguna (Choura, Ghotkali, South Amtoli and North Tiakhali), Bhola (Borhanuddin, Daulatkhan and Bhola Sadar) and Noakhali (Subarnachar, farm 13 and Hazirhat, farms 14–16). Varieties were as in 2008–09 with the inclusion of BAW 1064 and BAW 1059, at that time as unnamed lines. Sowing dates were earlier in an attempt to encourage longer durations and thereby to possibly advantage bed-plantings. Sowing dates and varieties used in each region are shown in Figure 5.

No region showed any consistent or significant advantage for either cultivation method or for any variety used for a cultivation method. One of the saline Hazirhat farms (farm 16) seemed visually to have better performance in beds. This was because

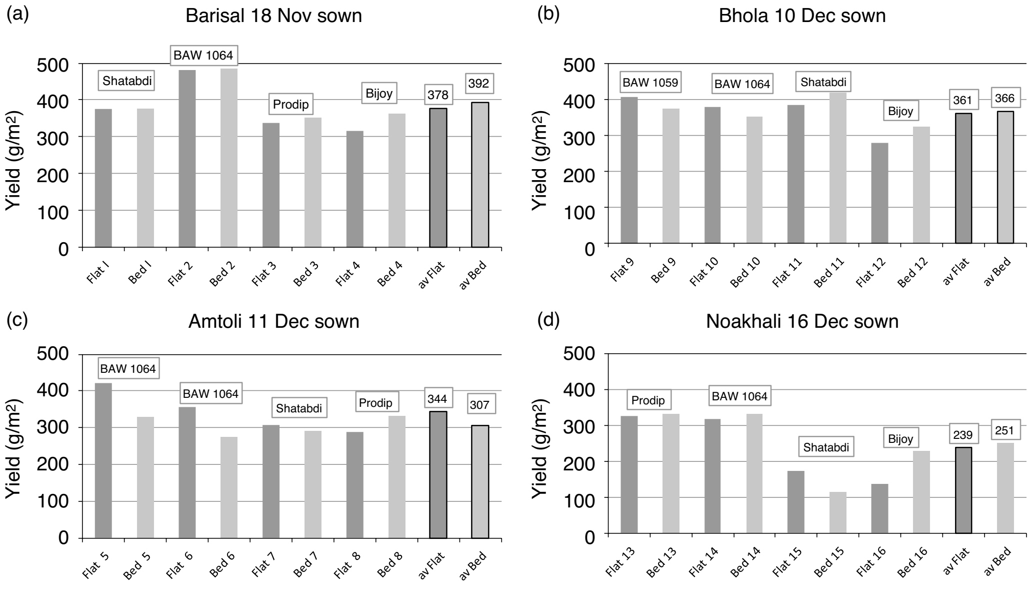


Figure 5. Grain yields of wheat crops planted on the flat or on beds on 16 numbered farms in (a) Barisal, (b) Bhola, (c) Barguna and (d) Noakhali. The average for the four farms in each region is shown as the last pair of histograms on each graph. The wheat varieties used appear over each pair of tillage comparisons.

the flat-plantings had areas of poor performance although the better areas had yields equivalent to those achieved in beds. However, a neighbouring farmer (farm 15) found the reverse situation, indicating the spatial variability of salinity and the chance of including saline patches in any treatment.

Crops generally were very good, with yields commonly being more than 3 t/ha (Figure 5). Photographs of crops at heading on Bhola and in Barguna are shown in Figures 6 and 7, respectively.

Conclusions

As in the FAO-funded studies that tested several planting options, there was no indication that bed-planting produces higher yields than planting on the flat. This is quite contrary to consistent findings in Rajshahi. The benefits of beds in the north and traditional wheat-producing zones of Bangladesh may come in part from the high efficiency of flood irrigation associated with beds. In those zones, with their relatively deep watertables, irrigation must be regular and effective, particularly if the soil is light and permeable. In the south, watertables are shallow and irrigation is not so critical (Chapters 2.2 and 3.4, this volume). It was expected that in the saline southern zones, salt effects might be less in beds, but this was not shown. There was only one clear finding, that beds are no worse than flat-plantings.

The only likely benefit of beds to yield in the south is that farmers might be more likely to weed their crops because the weeds will be more visible and easier to reach. But this is also a benefit of rows on the flat such as are planted by the power-tiller-operated seeder (PTOS) and in its favour is that it cultivates and plants more rows in one pass than a bed-planter. Those farmers who currently grow their vegetables on hand-built beds might be drawn to the machine, particularly since the one machine can be readily reconfigured from a flat-planter to a bed-planter.

Figure 6. Wheat variety Shatabdi flat-planting (left, yield 3.83 t/ha) and beds (centre-right, yield 4.10 t/ha) in Bhola (Photo: MS)

Figure 7. Wheat variety BAW 1064 flat-planting (far left, yield 4.22 t/ha) and beds (centre, 3.33 t/ha) in Barguna (Photo: HMR)

References

Boulal H. and Gomez-Macpherson H. 2010. Dynamics of soil organic carbon in an innovative irrigated permanent bed system on sloping land in southern Spain. Agriculture, Ecosystems & Environment 139, 284–292.

Rawson H., Gomez-Macpherson H., Hossain A.B.S., Saifuzzaman M., Rashid H., Sufian M.A., Samad M.A., Sarker A.Z., Ahmed F., Talukder Z.I., Rahman M., Siddique M.M.A.B., Hossain I. and Amin M. 2007. On-farm wheat trials in Bangladesh: a study to reduce perceived constraints to yield in traditional wheat areas and southern lands that remain fallow during the dry season. Experimental Agriculture 43, 21–40.

Sayre K.D. and Hobbs P.R. 2004. The raised-bed system of cultivation for irrigated production conditions. Pp. 337–355 in 'Sustainable agriculture and the rice–wheat system', ed. by R. Lal, P. Hobbs, N. Uphoff and D.O. Hansen. Ohio State University and Marcel Dekker: Columbus and New York.

3.6 Breeding wheat for heat and salt tolerance in southern Bangladesh

N.C.D. Barma, M. Saifuzzaman, A.B.S. Hossain,
M. Mahbubur Rahman, Nibir Kumar Saha and H.M. Rawson

Abstract

Genotypes were selected for tolerance to high temperatures by growing them from optimal planting dates of mid November to early December and from planting dates in late December when crops are exposed to higher temperatures so have shorter durations during vegetative growth and a shorter grain-filling phase. Performance from late planting indicated absolute high-temperature tolerance and percentage differences in performance between planting dates indicated relative stability. Selection for tolerance to salinity was done at saline field sites, first by a coarse assessment of many international and local wheat lines (salinity screening nursery) and then in detailed studies of the varieties that ranked best in that screening process (salinity observation trials, using four replicate blocks). This double process cycled across three seasons. Combined heat and salt tolerance was sought by planting late at saline sites.

The conclusion regarding heat is that all the recent elite varieties selected by the Wheat Research Centre (WRC) are similarly heat tolerant, judging by their similar yields; they differ primarily in seed boldness (size). Two lines (named BARI GOM 25 and BARI GOM 26) were selected for commercial production in the south as they demonstrated general suitability to normal or late planting. BARI GOM 25 also has a good level of tolerance to salinity so is probably the best variety overall for the south. V01078 also is a general-purpose line that yielded consistently well across environments.

Although the methods used to select salinity-tolerant lines resulted in identification of suitable materials, they were limited by the spatial and temporal variation in salinity at some sites. Replication in some instances did not identify tolerance with certainty because salinity varied several-fold between plots and even within plots. It is suggested that a better method for selection for salt tolerance is to measure the salinity level at every point where plants are harvested and then construct a graph of yield or biomass versus salinity for all screened lines combined. A power curve should describe the overall relationship. Yield for tolerant lines should fall above the curve and sensitive lines below. This approach uses the salinity variation at a site to advantage for selecting lines. Three or four spatially randomised plots for each line should reliably rank lines.

Introduction

Wheat production in Bangladesh using high-yielding varieties (HYVs) was initiated in 1975–76 by importing seeds from India. Major wheat-producing areas were concentrated in the north and north-western parts due to more favourable weather there. Area and production reached its peak in 1999 and after that began to decrease due to competition for land and inputs with boro rice, potato, maize and high-value vegetables. Area and production of wheat have now reduced to half compared with 1999. On average, 2.4–2.8 million ha of land are reported to remain uncultivated in the Rabi season in southern Bangladesh due to a lack of irrigation facilities, late harvest of transplanted (T.) aman rice and soil salinity. It has been estimated that 0.8–1.0 million ha of this fallow land could be brought under wheat cultivation by introducing suitable high-yielding wheat varieties. By expanding wheat into half of this fallow land, an additional 0.8–1.0 million t of wheat grain could possibly be produced. At present, only about 6,000 ha is cultivated with wheat in the south (excluding Jessore).

Wheat Research Centre (WRC) scientists began conducting screening trials and demonstrations with elite WRC wheat lines and commercial varieties in Noakhali and Barisal districts at the beginning of 2000. They found some of the lines and varieties performed well under late planting and moderately saline soils. Later, the technical and economic feasibility of wheat production in southern Bangladesh was assessed by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and WRC-Bangladesh Agricultural Research Institute (BARI) in a small scoping study funded by Australian Centre for International Agricultural Research (ACIAR) in 2006–07 using a combination of results from their on-farm wheat trials and those conducted through a Food and Agriculture Organization of the United Nations (FAO) project (2003–05). FAO-funded research achieved yields in excess of 2.5 t/ha on average from 15 farms in each of the saline areas of Char Bagga, Char Jublee and Hazirhat in Noakhali using the wheat variety Shatabdi (Rawson et al. 2007). The ACIAR project 'Expanding the area for Rabi-season cropping in southern Bangladesh' was initiated in January 2007 for a period of 3.5 years. The project team worked together to progress through characterising constraints in the region, identifying suitable genotypes and developing on-farm management packages.

The key activity from the viewpoint of this chapter was identifying and selecting suitable genotypes for the high temperature and saline environments of the region, for the likelihood of late planting by local farmers and for the likelihood that farmers would have no or limited access to irrigation. It is a great challenge for wheat breeders to develop wheat varieties well adapted to this demanding environment. And as most farmers in the region had no previous experience with growing wheat and no idea of how to harvest and properly store the seed, the challenge was even greater. The selection work necessarily should be done on farms in the region and accompanied by a program of farmer training.

Screening for wheat lines that tolerate heat stress

A major constraint for wheat production in southern Bangladesh is late planting. Due to the late harvest of T. aman rice, it is mostly planted in mid to late December, 2–3 weeks after the optimal planting window. Winter is shorter in the south than the north and the wheat crop is subjected to more heat stress at grain filling, resulting in shrivelled grain and lower yields. Heat accelerates leaf senescence (Al-Khatib and Paulsen 1984) and at the reproductive stage hastens spike development, resulting in abortion of late-forming florets and a reduction in the potential kernel number (Warrington et al. 1977; Pfeiffer et al. 2005). Both grain growth rate and grain growth period are reduced (Wardlaw et al. 1980; Bhullar and Jenner 1985). Yield reduction under north and north-western Bangladesh conditions was estimated to be 1.3%/day when planted after 1 December (Saunders 1988).

Several trials were conducted with advanced lines to identify high-yielding heat-tolerant genotypes well adapted to this environment for release as varieties for the region. Variety trials were conducted in 2006–07 with four wheat varieties (Shatabdi, Bijoy, Prodip, Sourav) and one advanced line (BAW 1059) with the addition of two more varieties/lines (Sufi and BAW 1064) in 2007–08 at the Noakhali, Barisal and Bhola sites. One plot of Shatabdi was also included under non-irrigated conditions in both Rabi seasons. All WRC-recommended practices were followed to grow the crops.

Variety trials 2006–08

In 2006–07 and 2007–08, BAW 1059 ranked top (368 and 391 g/m^2, respectively) in both years and BAW 1064 ranked second (390 g/m^2) in 2007–08 (Tables 1 and 2). These two lines also performed very well for the last several years from both optimal and late planting dates on WRC farms in the traditional wheat-growing areas (data not shown). Despite the pre-eminence of BAW 1059 and BAW 1064, varieties differed relatively little in average yield, indicating that all varieties have good potential in the southern regions and all have some heat tolerance. The average yield for the five cultivars tested over two seasons was almost the same (346 versus (vs) 357 g/m^2, Tables 1 and 2), indicating some stability with environmental fluctuation. The lowest yield was at the moderately saline site in Hazirhat, Noakhali. Without irrigation, the yield of Shatabdi in 2006–07 and 2007–08 was 296 and 359 g/m^2, respectively. There were several effective rains during the crop growth period in 2007–08, which resulted in almost the same yield under both irrigated and rainfed conditions.

Table 1. Variety trial 2006–07 (grain yield g/m²) for five wheat varieties with irrigation and for Shatabdi without

	Variety	Barisal		Bhola		Noakhali			
		Sanuhar	Babuganj	South Balia	North Joynagar	Bariopur	Hazirhat	All sites average	Rank
1	Shatabdi	402	355	374	412	403	235	363	2
2	Bijoy	334	316	371	394	311	277	334	4
3	BAW 1059	375	394	362	387	360	330	368	1
4	Prodip	310	341	304	387	292	272	318	5
5	Sourav	356	366	318	382	357	294	346	3
	Average irrigated	355	354	346	393	345	282	346	
	Shatabdi, no irrigation	296	307	332	230	367	242	296	

Table 2. Variety trial 2007–08 (grain yield g/m²) for seven wheat varieties with irrigation and for Shatabdi without

	Variety	Barisal (West Narayanpur)	Bhola (South Balia)	Bhola/Barisal average	Rank
1	Shatabdi	320	413	366	5
2	Bijoy	342	421	382	3
3	BAW 1059	357	425	391	1
4	Prodip	276	344	310	7
5	Sourav	274	396	335	6
6	Sufi	311	423	367	4
7	BAW 1064	383	396	390	2
	Average 1–5	314	400	357	
	Average irrigated	323	403	362	
	Shatabdi, no irrigation	336	382	359	

Variety trials 2008–09 done on-farm in seed-multiplication trials

During 2008, five elite varieties were provided to three farms each (15 farms total) in each of Noakhali, Bhola, Barisal, Jhalakati and Patuakhali and, additionally, three farms were asked to grow the Shatabdi variety without irrigation. Previous studies under the project had shown that high yields can be achieved in some areas without irrigation; the implication being that some of the required crop water can be accessed from shallow watertables. Using seed multiplication trials (SMTs) to provide data has problems in that many factors other than those measured affect results. Time of planting, quality of seedbed and degree of weed control are some variables that influence yields. Consequently, regional average yields from SMTs are only an indicator of the potential of the variety and recommended management methodology, but they do reflect the reality of likely farm management.

Averaged over all regions, Shatabdi did no better when irrigated than when it was rainfed (Table 3). This confirmed occasional findings from earlier years. Over all SMTs in 2007–08, rainfed Shatabdi crops yielded 20% less than irrigated crops. Often, failure to irrigate has resulted in very poor yields, so irrigation at least once at 20 days after sowing (DAS) along with nitrogen top-dressing remains as a management recommendation to minimise risk (Chapter 3.4, this volume).

Overall, Prodip was the best-yielding variety, but other varieties apart from Sourav were generally within 10% of Prodip. Prodip also produced the boldest (largest) grain, with Bijoy a close second and Sufi last. But average grain size varied with location, indicative of local conditions during the grain-filling phase. Bhola SMTs achieved best overall yield of 3.4 t/ha, falling 8% from the previous season, but Barisal dropped by a large 29% while Noakhali actually yielded 6% more.

Table 3. Varieties grown on-farm with variable planting dates and irrigation in 2008–09 and showing the average for on-farm trials for 2007–08

Varieties	Noakhali	Bhola	Barisal	Jhalakati	Patuakhali	Average	se	Rank
	Grain yield (g/m²)							
Shatabdi rainfed	250	240	301	249	299	268	±13	
Shatabdi irrigated	207	367	236	291	243	269	±28	3
Bijoy	250	348	296	234	269	279	±20	2
Prodip	280	363	319	198	271	286	±27	1
Sourav	230	291	265	164	248	239	±21	5
Sufi	232	313	279	199	298	264	±21	4
All irrigated farms	240	336	280	216	263	267	±20	
se	±12	±15	±14	±22	±10			
2007–08 SMTs	226	365	393					
	Weight/grain (mg)							
Shatabdi rainfed	36	37	38	36	42	38	±1.0	
Shatabdi irrigated	35	41	38	33	38	37	±1.3	3
Bijoy	38	42	41	35	41	39	±1.2	2
Prodip	40	46	40	33	40	40	±2.0	1
Sourav	32	35	35	29	36	33	±1.2	4
Sufi	26	31	36	25	30	29	±1.9	5
all irrigated farms	34	39	38	31	37	36	±1.5	
se	±2.4	±2.7	±1.2	±1.9	±2.0			
2007–08 SMTs	37	37	40					

Note: se = standard error; SMT = seed multiplication trial

Screening for wheat lines that tolerate salinity

Salinity screening trials 2006–07 and 2007–08

Salinity screening trials were initiated in 2006–07 with 52 wheat lines planted in non-replicated plots in Hazirhat, Noakhali. The soil in Hazirhat is moderately saline. Most of the materials used in the trial were from Australia, Pakistan, Nepal and India; some elite WRC advanced lines were included. Based on maturity, disease reaction, grain yield and grain weight, 12 lines were selected. In 2007–08 these materials were put into a salinity observation trial with four replications planted in Hazirhat, Noakhali, on 27 December 2007. Five promising lines (Table 4) were selected from this trial for further evaluation.

A further screening nursery with 42 other promising wheat lines was planted in non-replicated plots in Bariopur, Noakhali, on 28 December 2007. The grain yield and grain weight of the selected materials are in Table 5.

The best-performing materials from the trials in Tables 4 and 5 were included with several WRC advanced lines in a salinity observational trial planted on 31 December 2008 in Hazirhat, Noakhali, in four replications. There were 18 entries (Figure 1).

Yields of the check varieties Shatabdi and Prodip ranked poorly from this late planting where the two constraints of heat and salt combined to prevent their high potential being realised. Despite their relatively reduced yield, they did maintain acceptable kernel weights of 30–34 mg. Highest yielders that more or less doubled yields of the check varieties also achieved around 30 mg kernel weights. Taken together with results from 2007–09, V01078 is clearly a good candidate for use in this saline region, producing good yield whether sown at the normal time or very late. BAW 1059 and BAW 1064 were also reported to yield well under late-planting conditions in other WRC trials in the traditional areas. So these two lines were recommended for commercial cultivation in 2010 as named varieties BARI GOM 25 and BARI GOM 26, respectively.

Salinity screening nursery 2008–09

This study assessed a further batch of 63 WRC advanced crosses and entries from Nepal and the International Maize and Wheat Improvement Center (CIMMYT), Mexico, in a saline soil, again in Hazirhat

Table 4. Lines selected from the 2007–08 salinity observation trial listed by grain yield ranking

Entry no.	Variety name	Grain yield (g/m^2)	Grain weight (mg)
1	BAW 1059	221	41.0
7	V01078	206	34.9
9	SHATABDI (check)	203	36.9
4	BAW 680	198	30.3
3	GARUDA	195	29.9
2	BAW 1064	180	33.0

Table 5. Lines selected from the 2007–08 salinity screening nursery listed by grain yield ranking

Entry no.	Variety name	Grain yield (g/m^2)	Grain weight (mg)
25	HUW +	282	27.8
29	SABUF/7/ALTAR …..AE SQ.	262	34.9
4	PRODIP (check)	260	30.0
30	SABUF/7/ALTAR …..AE SQ.	257	31.5
27	NL 922	231	26.2
20	GARUDA/ BB/TOB…..ICTAL123	229	24.5
12	BL 3503	208	30.0
2	SHATABDI (check)	192	24.9

and again as part of the continuing search for heat and salinity tolerance characteristics. There were two replicates and areas of 2 m² were harvested from each replicate plot which was four rows wide by 2.5 m in length. The two check varieties were Shatabdi and Prodip (entries 1 and 2, respectively; yellow bars in Figure 2). Planting was on 27 December 2008, so was late and exposed the lines to both heat and salinity. The group of 63 lines was also tested at WRC non-saline stations in Joydebpur, Jamalpur, Jessore and Dinajpur from both optimal (15–30 November) and late (20–25 December) planting periods. The nursery at those sites is called the Bangladesh Wheat Screening Nursery (BWSN) and was intended to test responses to heat alone, by comparing performance from the two sowing dates.

Yields

These are shown in Figure 2 as the average of the two replicates. The highest yielding lines are at the top of the figure and the poorest at the bottom. Yield of the check varieties was very low at 600 and 450 kg/ha, reflecting the late planting and salinity level of the soil. More than 30 selections did better than the best check, showing salinity-tolerance promise in this collection of lines.

Considering the top 15 lines in Figure 2, only a few of the WRC crosses and their sisters derived from the same cross did well (see Table 6 for their background). Entries 19 and 58 had poor leaf traits, susceptible to foliar blights, and were excluded from further trials. In the (non-saline) Joydebpur yield data, the picture is quite different from Hazirhat. Under optimal conditions in Joydebpur (planting 15–30 November), Shatabdi ranked 1 (40 in the Hazirhat trial) but none of the top 15 lines in Figure 2 ranked well there.

Under late planting in Joydebpur (20–25 December), Shatabdi ranked 12 while E 44 ranked 2 and E 23 ranked 8 (rank 4 and 2, respectively, in Hazirhat). This indicates that E 44 and E 22 had the double tolerance to heat (late planting) and to salinity while Shatabdi is best when the environment does not constrain its capacity for generating many tillers and biomass.

Salinity yield trial 2009–10

A yield trial was planted in four replications at optimal and late dates, at three saline sites, Satkhira, Noakhali and Patuakhali, and at Joydebpur (non-saline). Twelve varieties/lines were used that were selected from the 2008–09 trials. WRC-recommended management practices were followed. The Patuakhali site (Figure 3) was not harvested due to time constraints and extreme spatial variability in salt.

Considering Satkhira is reputed to be saline, yields of between 4 and 5 t/ha from normal planting and 3 t/ha from late planting are remarkable. The effect of

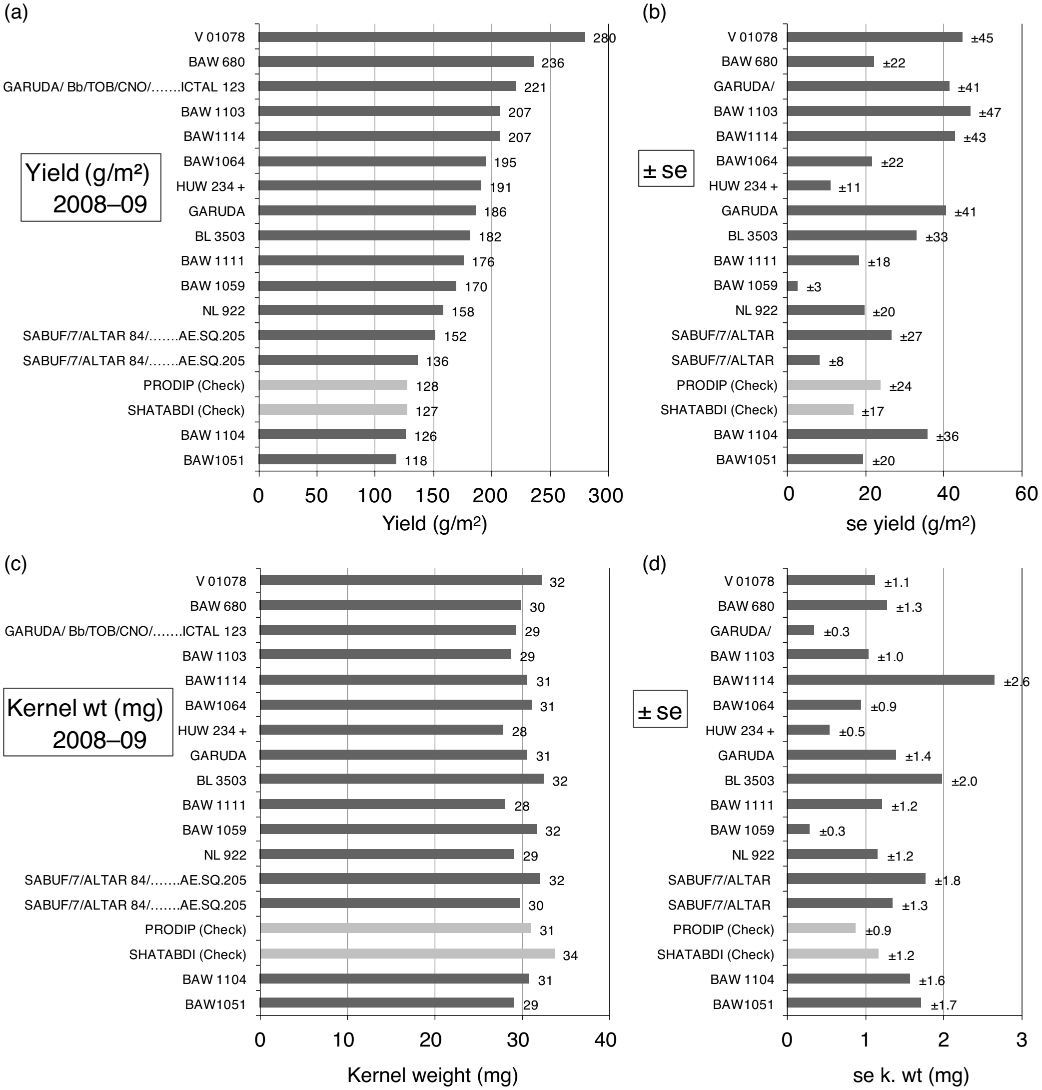


Figure 1. Salinity observational trial 2008–09 with 18 lines planted in Hazirhat, Noakhali, on 31 December 2008 with lines ranked for yield showing yield (a) ± standard error (se)(b), and kernel weight (c) ± se (d). The scales for the error bar figures (b, d) differ from those for yield and kernel weight (a, c). Check varieties are shown as pale grey bars.

late planting overall was to reduce yield by 27% (on average), although in BAW 1114 this was only 5% (Figure 4a). Joydebpur also produced 4 t/ha yields from optimal planting dates but reduced production to less than 3 t/ha as a result of planting late, or by 37% overall (Figure 4b). All varieties there were reduced similarly by late planting. By contrast, the saline Hazirhat (Noakhali) site showed the constraining effects of salt by averaging only 2 t/ha from optimal planting date and 9% less from late planting due to three lines actually improving their yield (Figure 4c). Again BAW 1114 showed stability, being joined, surprisingly, by Prodip. So despite using four replications, unexpected results can sometimes occur in places like Noakhali, in part because of the spatial variability of salt in the landscape.

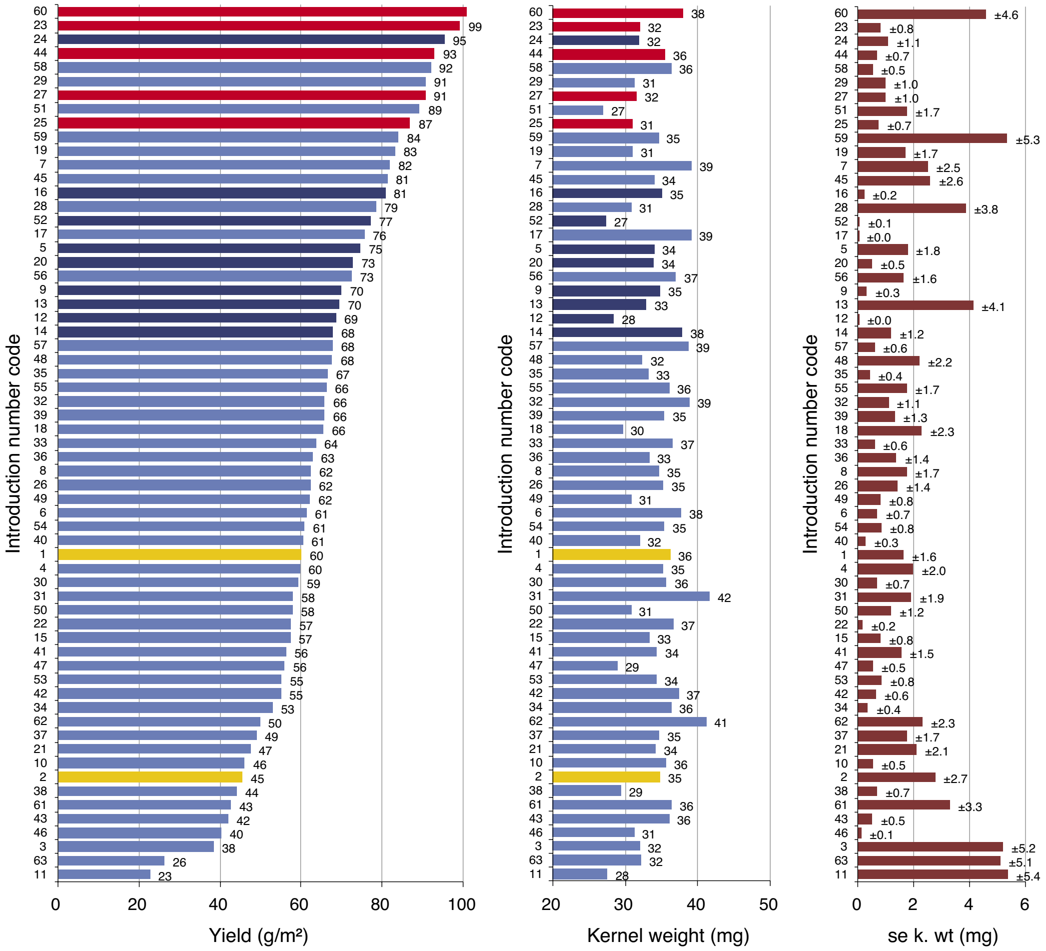


Figure 2. Salinity screening nursery 2008–09 planted in Hazirhat, Noakhali, on 27 December 2008 with the 63 entries ranked for yield and showing their yield (a), kernel weight (b) and standard error (se) (c). Check varieties Shatabdi (1) and Prodip (2) are shown in yellow. Kernel weight and se graphs have different scales.

Highest yield was obtained in V01078 under both optimal and late planting dates in Shatkhira followed by BAW 1111, Prodip and BAW 1104 (Figure 4a). V01078 also ranked top in Joydebpur (Figure 4b). In Noakhali, the highest yield was produced by BAW 1114, followed by GARUDA/BB/TOB…ICTAL123 under optimal conditions. Considering several years of data, V01078 has been reliable for late planting and salinity and clearly has good potential in non-saline areas when planted on time, so this genotype could be recommended for general use in the southern belts. Other genotypes such as BAW 1104, GARUDA/BB/TOB…ICTAL123, BAW 1111 and BAW 1114 may also be showing some heat and salt tolerance and these lines should be included as parents for crossing purposes.

Salinity screening nursery 2009–10

Twenty-three advanced lines of wheat were in this nursery, with Shatabdi, Prodip and Sourav as checks. There were three replications in farmers' fields in Hazirhat, Noakhali and Patuakhali. Plots were 2.5 m long by four rows with 20 cm spacing. Management followed WRC practice.

Table 6. Summary of comments on the top-15-yielding lines in the late-planting salinity nursery in Hazirhat detailed in Figure 2

Line number	Top 15 yield rank	Salinity screen 2008–09	Yield comment	Kernel wt comment
60	1	OASIS/3*ANGRA//708E BD01JA666S-3JA-010JA-010JA-010JO-HRJO-RC9JO	stable	high but unstable
23	2	BAW 923/4/GEN/3/GOV/AZ//MUS BD(DI)1208S-0DI-4DI-010DI-010DI-DI5	stable	mod but stable
24	3	BAW 923/4/GEN/3/GOV/AZ//MUS BD(DI)1208S-0DI-4DI-010DI-010DI-DIRC7	± stable	mod but stable
44	4	KAN//IAS 63/ALDAN BD(DI) 961S-0DI-62DI-010DI-010DI-0DI-03DI-DIRC6	stable	high & stable
58	5	K 9211//BKT/HUW 428 BD(DI)1082T-0DI-8DI-010DI-010DI-0DI-02DI-DIRC8	± stable	high & stable
29	6	BAW 923/BAW 824 BD(JE)1108-0DI-5DI-010DI-010DI-DIRC7	unstable	low stable
27	7	BAW 923/BAW 824 BD(JE)1108-0DI-5DI-010DI-010DI-DIRC4	v stable	mod but stable
51	8	URES/JUN//KAUZ/3/K 9211 BD(DI)1028S-0DI-5DI-010DI-010DI-0DI-01DI-DIRC9	unstable	low unstable
25	9	K 9107/GARUDA BD(JE)1105-DI-6DI-010DI-010DI-DIRC4	stable	mod but stable
59	10	OASIS/3*ANGRA//708E BD01JA666S-3JA-010JA-010JA-010JO-HRJO-RC6JO	unstable	high & stable
19	11	SH-2002	unstable	low unstable
7	12	GAA/KEA//GAA/BL 1887 NC 001B3421-3B-020B-020M-3B-0B	unstable	v high unstable
45	13	KAN//IAS 63/ALDAN BD(DI) 961S-0DI-62DI-010DI-010DI-0DI-05DI-DIRC8	v unstable	mod v stable
16	14	KIRITATI/4/SERI1B*2/3/KAUZ*2/BOW//KAUZ CGSS02Y00140S-099M-099Y-099M-9Y-0B	stable	mod v stable
28	15	BAW 923/BAW 824 BD(JE)1108-0DI-5DI-010DI-010DI-DIRC6	stable	low & unstable

Note: entries 58 and 19, ranked 5 and 11, had symptoms of foliar blight so were discarded

Most of the entries were earlier or similar to the check varieties in heading, maturity and plant height. There was significant variation in salinity between plots, ranging from 6.3 to 24.3 dS/m in Noakhali and from 8.2 to 20.4 dS/m in Patuakhali at sowing time. This variation caused a high standard error for each genotype in grain yield and 1,000-grain weight but, despite this, the varieties/lines tested showed apparent variation in response to salinity (Table 7). Entries 21, 7, 8, 3, 24, 11 and 16 all yielded better than the check varieties and had good visual grain quality so were selected as potentially saline-tolerant genotypes that will be further tested in a saline environment next year. However, none of these lines were significantly better than Prodip, calling into question this method of salinity screening at highly variable sites such as the aforementioned Patuakhali site (Figure 3).

Discussion

Difficulty of selecting lines for salinity tolerance

Salinity within the south of Bangladesh varies on a regional scale from ‘strongly saline’ to ‘no salinity’ (see Figure 7, Chapter 1.1, this volume). Because of the seasonal monsoon when the soil is flushed with fresh water and the salt forced down the profile, salinity in the root zone also varies with season. During the dry Rabi season, the salt moves in solution back

Figure 3. Variability in response to salinity in the field (Patuakhali), 2009–10

up the soil profile by capillarity and can crystallise on the soil surface as the water evaporates (Figure 8, Chapter 1.1, this volume). Salt concentration is very variable temporally and spatially, both vertically and horizontally. It can differ substantially, not only at the scale of experimental replications as described for Table 7, but even at the scale of neighbouring plants. In Patuakhali (Figure 3) some plants grew well while plants of the same line in the same plot could be dead.

This spatial variability was also shown in the Noakhali 2009–10 late-planted salinity yield trial. There, the average salt content in the surface soil of the four replicate (rep) blocks was 13.1 dS/m, varying from an average of 9.2 dS/m in rep 2 to 18.8 dS/m in rep 4, but within those blocks individual plots ranged between 2.0 and 29.0 dS/m at planting to 3.3 to 35.0 dS/m 2 months later. The adjacent optimal-sowing-date yield trial had lower salinity, averaging only 5.4 dS/m. Individual plots ranged between 2.2 and 11.2 dS/m even for similar dates to those for the late-planting trial. So it can be difficult to select lines for salinity tolerance at very variable locations without measuring individual plot salinity and matching plant performance in the plot to that salinity level. Even more difficult is to unscramble a date of sowing effect from a salinity effect without rigorous salinity measurements. Even four replications of treatments can be inadequate in the absence of salinity measurements of every plot: if each plot is measured, then the replications should be ignored and each plot treated as a point on a surface of response to salinity. This approach will provide far more understanding of responses to salinity of varieties individually and collectively than a single number or rank for a variety.

Figure 5 shows a cursory attempt at this approach. Biomass production at maturity for the 2009–10

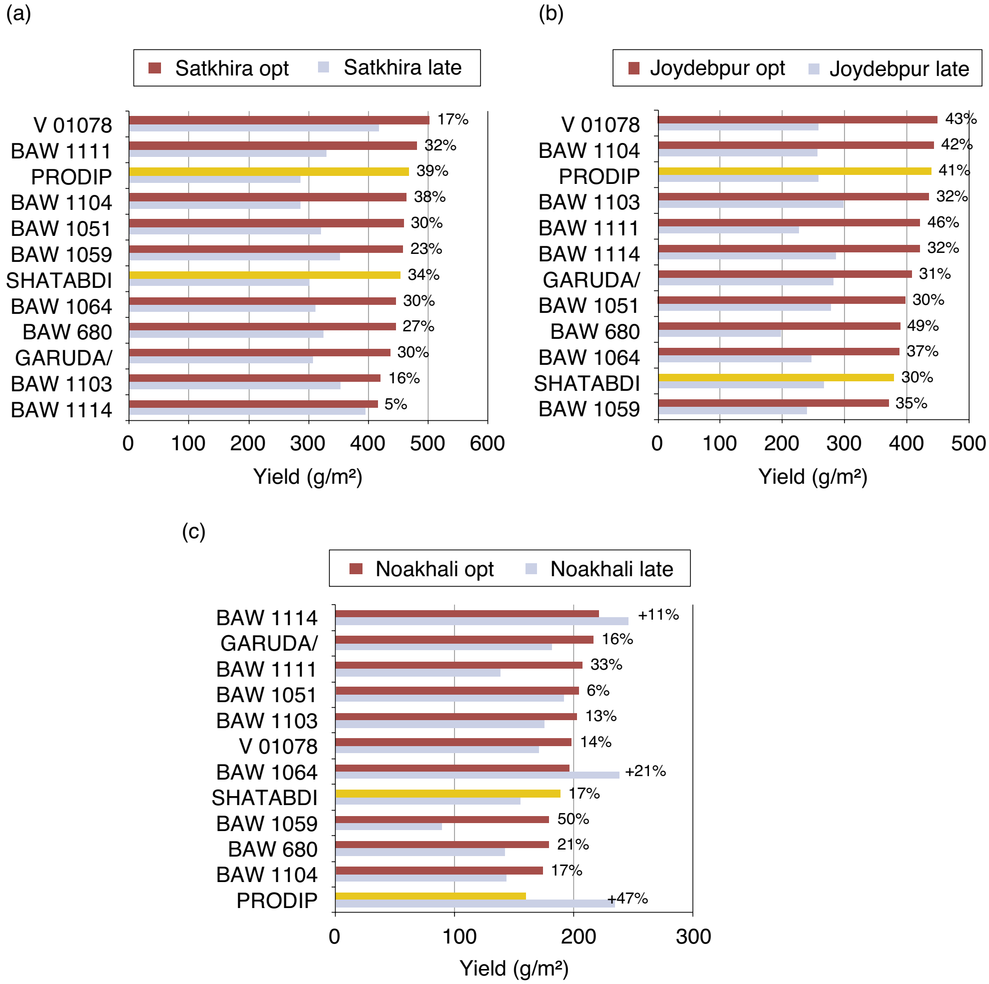


Figure 4. Salinity yield trial 2009–10, showing yield after planting at optimal date and late and percentage reduction from late planting for 12 wheat lines in (a) Satkhira (slightly saline), (b) Joydebpur (non-saline check site) and (c) Noakhali (saline). Check varieties are shown in yellow.

salinity screening trials (three replicates) of Table 7 is plotted against salinity (ECe) measured in each plot in the surface soil on one date and then on a date 6 weeks later. On the first date of Figure 5, ECe of plots ranged randomly between 6 and 24 dS/m, and did not follow replicates. Plotting the biomass of every plot independently against its plot salinity (the red curves of Figure 5) reveals a general response of wheat to salinity with hopefully the varieties providing the variation in tolerance around the fitted power curve. Feasibly, the more salt-resistant lines are above the curve and the salt-sensitive lines below it.

To test if this method of above and below the curve agrees with the traditional analysis of varieties using replications, the lines in Table 7 that ranked highest (Entry 21 with 113 g/m² yield) and lowest (Entry 5 with 20 g/m² yield) are plotted as yellow and red markers, respectively, in Figure 5.

It can be seen on either graph of Figure 5 that the best ranked line was grown at lower than average salt levels than the worst ranked line and that their points lie close to the average red curve for all lines. There is no indication that the best line is above the

Table 7. Grain yield and 1,000-grain weight (TGW) of the advanced lines/varieties in farmers' fields in Noakhali, 2009–10

Entry	Variety	Grain yield (g/m^2)	± se	TGW (g)	±se	Yield rank	TGW rank
21	BAW 1133	113	56	29	2	1	15
7	KAN//IAS 63/ALDAN	100	28	36	1	2	4
8	OASIS/3*ANGRA//708E	92	61	36	2	3	2
3	BCN//CEAT/AE.SQUA(895)/NL 745	87	16	31	0	4	10
24	BAW 1138	86	59	29	2	5	16
11	BL 1473/BL 1905	86	35	34	1	6	6
16	BAW 923/BAW 824	84	24	31	1	7	9
2	PRODIP	83	34	36	1	8	3
19	SABUF/ALTAR-84…AE….SQ 205	82	19	29	3	9	12
23	BAW 1137	76	53	27	3	10	20
17	GARUDA	73	40	29	3	11	13
13	EMB16/CBRD//*2CBRD	73	48	25	0	12	25
18	NL 922	70	45	27	3	13	21
20	BL 3503	68	35	38	4	14	1
6	KAN//IAS 63/ALDAN	59	9	29	2	15	11
14	BAW698/SHATABDI	58	29	32	1	16	7
25	BAW 1140	53	21	29	2	17	14
15	BAW 923/4/GEN/3/GOV/AZ//MUS	50	20	26	2	18	24
1	SHATABDI	50	9	35	6	19	5
9	OASIS/3*ANGRA//708E	46	21	31	4	20	8
22	BAW 1135	46	23	28	5	21	18
26	SOURAV	44	3	27	0	22	23
4	BAW 923/BAW 1004	41	16	28	3	23	17
10	GAA/KEA/GAA/BL 1887	29	12	27	3	24	22
12	UP 2338*2/4/SNI/TRAp#1/3/ KAUZ/*2TRAP//KAUZ	28	5	28	0	25	19
5	BAW 923/BAW 1004	20	3	22	0	26	26

Note: check varieties are in yellow; se = standard error

curve and the worst below. Using a linear fit to the data does not change the conclusion.

Using the proposed 'above and below the fitted line' in the current study would pick out Entry 14, BAW 698/Shatabdi, as a promising salt-tolerant cross because all of its replications fall well above the average curve of Figure 5. This ranked lower mid range in Table 5 so would not be included in further trials.

Does this mean that the selection methods used throughout this project do not work? The method used was to select best performers in a multi-line nursery (with two to three replications) for more detailed assessment in a salinity observation trial (with more replicates and larger plots). The method has worked to identify some lines that seem more tolerant of salt but as they have not always ranked best in consecutive trials, there has been some doubt as to the choices. The likelihood is that unmeasured plot-to-plot variation in salinity has generated the varying responses. The problem of spatial variation of salinity in fields has long been recognised in plant-breeding literature (Richards 1983; Richards et al. 1987).

There are other issues associated with trying to understand what salinity value is actually controlling crop growth and yield. The measurements discussed above are from the top few cm of the soil profile while salinity varies with depth through time. Roots also vary in their depth of penetration with time and in their lateral spread. At each salt measurement in the study of Figure 5, salt in the near-surface soil was more concentrated than at 1 m depth. Hypothetically, wheat lines with deeper roots may appear to be salt tolerant because they utilise the less saline part of the profile. Such a variety would not be selected as tolerant in standard screening procedures using hydroponics (e.g. Rawson et al. 1988) or using large

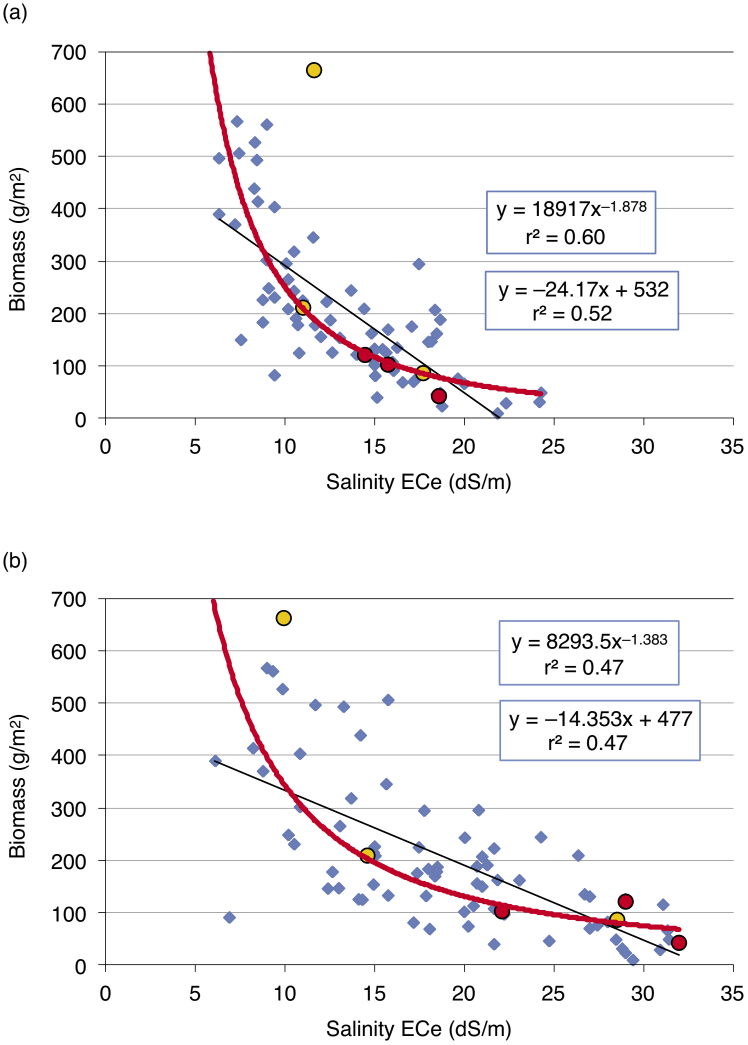


Figure 5. Biomass at maturity for each of three replicates of each wheat line as related to salinity of the surface soil in its plot measured on (a) 23 December 2009 and again on (b) 9 February 2010 for the study shown in Table 6. Curves are fitted to all data; the power curve is in red. The yellow circles are from the best-yielding line (E 21) and the red from the worst (E 5).

tanks of soil with premixed salt concentrations that are the same throughout the profile.

A question of physiology that could affect the methodology used to screen lines for salt tolerance is how salinity alters plant metabolism. One finding was that crop respiration increased significantly and quickly when plant roots were exposed to salt and this was rapidly reversed when salt levels were reduced (Rawson 1986), the degree being related to salt concentration. Plants that could fix more carbon through having a higher absolute growth rate could more readily support this respiration load. In that case, it might be guessed that wheat lines that have higher growth rates in the absence of salt might also more readily tolerate saline soils (Richards et al. 1987). High growth rates could be achieved by rapid seedling emergence and a large first leaf to take advantage of a salt-free seed endosperm; a characteristic of barleys in and out of salt (Rawson 1986; Rawson et al. 1988). So, selection for high yield in optimal conditions would automatically lead to higher yield in salt. This does not seem to follow in the current salinity trials where the check varieties have commonly been out-yielded by new crosses. This finding supports continuing the approach of selecting for salinity-tolerant lines in saline fields.

The need to measure salinity of individual plots remains critical, however, and whether this is done by soil sampling and electrical conductivity (EC) meter or whether the more rapid scanning approach of magnetic reflectometry is used depends on resources. In the current studies, the latter method was considered at the outset but, despite its ability to assess salinity at varying depths, not used, because of the difficulty of accurately calibrating the system, cost and technical skill required.

Conclusions

Different yield trials and salinity nurseries and trials were conducted in the south both in saline and non-saline areas and under late planting (heat stress) conditions during 2007–10. The salinity observation nursery worked well to test varieties identified in the screening nursery for tolerance to salinity and late planting. The salinity observation nurseries, salinity screening nurseries and salinity trials were conducted during 2007–10 in saline soil at several locations. Variable numbers of advanced lines and elite varieties were grown in saline soils under field conditions. BAW 680, BAW 1059, BAW 1064, GARUDA/BB/TOB…ICTAL123 are all maintaining their superiority over the high-yielding check varieties Shatabdi and Prodip. The advanced lines BAW 1103, BAW 1104 and BAW 1114 also showed good grain filling and performed better than Shatabdi and Prodip, even under very late planting. Taken together with the salinity trial results from 2007–09, V01078 is clearly a good candidate for use in this saline region, producing good yield whether sown at normal time or very late. BAW 1059 and BAW 1064 were also reported to be higher yielding under late-planting conditions in the traditional areas. So these two lines were recommended for commercial cultivation in 2010 as BARI GOM 25 and BARI GOM 26, respectively.

References

Al-Khatib K. and Paulsen G.M. 1984. Mode of high temperature injury in wheat during grain development. Plant Physiology 61, 363–368.

Bhullar S.S. and Jenner C.F. 1985. Differential response to high temperature of starch and nitrogen accumulation in the grain of four cultivars of wheat. Australian Journal of Plant Physiology 12, 363–375.

Pfeiffer W.H., Trethowan R.M., van Ginkel M., Ortiz-Monasterio I. and Rajaram S. 2005. Breeding for abiotic stress tolerance in wheat. Pp. 401–489 in ‘Abiotic stresses: plant resistance through breeding and molecular approaches’, ed. by M. Ashraf and P.J.C. Harris. The Haworth Press: New York.

Rawson H.M. 1986. Gas exchange and growth of wheat and barley grown in salt. Australian Journal of Plant Physiology 13, 475–489.

Rawson H., Gomez-Macpherson H., Hossain A.B.S., Saifuzzaman M., Rashid H., Sufian M.A., Samad M.A., Sarker A.Z., Ahmed F., Talukder Z.I., Rahman M., Siddique M.M.A.B., Hossain I. and Amin M. 2007. On-farm wheat trials in Bangladesh: a study to reduce perceived constraints to yield in traditional wheat areas and southern lands that remain fallow during the dry season. Experimental Agriculture 43, 21–40.

Rawson H.M., Richards R.A. and Munns R. 1988. An examination of selection criteria for salt tolerance in wheat, barley and triticale genotypes. Australian Journal of Agricultural Research 39, 759–772.

Richards R.A. 1983. Should selection for yield in saline conditions be made on saline or non-saline soils? Euphytica 32, 431–438.

Richards R.A., Dennett C.W., Qualset C.O., Epstein E., Norlyn J.D. and Winslow M.D. 1987. Variation in yield of grain and biomass of wheat, barley and triticale in a salt-affected field. Field Crops Research 15, 227–287.

Saunders D.A. 1988. Crop management research: summary of results, 1983–1988. Monograph No. 5. Bangladesh Agricultural Research Institute (BARI): Gazipur.

Warrington I.J., Dunstone R.L. and Green L.M. 1977. Temperature effects at three developmental stages on the yield of the wheat ear. Australian Journal of Agricultural Research 28, 11–27.

Section 4

Crops to replace or sequence with wheat

4.1 Economic viability of Rabi-season crops

Md Jahangir Kabir, Peter S. Carberry, Rohan Nelson,
Iqbal Alam Khan, Neal P. Dalgliesh and Perry L. Poulton

Summary

Increased Rabi-season crop production in southern Bangladesh could help meet the country's growing food demand. This paper reports on an assessment of the economic viability of wheat and other Rabi-season crops based on farmer surveys of crop yields and economic performance. In addition, it considers the agroeconomic and socioeconomic factors that influence farmers' choice of Rabi-season crops.

Current Rabi-season crops in southern Bangladesh include boro rice and vegetable production on lands with irrigation facilities. A range of other crops are grown, with and without irrigation, including chilli, potato, grasspea, chickpea, mungbean and soybean. Although farmers in some southern regions had grown wheat in the past, wheat is not a significant crop across the region. The recent increased interest in wheat in some villages corresponded to project activities of a development project, funded by the Australian Centre for International Agricultural Research (ACIAR) and specifically to the availability of newly released varieties with higher yield potential and disease resistance. In those villages where project trials were conducted, irrespective of seasonal conditions, wheat-based rotations provided higher gross margins than the alternative crops of chilli and cowpea. Even in a relatively poor season, wheat offered a significantly higher gross margin and thus lower risk than the other crops. However, the crop establishment costs of wheat are high and wheat requires at least one irrigation when many farmers lack any irrigation facilities. Formal education, off-farm income and farming experience are the socioeconomic factors that displayed significant positive correlation to the surveyed farmers' decision to adopt wheat production.

This study confirmed the economic viability of Rabi cropping in southern Bangladesh. While the crops currently grown in the Rabi season are profitable under most seasonal conditions, this study confirmed that wheat offers farmers a profitable and low-risk option.

Introduction

Wheat was a minor crop in Bangladesh before the early 1970s but, thereafter, increased in importance to become the second most important cereal in terms of both production and consumption. During the decade from 1973–74 to 1983–84, wheat production rose from 111,000 t to 1,211,000 t (BBS 1999). During this expansion of wheat, a number of high-yielding varieties and modern production technologies were developed and disseminated to the farmers. In 1998–99, wheat area and production was 883,000 ha and 1,908,000 t, which represented the highest wheat area and production in the history of Bangladesh (BBS 2002). However, between 2000 and 2007, wheat area and production has decreased (DAE 2010). Over the past 5 years (2006–10), average production was about 750,000 t, yet average demand (consumption + seed) was about 2,850,000 t/year. As a result, about 2,100,000 t of wheat are imported from foreign countries each year (BBS 2007).

The coastal districts of southern Bangladesh are expanding into the Bay of Bengal as the Padma and Meghna river systems deposit silt. The salinity of these soils and underlying aquifers gradually declines over successive wet seasons. The result is a succession of land uses combining wet-season rice cropping (transplanted (T.) aman) with an eclectic and complex sequence of Rabi-season land uses. Although rarely linear, this sequence can begin with a mix of fish farming and extensive grazing, and progress through a variety of pulses of increasing productivity, including grasspea, chickpea, mungbean and soybean. Vegetable and boro rice production tends to dominate as soils and aquifers become less saline, and as irrigation and marketing infrastructure expands. Areas of higher salinity may continue to lie fallow during the Rabi season or be used for low-productivity cropping or extensive grazing.

Wheat already occupies several niches within these farming systems. During the intermediate stages of this land-use succession, which may last decades, the production of preferred Rabi-season crops such as boro rice and vegetables can be constrained by a lack of surface water and saline soils and groundwater. In areas with irrigation infrastructure, there may be insufficient water in the Rabi season to grow boro rice, but sufficient to profitably grow wheat and a variety of pulses.

Increased wheat production across these southern regions could significantly reverse a growing imbalance between Bangladesh's national production and imports of wheat to meet growing food demand. Strong demand for wheat is evident in the high price of wheat relative to rice since the mid 1990s (Figure 1).

An indication of Bangladesh's comparative advantage in supplying wheat for domestic consumption is that imports have not automatically increased to meet this growing demand, despite low trade protection, resulting in declining consumption. High pulse prices (Figure 1) help to explain a shift in land use toward pulses as wheat has become less profitable.

Domestic production of wheat in Bangladesh has declined as disease has reduced the productivity and profitability of the domestic variety Kanchan, leading to declines in both yield and area harvested. Preliminary trials have indicated the potential for improved wheat varieties and agronomic practices to enable wheat to be profitably produced on land in coastal districts with irrigation infrastructure but insufficient water resources for boro rice production (Rawson et al. 2007).

This paper reports on an assessment of the economic viability of wheat and other Rabi-season crops based on farmer surveys. In addition, it considers the agroeconomic and socioeconomic factors that influence farmers' choices of Rabi-season crops and concludes with a perspective of the likely adoption of these new crops and associated technologies.

Materials and methods

Village and farmer selection

Two southern districts of Bangladesh, Bhola and Noakhali, were selected for surveying based on their agronomic potential for wheat-based cropping systems. A two-stage sampling framework was used in which field data were collected from sample farmers from four villages in the two districts. In each district, a pair of villages was selected during the 2007–08 Rabi season. One of the paired villages was randomly selected from the list of those villages in each region where wheat crops were being demonstrated during the 2007–08 season. The other village was selected randomly to be outside the 'sphere of influence' of the nearest cluster of trial sites by being sited more

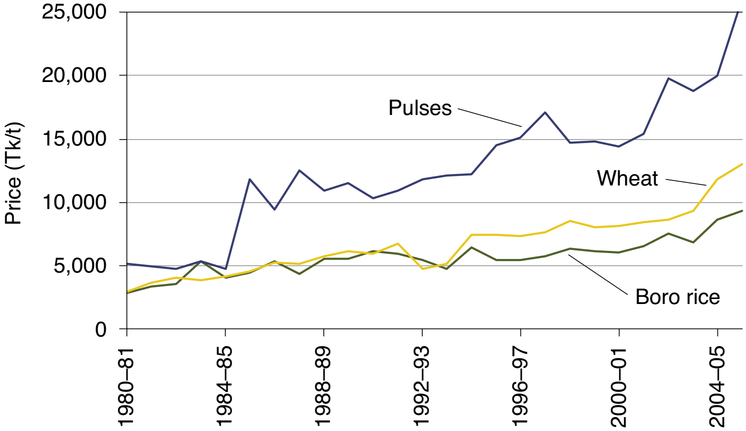


Figure 1. Relative price of Rabi-season crops (Source: Bangladesh Agricultural Statistics)

than 4 km from the nearest trial site and not located on the same section of a main road.

After selecting the village, a social map was drawn with the help of a group of leading farmers and landholders in order to identify important infrastructure such as markets, roads and businesses that affect livelihood opportunities, and to broadly map the types of households across the village. The survey also needed to know of any recent non-government organisation (NGO) activity in the area (past 5 years), especially any that may have had an impact on Rabi-season cropping.

A stratified random-sampling technique was followed for selecting sample farmers. Respondents were stratified as:

- Owner wheat grower and owner non-wheat grower. Owner farmers have significantly more land than that required to meet basic livelihood needs and so rent a significant area of land to others. Usually the owner farmers were older with less household labour.
- Owner-tenant wheat grower and owner-tenant non-wheat grower. Owner-tenant farmers own some of the land that they farm plus rent some more land from others to supplement basic livelihood needs.
- Tenant wheat grower and tenant non-wheat grower. Tenant farmers have households on their own land, but rent land from others to meet almost all of their livelihood needs. They are often strongly focused on subsistence.

A total of 120 farmers was selected. Sixty farmers were selected from each region, with 30 from each village. Five farmers were randomly selected from each stratum.

Survey methods

The senior author collected the field survey data from each sampled farmer using interviews conducted at farmers' homes. Structured interviews, taking up to 1.5 hours per farmer, were conducted between mid January and mid May 2008.

To assess the profitability of wheat-based crop rotations against other major Rabi crops, an enterprise-budgeting technique was followed in the surveyed data collection. Most farmers try to receive the maximum gross margin or, in some instances, to incur the minimal cost at each level of output. To achieve either of these aims, farmers have to work with several technical and economic constraints and drivers. In addition, farmers are often motivated by other objectives, such as meeting household consumption needs, ensuring food security, protecting against risk, and so on.

In this study, the conditions for maximising gross margins were given emphasis as this is a plausible goal for many farms, especially those that are operating in a competitive economic system. Gross margin is the difference between the gross return and the total variable costs. It is also defined as the difference between the value of goods and services produced by a farm and cost of resources used in production.

During the interviews, farmers' comments were recorded on actual and desired extension activities, on the prospects for wheat, on their decision-making and on the role of gender in farming. Content analysis and the frequency of response of agronomic and economic criteria were analysed.

Computation of gross margins

Farmers' gross margins (GMs) were calculated by deducting variable costs from gross return for each enterprise (Dillon and Hardaker 1980). Gross return was calculated by multiplying the total volume of production of an enterprise by the average price (the average of the farm-gate price) of that product in the harvesting period. Total variable cost of a product is the monetary value of all inputs used for producing that product. In other words, it is estimated by combining all market values of inputs and services used to produce that product.

Estimating the total variable cost of producing each crop included the costs of human labour, ploughing, seed, fertiliser, irrigation, insecticide etc. For purchased inputs, the actual cost paid was used. But for the home-supplied inputs, such as family labour and kept seed, the cost was calculated by applying the principle of opportunity cost. While there is a difference in wage rate between male and female labour, in this study the average wage rate of male labour in the survey area was used. Per hectare gross return was determined by multiplying the farmer's received output of each crop with their respective market price. A limitation of determining gross return is that it does not consider the economic value of by-products such as the straw of rice and wheat. An Excel spreadsheet was used for calculating GMs.

A sensitivity analysis of wheat profitability was undertaken by altering variables such as wheat price, production costs (especially fertiliser price) and yields, and considering yields in good, normal and bad years at trial and non-trial villages in Bhola. Old fertiliser price is the price that farmers paid for buying fertiliser in the survey year and new price is for the following year. A good year indicates favourable weather for crops and so maximum yields. A normal year indicates average weather conditions for crops and reasonable yields. A bad year indicates unfavourable weather conditions and low yields.

A paired t-test was used to test the significance between wheat and other competing Rabi crops. The pairing of the observations helped dissociate the variation in costs and returns among the Rabi crops. The statistical tool of SPSS-13 was used for the paired t-test analysis.

A logit model was used for determining the socioeconomic factors that influenced wheat adoption on any particular farm. The logit regression model is one of the binary choice regression models in which the dichotomous (or binary) regression variables, adoption or non-adoption of wheat, were considered as the dependent variables.

The logit model was chosen for this study instead of the linear probability and probit models because, according to Gujarati (1995), the logit model guarantees that the estimated probabilities lie in the 0–1 range and that they are not linearly related to the explanatory variables. This is an advantage over the linear probability model. In addition, it is easier and more convenient to compute than the probit model. Nevertheless, we made an attempt to estimate the logit model using several explanatory variables and hypothesised which were major determinants of wheat adoption. Finally, we included the following variables: (a) farming experiences (number of years), (b) off/non farm income, (c) education (years of schooling) and (d) family size etc. as explanatory variables where the dependent variable was wheat adopter = 1 and 0 = otherwise. The EasyReg International statistical tool was used for logit model analysis.

Results

Profitability survey of alternative rotations

The comparative profitability of major crop rotations at trial and non-trial villages based on the 2007–08 season and farmers' perceptions of good, normal and bad seasonal conditions is presented in Table 1. All rotations involved T. aus and T. aman rice preceding the Rabi crops nominated in Table 1.

Bhola

In the trial village in Bhola in 2007–08, farmers earned the highest per hectare gross margin (Tk81,620/ha) from the wheat rotation, followed by the chilli (Tk78,478/ha) and cowpea (Tk55,866/ha) rotations. This outcome was due to comparatively lower production costs, good market prices and good yields of wheat. In the trial village, farmers received comparatively lower gross margins from the cowpea rotation, yet cowpea was grown in a significant proportion of the available area. This may be due to the fact that the production cost of cowpea (Tk16,704/ha) was considerably lower than that for either chilli (Tk37,681/ha) or wheat (Tk30,832/ha) (Table 1).

In the non-trial village in Bhola, farmers earned the highest per hectare gross margin from the potato rotation (Tk116,652/ha) followed by the wheat (Tk96,043/ha) then chilli (Tk88,998/ha) rotations. Farmers achieved significantly higher gross margin from the potato rotation due to high yields and reasonable prices. Despite the chilli-based rotation producing the lowest gross margin, it occupied the highest proportion of area in the village.

The wheat-based rotation in the Bhola trial village provided a higher gross margin than the chilli or cowpea rotations irrespective of the seasonal situation. Significantly, in a bad year, the wheat rotation offered a higher gross margin than the other two crop rotations, which suggests that wheat may be regarded as less risky than chilli or cowpea crops. Likewise, at the non-trial village, potato rotations produced the highest gross margins compared to the other crop rotations.

Table 1 also contains a breakdown of the major input costs for the widely adopted Rabi crops at trial and non-trial villages in Bhola. It was observed that farmers paid significantly lower costs for growing cowpea than the other crops. Costs of ploughing, fertiliser and labour were highest for producing chilli, followed by wheat and cowpea, while seed cost was significantly higher for producing wheat than chilli and cowpea.

It was found that farmers did not pay for irrigation for growing chilli and cowpea but did so for irrigating wheat. In practice, farmers manually irrigated chilli by bucketing water from adjacent ponds. In fact, for growing chilli, farmers paid wages for hired labour for irrigation and thus the labour costs were higher for growing chilli than the other crops. This suggests that chilli generated higher employment opportunities, followed by wheat and cowpea.

Table 1. Comparative profitability of major Rabi crop rotations at trial and non-trial villages in the Bhola and Noakhali districts based on the 2007–08 season and farmer estimates of good, normal and bad seasonal conditions—gross margins (GM) are in Tk/ha, yields in kg/ha, prices in Tk/kg and input costs in Tk/ha

Bhola		Trial village			Non-trial village		
		Wheat	Chilli	Cowpea	Chilli	Potato	Wheat
2007–08	GM	81,620	78,478	55,866	88,998	116,652	96,043
	Yield	2,770	1,401	9,52	1,349	17,717	2,838
	Price	29	60	43	60	9	29
Good	GM	121,085	116,268	90,230	115,377	154,652	106,817
	Yield	3,212	1,572	1,112	1,740	22,368	3,118
	Price	28	58	37	58	8.5	28
Normal	GM	95,484	93,575	64,171	89,134	127,377	87,121
	Yield	2,299	1,108	798	1,117	15,712	2,236
	Price	34	73	41	73	11	34
Poor	GM	54,560	46,600	33,834	44,517	62,209	51,727
	Yield	1,731	670	585	756	11,713	17,04
	Price	40	80	48	80	13	40
Costs	Total	30,832	37,681	16,704	36,277	87,112	30,569
	Plough	3,796	4,009	2,644	3,966	6,056	4,265
	Seed	6,182	2,832	1,904	3,026	35,175	5,675
	Fertiliser	7,513	11,235	4,115	7,888	24,108	7,752
	Irrigation	1,198	0	0	0	1,648	929
	Labour	12,143	19,605	9,945	21,397	20,125	11,947

Noakhali		Trial village			Non-trial village		
		Wheat	Boro	Fallow	Grasspea	Sweet-potato	Peanut
2007–08	GM	83,394	78,675	–	58,288	93,757	69,160
	Yield	1,815	4,395	–	815	7,654	1,052
	Price	35	19	–	23	9	43
Good	GM	110,241	87,582	–	71,636	120,701	76,721
	Yield	3,100	4,880	–	1,155	11,770	1,381
	Price	33	18	–	19	7	34.5
Normal	GM	83,394	72,541	–	58,288	93,757	69,160
	Yield	1 815	3,701	–	815	7,654	1,052
	Price	35	21	–	23	9	43
Poor	GM	48,504	66,584	–	49,762	64,624	49,767
	Yield	1 400	3,200	–	540	4,717	741
	Price	35	23	–	23,	10	43
Costs	Total	26,208	38,691	–	7,330	24,591	27,242
	Plough	4,076	4,392	–	0	4,076	4,076
	Seed	4,613	1,394	–	981	478	4,087
	Fertiliser	5,745	7,658	–	302	1,530	3,204
	Irrigation	1,000	9,263	–	0	0	0
	Labour	11,775	15,984	–	6,047	18,508	15,875

Note: costs did not change with season type and yields, prices and input are only for Rabi crops

At the Bhola non-trial village, seed, fertiliser and irrigation costs were higher for producing potato, followed by wheat and chilli. Due to these significantly higher production costs of potato, resource-poor farmers cannot afford to grow it. Tenant farmers grow grasspea that produces lower gross margins and has lower employment scope.

Noakhali

In the Noakhali district, the exclusively dominant crop rotation in the trial village was fallow in the early wet season (Kharif-1), followed by T. aman rice and irrigated boro rice in the Rabi season. However, due to the influence of wheat trials in the village, a promising crop rotation is fallow/T. aman rice/Rabi wheat. In the non-trial village, the dominant crop rotations were T. aus and T. aman rice preceding the Rabi crops nominated in Table 1.

There were other significant differences between the trial and non-trial villages in Noakhali. The trial village is situated beside the upazila headquarters with access to a good extension network, in contrast to the non-trial village, which is located far from the upazila headquarters and extension facilities. In addition, the economic and agroeconomic conditions in the trial village were far more favourable than the non-trial village as it had available irrigation facilities whereas the non-trial village did not.

Table 1 shows the comparative profitability of major crop rotations at the trial and non-trial villages in Noakhali. It was observed from the farmer surveys that, in the trial village, gross margins were higher for growing wheat in the rotation in both the good (Tk110,241/ha) and 2007–08 (Tk83,394/ha) seasons compared to boro rice (Tk87,582/ha and Tk78,675/ha for good and 2007–08, respectively). This result was due to the good market price (Tk35/kg) and lower production cost (Tk26,208/ha) for wheat compared to boro rice (costs ofTk 38,691/ha). However, in bad years, boro gross margin was higher than wheat because of the low wheat yield.

At Noakhali's non-trial village, gross margins were higher for growing sweetpotato, followed by peanut and grasspea, irrespective of the season type. Total variable costs were higher for growing peanut, followed by sweetpotato and grasspea. Grasspea rotations occupied the highest proportion of area but produced the lowest gross margin. This observation may be due to a lack of financial capability for buying inputs, scarcity of irrigation facilities and lack of knowledge about the availability of alternatives.

Influence of land tenure

There are different types of farmers in Bangladesh based on their ownership of land assets and these differences may significantly influence the adoption and livelihood impacts of Rabi crop intensification. Figure 2 presents the impact of land tenure on the comparative profitability of major crop rotations at trial and non-trial villages in Bhola. In the trial village (Figure 2a), owner farmers earned higher gross margins from all three important crop rotations compared to tenant and owner-tenant farmers. The production costs of owner-tenant farmers were comparatively higher for all three crop rotations, suggesting that they were comparatively less efficient than owner and tenant farmers. Of the dominant three crop rotations, the wheat rotation provided higher gross margins to owner, owner-tenant and tenant farmers, followed by chilli and cowpea rotations.

At the non-trial village in Bhola (Figure 2b), owner-tenant farmers achieved similar gross margins to owner farmers from the potato and wheat rotations despite their production cost being marginally higher for all three crop rotations. Tenant farmers received low gross margins from their grasspea rotation but costs were also low.

At the Noakhali trial village, tenant farmers earned slightly higher gross margins from boro rice rotations, followed by owner farmers and owner-tenant farmers (Figure 3a). This may be interpreted as tenant farmers farming only a small area with intensive care. In the case of wheat rotations, tenant farmers achieved higher gross margins with higher production costs, followed by owner-tenant farmers and owner farmers.

There were little differences between owner, owner-tenant and tenant farmers in the non-trial village (Figure 3b), which indicates that there was no noteworthy difference in knowledge of new technology and input use capability of different types of farmers. This may be due to the lack of proper extension activities in the region. Owner, owner-tenant and tenant farmers earned their highest gross margin from the sweetpotato rotation followed by the peanut and grasspea rotations.

Sensitivity analysis of wheat profitability

Sensitivity analysis on profitability of the most important Rabi crops was done by altering product price, production cost and yield based on different year situations in Bhola. Per hectare gross margins of wheat, chilli, potato and cowpea ranged

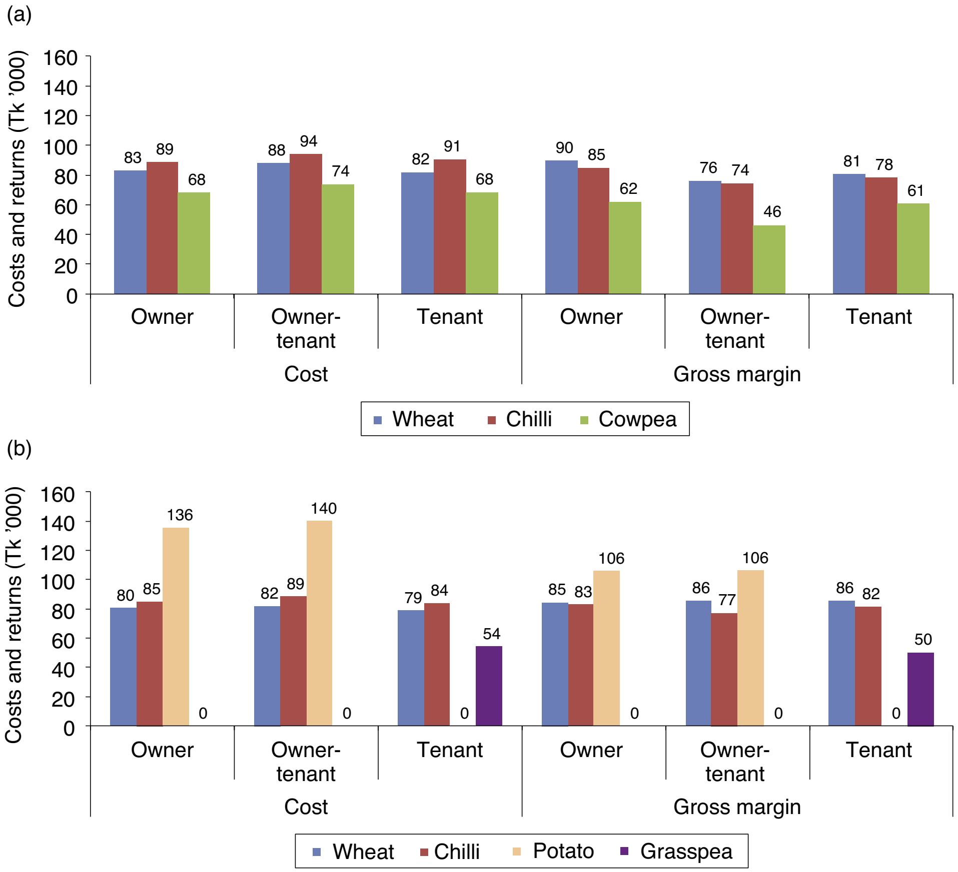


Figure 2. Land tenure and comparative profitability of the dominant cropping rotation at the (a) trial and (b) non-trial villages in Bhola—crops mentioned were in sequence with transplanted (T.) aus and T. aman rice

between Tk28,000–30,000/ha, Tk25,000–49,000/ha, Tk32,000–78,000/ha and Tk8,000–14,000/ha, respectively, when price was averaged over the past 10 years or past 3 years or decreased by 25% (Figure 4a). Among the highly adopted crops, cowpea is the least profitable and, across this range of assumptions, wheat profitability is comparatively more stable than other Rabi crops, although gross margin rankings altered particularly with price paid at market for each commodity. If fertiliser costs increase, crop selection by farmers, especially of potato, will be highly influenced.

Farmers' gross margins also changed with season. Gross margins were high in good seasons, assessed in terms of rainfall and temperature, and low in bad seasons (Figure 4b). However, the rankings of the various crop rotations were not changed by weather factors.

The costs and returns of wheat and its competing crops

This study found that the costs of growing wheat were higher and significantly different from the costs of growing cowpea in the Bhola district. Per hectare gross return and gross margin for wheat and cowpea differed by Tk43,668 and Tk29,672, respectively (Table 2). Per hectare fertiliser, labour and total costs of producing wheat were lower than for chilli and the gross margin for wheat was higher. The findings suggest that there were significant differences in cost and return in producing wheat versus cowpea or chilli and producing wheat will be significantly more profitable compared to these other crops (Table 2).

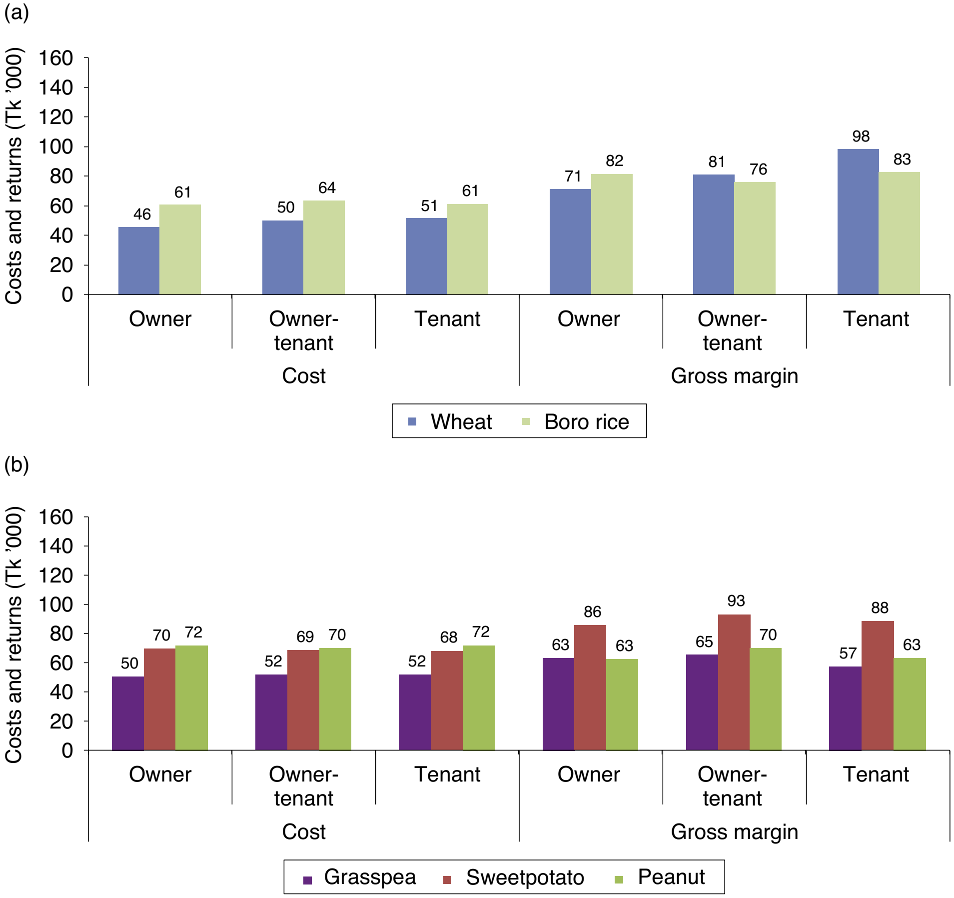


Figure 3. Land tenure and comparative profitability of the dominant cropping rotation at the (a) trial and (b) non-trial villages in Noakhali—crop sequences are described in text

In Noakhali, all input costs were significantly higher for producing wheat compared to grasspea (Table 3). However, differences in gross return (Tk44,545/ha) and gross margin (Tk40,245/ha) favoured growing wheat in preference to grasspea. Moreover, differences in fertiliser, labour and total costs were significantly lower for growing wheat than for boro rice. Differences in gross return for wheat were significantly lower than for boro rice. However, the difference in gross margin for wheat was higher than that for boro. Wheat may be a suitable option as a Rabi crop for resource-poor farmers of the study areas because of the lower production cost yet still reasonable returns.

Social factors that influence the decision to adopt wheat

The farming experience of the member of the household who manages the farm is an indicator of their capacity to take a decision to adopt a new technology. The maximum likelihood analysis results (Table 4) showed a positive and significant relationship between farming experiences and the decision to adopt wheat. This indicates that farming experience influences a farmer's decision to adopt. The relative experience of a farmer affects their knowledge and awareness of the activities of others in their surrounding environment. Analysis of the data using chi-square showed that $\chi^2 = 4.61$, which was statistically significant at the 0.1 level of significance.

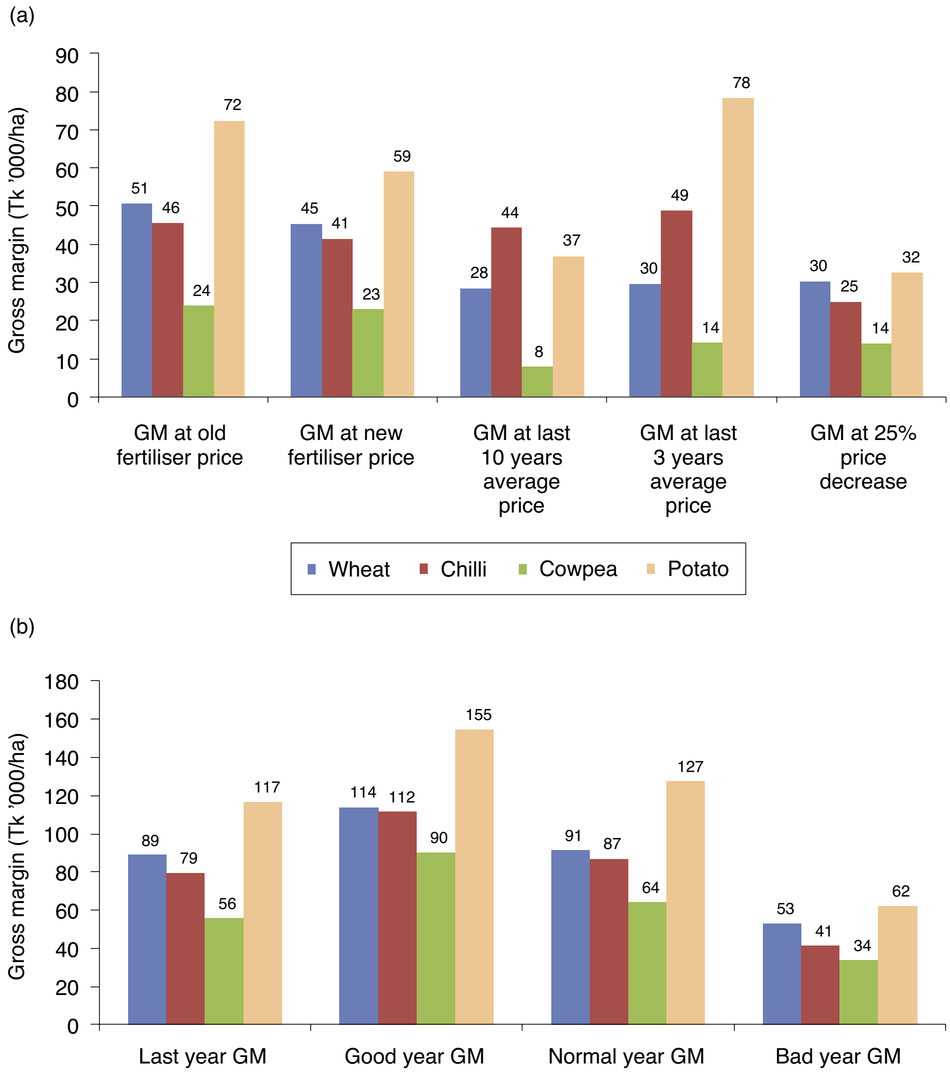


Figure 4. Sensitivity analysis of Rabi-crop gross margin (GM) in Bhola based on (a) costs and (b) the impact of different seasonal conditions on dominant crop rotations

Off-farm or non-farm income incorporates income earned by the household from different sources other than their own farm. It includes petty business, employment, casual work, farm and non-farm labour, credit, remittances, miscellaneous sources etc. Thus, the off-farm income earned by the household affects the farmer's ability to adopt wheat, as the initial investment for wheat is a high cost. The logit model in Table 4 showed a significant relationship between off/non-farm income and the farmer's decision to adopt wheat which is statistically significant at the 0.01 level of significance. The result of chi-square $\chi^2 = 5.99$h is also statistically significant. Off/non-farm income is an indicator of the available economic resources and the willingness to adopt a new technology like wheat.

A significant difference was found between the level of literacy among adopters and non-adopters at the 0.01 level of significance. The logit model indicated a positive significant relationship between

Table 2. Item-wise per-hectare costs and returns (Tk) for producing Rabi crops in Bhola

Item	Wheat versus cowpea			Wheat versus chilli		
	Mean difference	Standard deviation	t value	Mean difference	Standard deviation	t value
Ploughing cost	1,386	447	17.0***	42	580	0.40
Seed cost	4,024	371	59.5***	2,999	411	39.98***
Fertiliser cost	5,422	1,530	19.4***	–1,929	1,854	–5.70***
Labour cost	2,100	1,360	8.5***	–8,456	1,691	–27.38***
Total cost	13,996	2,243	34.2***	–6,279	2,530	–13.59***
Gross return	43,668	12,968	18.4***	–1,185	6,903	–0.94
Gross margin	29,672	13,189	12.3***	5,093	7,207	3.87***

*** Significant at the 0.01 level of significance

Table 3. Item-wise per-hectare costs and returns (Tk) for producing Rabi crops in Noakhali

Item	Wheat versus grasspea			Wheat versus boro rice		
	Mean difference	Standard deviation	t value	Mean difference	Standard deviation	t value
Ploughing cost	4,076	357	62.57***	–317	685	–2.54**
Seed cost	3,793	839	24.76***	3,380	826	22.40***
Fertiliser cost	5,534	1,958	15.48***	–1,822	2,206	–4.52***
Labour cost	5,583	1,515	20.18***	–27,061	2,030	–73.01***
Total cost	18,985	2,936	35.42***	–12,376	3,014	–22.49***
Gross return	44,545	30,190	8.08***	–24,870	35,238	–3.87***
Gross margin	40,245	29,253	7.54***	2,191	35,365	0.34

*** Significant at the 0.01 level of significance
** Significant at the 0.05 level of significance

adoption of wheat and education. Formal education would therefore be a critical factor in influencing the effectiveness of the farmer's decision to adopt wheat. Chi-square $\chi^2 = 7.78$, indicating education is statistically significant at the 0.1 level of significance. An educated farmer can readily access information on the advantages of wheat and how cropping it can be effectively implemented.

The results of the maximum likelihood analysis in Table 4 showed that there was a non-significant negative relationship between family size and the decision to adopt wheat, which indicates that large family size households are not necessarily better adopters than small family households. Analysis using chi-square gave $\chi^2 = 9.49$, which was statistically significant at the 0.05 level of significance. Family size is thus not a critical issue in a farmer's decision to adopt wheat because it is comparatively less labour intensive than other Rabi crops.

Discussion

Rice is the traditional food crop in the pre-monsoon and monsoon seasons in the villages surveyed as part of this study. While some farmers have cultivated boro rice in the surveyed villages, especially those with access to irrigation or on land adjacent to ponds, most farmers in this survey do not grow boro rice due to the lack of irrigation facilities.

In the Rabi season, pulses and chilli are the major cash crops in the surveyed villages because these crops produce good yields under rainfed conditions. The range of considered Rabi crops include chilli, potato, wheat, cowpea and grasspea and this survey indicates that all of these crops are profitable under normal seasonal conditions. Chilli is profitable with good yields under rainfed conditions and reasonable prices. It has the advantage of multiple harvests, which enables weekly market sales and so provides for buying necessary household commodities for a 2-month period. Cowpea is a rainfed crop, with low production costs, but also low yields. Potato is very

Table 4. Socioeconomic factors that influence the decision to adopt wheat in Bhola

Item	Coefficients	t value	χ^2
Farming experiences	0.0174333	6.409***	4.61*
Off /non-farm income	0.0000032	5.445***	5.99**
Education	0.0504751	5.180***	7.78*
Family size	–0.0133823	–0.871	9.49**

*** Significant at the 0.01 level of significance
** Significant at the 0.05 level of significance
* Significant at the 0.1 level of significance

profitable because of good yields, but production costs are often too high for many farmers and it needs one or two irrigations. Only rich farmers can afford the production cost of potato and so more marginal farmers often choose to grow grasspea, which produces a much lower gross margin. The production costs of grasspea are comparatively low but so are the yields. Some farmers have started to grow mungbean instead of aus rice in the pre-monsoon season, due to recent promotions. However, there are risks of mungbean damage from monsoonal rain or attacks from insects and disease.

Before the promotion of recent trials in the region, wheat had not been a significant crop among the villages of the Noakhali cluster, although farmers in Bhola had previously grown wheat on some land. Farmers reported that they were disheartened with wheat in the past because of the low yields of the old variety Kanchan. The newly released varieties, e.g. Shatabdi, Bijoy and Prodip, have now increased their interest in wheat as an option in their districts. At the trial villages, irrespective of seasonal conditions, wheat-based rotations provided higher gross margins than chilli and cowpea rotations. It was observed that, in the case of a bad year, wheat offered a significantly higher gross margin than either chilli or cowpea, which suggests that wheat may be less risky. The other advantage of wheat is that it is harvested when food is scarce. However, the crop-establishment cost of wheat is high and wheat requires one or two irrigations when many farmers lack any irrigation facilities. Seeding can also become late due to excessive soil moisture at the start of the Rabi season. Formal education, off/non-farm income and farming experiences are the vital socioeconomic factors that influence the decision to adopt wheat.

The main extension activities at trial villages were training on new technology, variety demonstrations, farmer field days and field visits by extension staff. Such training provided up-to-date knowledge on new technologies, which were demonstrated on local farms. Thus, farmers received practical experience on wheat production and were able to observe the yield potential of new varieties during farmers' field days. In contrast, extension activities on Rabi crops, especially on wheat production, were very scarce in the non-trial villages.

In conclusion, the results reported in this study confirm the economic viability of Rabi cropping in southern Bangladesh. This study indicates that the current Rabi crops are profitable under normal seasonal conditions and that wheat adds a profitable and low-risk option available to farmers.

References

BBS (Bangladesh Bureau of Statistics) 1999. Statistical year book of Bangladesh. BBS, Ministry of Planning: Dhaka.

BBS (Bangladesh Bureau of Statistics) 2002. Statistical year book of Bangladesh. BBS, Ministry of Planning: Dhaka.

BBS (Bangladesh Bureau of Statistics) 2007. Statistical year book of Bangladesh. BBS, Ministry of Planning: Dhaka.

DAE (Department of Agricultural Extension) 2010. Khamar Bari, farmgate. DAE: Dhaka.

Dillon J.L. and Hardaker J.B. 1980. Farm management research for small farmer development. FAO Agricultural Services Bulletin No. 41. Food and Agricultural Organization of the United Nations: Rome.

Gujarati N.D. 1995. Basic econometrics, third edition. McGraw-Hill Books: Singapore.

Rawson H., Gomez-Macpherson H., Hossain A.B.S., Saifuzzaman M., Rashid H., Sufian M.A., Samad M.A., Sarker A.Z., Ahmed F., Talukder Z.I., Rahman M., Siddique M.M.A.B., Hossain I. and Amin M. 2007. On-farm wheat trials in Bangladesh: a study to reduce perceived constraints to yield in traditional wheat areas and southern lands that remain fallow during the dry season. Experimental Agriculture 43, 21–40.

4.2 Potential yields for wheat crops

Peter S. Carberry, Perry L. Poulton and Neal P. Dalgliesh

Abstract

Due to the hot and dry Rabi season in southern Bangladesh, and the lack of irrigation infrastructure, arable lands in the region were long considered too risky for wheat production. Recent on-farm trials have challenged this perception, with economic wheat yields achieved by southern farmers. The aim of this chapter is to assess the long-term potential wheat yields in southern Bangladesh by combining data from on-farm trials with system modelling to assess the production potential for this region. Field crop–soil–climate datasets collected from on-farm trials were used to set up and test the Agricultural Production Systems Simulator (APSIM) model for this production system. Using these data, the feasibility of Rabi-season cropping systems was simulated for 27 years of climate data (1980–2007) in southern Bangladesh, including traditional wheat-production areas and the new areas being considered for cropping.

When configured for the local soils and genotypes, the APSIM model adequately simulated a range of wheat yields from the on-farm trials. Importantly, APSIM also mimicked the annual changes in watertable depth as soil water is first used by Rabi crops and then replenished as the wet season commences. Long-term simulations suggest that average wheat yields of over 3 t/ha can be achieved for the most southern sites when a single irrigation is applied at 20 days after sowing (DAS). These sites have high watertables and low salinity and the modelling suggests that yields are supplemented by plants accessing water supplied by the near-surface watertable. The conclusion is less certain for southern sites with high salinity, as APSIM has yet to capture the full impact of salinity on wheat physiology and yield.

This study provided promising argument for continued research and development investment into the production of Rabi-season crops using available surface-stored water on currently underutilised lands in southern Bangladesh.

Introduction

In southern Bangladesh, there are lands that produce rice in the wet (Kharif) season, but remain uncultivated during the dry (Rabi) season. A reason for these lands remaining uncultivated is the lack of shallow and deep tube wells to provide water for dry-season crop production. Irrigation development has not progressed in southern Bangladesh due to the concerns of saltwater intrusion if tube wells overexploited groundwater resources. However, Rawson et al. (2007), and the Australian Centre for International Agricultural Research (ACIAR) project reported in this volume, have shown that wheat production can occur in the southern regions with minimal input of irrigation water.

Assessing the technical and economic feasibility of crop production in a new region is difficult to achieve through experience alone. Experiments cannot be run for sufficient duration to sample the range of environmental constraints likely to occur over the long term. A supplementary approach is to utilise crop simulation models combined with the historical climate records to analyse the prospects for innovation in crop-production systems. Such approaches have been applied in investigation of rice–wheat cropping systems in the traditional regions of northern Bangladesh (Timsina et al. 2002; Mahmood et al. 2004). However, the ability to assess such innovation relies on the model's capability to simulate the key components of the system of interest.

This chapter aims to assess the long-term yield potential of wheat production in southern Bangladesh. A specific question is what yields can be expected from a wheat crop grown on water in the profile alone or with a single irrigation. In scoping the long-term feasibility, the Agricultural Production Systems Simulator (APSIM) model (Keating et al. 2003) was first assessed against the on-farm trial data collected in southern Bangladesh. Once tested, APSIM was employed to undertake a systems simulation analysis on the technical feasibility of wheat production in specific regions of southern Bangladesh.

Set-up of APSIM in Bangladesh

APSIM is a framework designed to simulate the production and resource consequences of agricultural systems, including fallowing and cropping sequence (further information is available on the website <www.APSIM.info>). APSIM has been specified for, and its simulations tested against, a range of crop and farming systems both in Australia and internationally (Keating et al. 2003). APSIM version 6.0 was set up to simulate smallholder farming systems in southern Bangladesh, including the simulation of wheat, rice and mungbean crops grown under rainfed and supplementary irrigation. The simulations also incorporated the influence of watertables and consequent movement of solutes (salt).

The key parameters required to test APSIM for a new region are the phenology of the local wheat varieties, the characterisation of the physical and chemical properties for location-specific soils and measured climate data. Experience in parameterising APSIM for new crops and regions indicates that establishing the appropriate phenology (dates of flowering and maturity) for the local variety will capture most of the observed genotypic variation. Consequently, parameter values were calibrated to ensure the local variety flowered and matured at dates close to observed values in southern Bangladesh. (Chapter 3.1, this volume, discusses phenology timing in relation to sowing date and climate.)

Soil characterisation data were collected as part of this study for the trial sites (Chapter 2.2, this volume) and these data were used to both estimate soil parameter values and determine starting soil water and nitrate nitrogen conditions. The simulation of soil watertables was calibrated using measured weekly values for the change in watertable depth supplied by the Bangladesh Water Development Board (BWDB) for the periods and locations being simulated.

Long-term daily climate data to 2007 were obtained from the Bangladesh Meteorological Department (BMD). Data include daily sunshine hours (h), maximum and minimum temperatures (°C) and rainfall (mm). A set of eight key regional areas for southern Bangladesh was selected and converted to a format suitable for climatic evaluation and as input into a farming system modelling analysis (Table 1). These data were supplemented by measured temperature and solar radiation data recorded at experimental sites in Noakhali, Barisal and Bhola from 2004 to 2009 (data not presented). Sunshine hour data were converted to daily total radiation (MJ/d) using coefficients sourced from a publication entitled 'Measurement and study of solar radiation over Bangladesh' (see REIN 2008). Generated daily radiation was compared with long-term monthly mean values of solar radiation (MJ/d).

Once parameterised, APSIM was tested for yield and biomass production against 14 on-farm seed multiplication trials (SMTs) conducted during the 2008–09 Rabi season (see Chapters 3.2 to 3.4, this volume, for agronomic details of these trials). Results included five sites sown to cultivar Shatabdi and nine sites sown to cultivar Prodip in four districts (Noakhali, Bhola, Barisal and Jhalakati). These simulations of wheat crops supplemented earlier testing of APSIM against trial data from southern Bangladesh (Carberry et al. 2008). Also simulated is the depth of watertable beneath a transplanted (T.) aus rice/T. aman rice/wheat rotation at Bhola which is compared to the reported weekly change in depth of watertable between 2000 and 2005. Finally, an example simulation of a full crop rotation consisting of a sequence of wheat/mungbean/T. aman rice/wheat is reproduced for an actual SMT site located at Bhola during 2007–09.

Production risks for wheat can be assessed by generating annual wheat yields over a range of seasons. Accordingly, APSIM was configured to simulate wheat crops grown at the locations nominated in Table 1. The soil data were similar across all sites, with plant available water capacity (PAWC) ranging up to 160 mm to a depth of 1.2 m—the exceptions were the Noakhali and Feni sites where salinity reduced the PAWC to below 130 mm. At least 27 years of climate data (1980–2007) were available for all sites to use in the long-term simulation scenarios. In each simulation, the agronomy was largely the same. Sowing date was specified as 20 December each year. Nitrogen fertiliser was applied as urea both

Table 1. Long-term climate stations converted to the Agricultural Production Systems Simulator (APSIM) input file format and used for simulation analyses

Long-term climate station location	Station code	International identification	Latitude—longitude (°), altitude	Start of record[a]
Patuakhali	12103	960	22.21N—90.20E, 3 m	1973
Khulna	11604	947	22.40N—89.04E, 4 m	1948
Barisal	11704	950	22.42N—90.21E, 4 m	1949
Bhola	11706	951	22.42N—90.39E, 5 m	1966
Noakhali	11809	953	22.49N—91.04E, 6 m	1951
Feni	11805	943	23.00N—91.22E, 8 m	1973
Jessore	11407	936	23.10N—89.13E, 7 m	1948
Madaripur	11513	939	23.10N—90.10E, 5 m	1977

[a] Not all variables start in the same year

at sowing (50 kg nitrogen (N)/ha) and top-dressed (50 kg N/ha) at the time of the first irrigation at 20 days after sowing (DAS). Rainfed treatments received 100 kg/ha applied at sowing. Within each simulation run for a site, the soil-water profile was reset to drained upper limit (DUL) at the nominated time of sowing—this represents the system status at the end of the Kharif season in most years. Measured monthly values for watertable depth were input into APSIM for the periods and locations being simulated.

Simulation performance of APSIM

The performance of APSIM in simulating wheat yields and biomass in the 2008–09 season at four sites (Noakhali, Bhola, Barisal, Jhalakati) in southern Bangladesh is presented in Figure 1. This performance of APSIM in simulating measured on-farm trial results was promising, with r^2 of 0.72 for grain yield and 0.67 for biomass. This result is similar to the APSIM simulation of measured wheat grain yields in southern Bangladesh for six sites and three seasons as reported by Carberry et al. (2008). It is also well within the validation outcomes for wheat simulation models developed and tested internationally (Timsina and Humphries 2006a). As a comparison, when the CERES-Wheat model was used to simulate wheat in northern Bangladesh, it resulted in a r^2 of 0.95 for the one site at Nashipur (Timsina et al. 1998) and an r^2 of 0.59 with significant over-prediction bias at the three sites of Nashipur, Ishurdi and Joydebpur (Timsina et al. 2002).

When considering wheat crops grown during the Rabi season in southern Bangladesh, it is imperative that the influence of near-surface watertables is accounted for in the simulations. A shallow watertable can provide water for crop growth if plant roots can access it or its capillary fringe. Accordingly, APSIM was set up to mimic the depth of shallow watertables as recorded across southern Bangladesh and for crops accessing this source of water. Figure 2 presents the simulation of seasonal change in depth of watertable between 2000 and 2005 at Bhola and compares such to measured weekly data. Overall, APSIM well reproduced the draw-down in watertable depth during the dry Rabi season and its rise at the beginning of each wet Kharif season. The differences in the simulated and observed soil-water levels at the soil surface during the Kharif season are because the modelled system was configured to simulate the effects of ponding surface water during successive rice crops, whereas the BWDB data are measured beneath a non-cropped site.

While the ACIAR project concentrated on measuring the performance of wheat crops during the Rabi season at many locations across southern Bangladesh, crop yield and biomass data were also collected from a few full seasonal rotations at selected sites. Figure 3 presents the simulated daily changes in crop growth for an actual wheat/mungbean/T. aman rice/wheat cropping sequence recorded at Bhola over the 2007–09 seasons. This simulation demonstrated that APSIM captured the changes in grain yield and biomass for the four crops grown in this sequence. In contrast to other applications of APSIM in simulating crop sequences (Probert et al. 1998), this crop sequence has the advantage that soil water is reset to SAT (saturated) annually during the Kharif season and so the influence of preceding crops is less critical than in other systems.

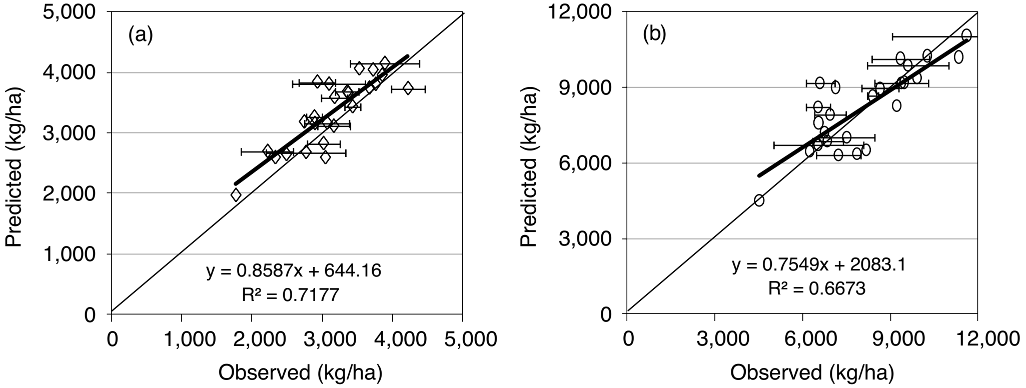


Figure 1. Observed and predicted (a) grain yield at maturity and (b) biomass at maturity for 14 seed multiplication trials (SMTs) for 2008–09 Rabi season

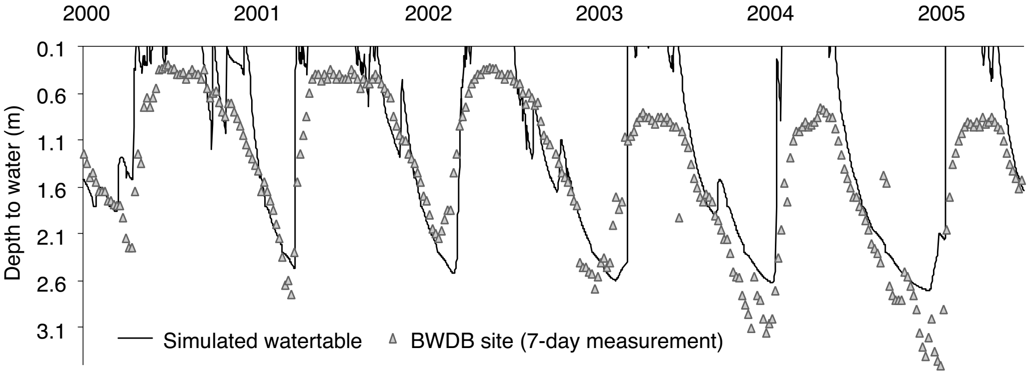


Figure 2. Simulated and measured changes in depth of watertable between 2000 and 2005 at Bhola. The simulation was for a transplanted (T.) aus rice/T. aman rice/wheat rotation and the measured data were accessed from Bangladesh Water Development Board (BWDB) for this same site and years.

Yield prospects for wheat production in southern Bangladesh

The annual production of grain yields simulated for wheat crops grown at Bhola over the 27 seasons from 1980 to 2007 is presented in Figure 4. Under the scenario where crops are irrigated once, the mean simulated wheat yield is 3,631 ± 345 kg/ha. The inter-annual variability is surprisingly high, ranging from 3,248 to 4,889 kg/ha. Such differences are attributed, in part, to variation in the photothermal quotient between years (see Chapter 1.1, this volume). There are also some seasons that produced low yields because the applied single irrigation at 20 DAS provided insufficient water to allow the simulated crop to reach its full environmental potential. While Chapter 3.4 (this volume) attempts to explore the value of more than a single irrigation applied later in crop development, trials were not conclusive. The finding that crop water deficits were simulated in some seasons over a 27-year period is likely a realistic situation.

Under the rainfed conditions, the mean simulated yield is 23% lower than the irrigated treatment, at 2,809 ± 628 kg/ha, with a wider range of 2,660 to 5,073 kg/ha. The small difference in simulated yields between the single irrigated and rainfed crops

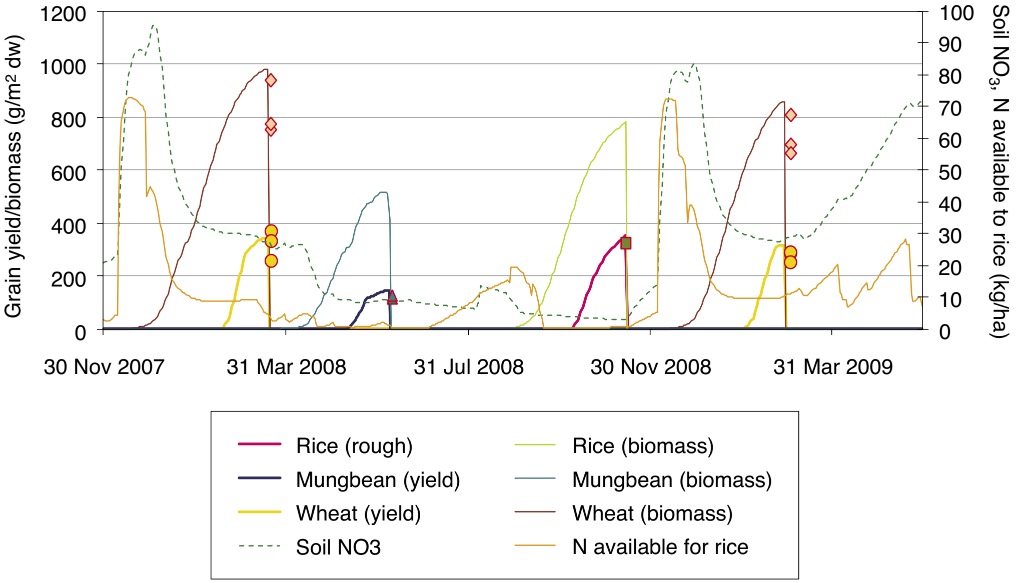


Figure 3. Simulated wheat/mungbean/transplanted (T.) aman rice/wheat cropping sequence planted at Bhola during 2007–09. Lines represent simulated values for grain yield, total biomass (dry weight, dw), soil nitrate (NO_3) and nitrogen (N) available to rice. Symbols represent the measured values of grain yield and biomass for individual replicates from the on-farm seed multiplication trial (SMT).

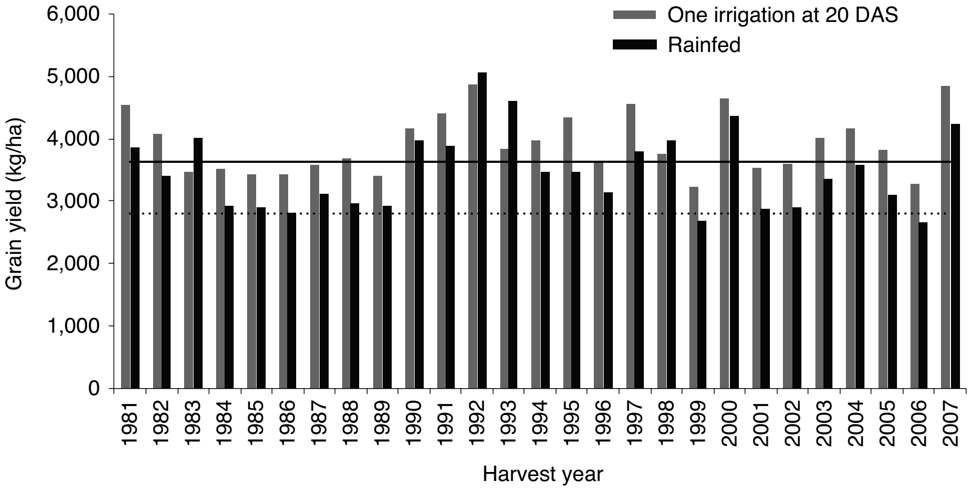


Figure 4. Simulated wheat grain yields for wheat crops grown at Bhola over 27 years (1980–2007) under irrigated and rainfed conditions. Means for irrigated (solid) and rainfed (dots) crops are represented by horizontal lines.

corresponds to the findings from the on-farm SMT trials conducted in Bhola over several seasons (see results presented in Chapter 3.4, this volume). In the simulations, and in the actual farmers' fields, the watertable during the Rabi season was close enough to the soil surface (Figure 2) to provide some support to the growing crop.

Figure 5 summarises the simulated wheat yields for eight sites across southern Bangladesh (as detailed in Table 1). Average simulated grain yields for wheat grown with a single irrigation 20 DAS across this selection of upazilas showed some variation, ranging from 3,601 kg/ha at Bhola to 2,574 kg/ha at Madaripur. Rainfed crops showed more seasonal variability and yielded lower, with reductions ranging from 7% (Khulna) to 29% (Barisal).

The simulations suggested wheat yields of 3,000 kg/ha or better can be averaged for the most southern sites (Patuakhali, Khulna, Barisal, Bhola) when a single irrigation is applied at 20 DAS and 100 kg N/ha is applied. As there are considerable areas of land in these regions with high watertables and low salinity, it is reasonable to expect farmers can achieve these simulated yields. Certainly, on-farm trial results over several years confirm this expectation (Chapter 3.3, this volume). In contrast, the sites in the south-eastern Chittagong division (Noakhali, Feni) are hampered by salinity to the point where crop yields were significantly reduced in on-farm trials (Chapter 3.6, this volume). In this case, the simple reduction in soil PAWC for the simulations at these sites (130 mm PAWC compared to 160–170 mm PAWC at other sites) did not represent the full impacts of salinity. The impact of high salinity on wheat physiology and yield remains an issue requiring research in relation to APSIM development.

The most northern sites in this simulation study (Jessore, Madaripur) represent more traditional wheat-production areas. Here, the simulated average yields for a single irrigation (Figure 5) are uncharacteristically low compared to the expectations for this region; Carberry et al. (2008) simulated the long-term average yield potential for fully irrigated wheat at Jessore at 4,300 kg/ha. With deeper watertables at these sites, the standard recommendation is to apply three irrigations to wheat crops. The simulated crops at these sites are clearly affected by water deficits during grain filling.

Conclusions

Simulation analyses using APSIM and local climate and soil data confirmed the results from on-farm trials in indicating that regions in southern Bangladesh show promising potential for wheat production. These findings challenge the view that wheat production is

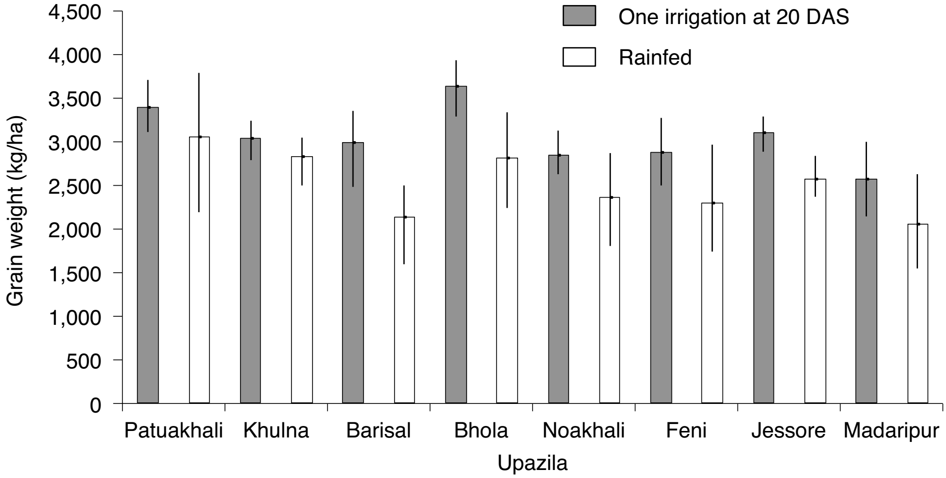


Figure 5. Simulated wheat grain yields for crops grown in eight upazilas under irrigated (once at 20 days after sowing, DAS) and rainfed conditions. Sites are ordered from the most southern to the most northern. The bars represent mean yields for crops simulated for 27 years (1980–2008); the vertical lines represent the 20 and 80 percentiles.

largely unsuited to southern Bangladesh (CIMMYT 2006) and support the contention of Rawson et al. (2007), and this ACIAR publication, that the historically fallow lands in the south could provide additional wheat production for the country.

A key question to realising Rabi-season cropping from southern lands is the extent to which production is dependent on access to irrigation water. While Zaman (2004) presented data suggesting much of the southern regions has significant amounts of accessible water, as surface water or shallow watertables of high quality at the start of the Rabi season, access by farmers to irrigation will likely be limited. However, this study raised the prospect that rainfed wheat crops in southern regions can achieve reasonable yields if their roots can access shallow watertables. On-farm trials (reported in Chapter 3.3, this volume) and the simulation modelling in this chapter suggest that consistently high yields can be achieved by using limited surface water as a single irrigation applied at a recommended 20 DAS.

This study has ignored the possible impact of global warming, which seriously threatens the productivity of Bangladesh's traditional cropping zones (Timsina and Humphreys 2006b). In expanding the area for Rabi-season cropping in southern Bangladesh, probable changes in temperature and rainfall regimes and consequent impacts on crop choice, systems management and their viability cannot be ignored. Modelling analyses that address climate change scenarios are of interest to policymakers and need to be included in any further analysis of crop-production options in Bangladesh.

References

Carberry P., Saifuzzaman M., Rawson H., Sufian M., Hossain A. and Dalgliesh N. 2008. Scoping study to assess the technical and economic feasibility of wheat production in southern Bangladesh. ACIAR Project LWR/2005/042 Final report. Australian Centre for International Agricultural Research: Canberra. Accessible at <http://aciar.gov.au/publication/FR2008-02>.

CIMMYT (International Maize and Wheat Improvement Center) 2006. Bangladesh country almanac version 3.0 (CD). CIMMYT: Dhaka.

Keating B.A., Carberry P.S., Hammer G.L., Probert M.E., Robertson M.J., Holzworth D., Huth N.I., Hargreaves J.N.G., Meinke H., Hochman Z., McLean G., Verburg K., Snow V.O., Dimes J.P., Silburn M., Wang E., Brown S., Bristow K.L., Asseng S., Chapman S.C., McCown R.L., Freebairn D.M. and Smith C.J. 2003. An overview of APSIM, a model designed for farming systems simulation. European Journal of Agronomy 18, 267–288.

Mahmood R., Legates D.R. and Meo M. 2004. The role of soil water availability in potential rainfed rice productivity in Bangladesh: applications of the CERES-Rice model. Applied Geography 24, 139–159.

Probert M.E., Carberry P.S., McCown R.L. and Turpin J.E. 1998. Simulation of legume–cereal systems using APSIM. Australian Journal of Agricultural Research 49, 317–327.

Rawson H.M., Gomez-Macpherson H., Hossain A.B.S., Saifuzzaman M., Rashid H., Sufian, M.A., Samad M.A., Sarker A.Z., Ahmed F., Talukder Z.I., Moznur Rahman, Siddique M.M.A.B., Hossain I. and Amin M. 2007. On-farm wheat trials in Bangladesh: a study to reduce perceived constraints to yield in traditional wheat areas and southern lands that remain fallow during the dry season. Experimental Agriculture 43, 21–40.

REIN (Renewable Energy Information Network, Bangladesh) 2008. Measurement and study of solar radiation over Bangladesh. REIN: Dhaka. At <www.lged-rein.org>, accessed 3 October 2008.

Timsina J. and Humphreys E. 2006a. Performance of CERES-Rice and CERES-Wheat models in rice–wheat systems: a review. Agricultural Systems 90, 5–31.

Timsina J. and Humphreys E. 2006b. Applications of CERES-Rice and CERES-Wheat in research, policy and climate change studies: a review. International Journal of Agricultural Research 1, 202–225.

Timsina J., Humphreys E., Quayyum M.A., Saleque M.A., Panaullah Haq F. and Connor D.J. 2002. Nutrient and irrigation management for sustainable rice–wheat cropping systems in Bangladesh and Australia. ACIAR project LWR2/1994/032. Australian Centre for International Agricultural Research: Canberra. Accessible at: <http://aciar.gov.au/project/LWR2/1994/032>.

Timsina J., Singh U., Badaruddin, M. and Meisner C. 1998. Cultivar, nitrogen, and moisture effects on a rice–wheat sequence: experimentation and simulation. Agronomy Journal 90, 119–130.

Zaman M. 2004. Databank: groundwater and surface water resources. Barind Multipurpose Development Authority: Bangladesh.

4.3 Potential for mungbean in sequence with Rabi-season wheat in southern Bangladesh

Neal P. Dalgliesh and Perry L. Poulton

Abstract

At first glance, a sequence of short-duration Kharif-1 mungbean (*Vigna radiata*) after Rabi wheat would be expected to have high potential when grown as part of a rice/wheat-based farming system in southern Bangladesh. Research at more than 150 on-farm trial sites across southern Bangladesh between 2008 and 2010 confirms that well-managed mungbean crops, planted immediately after wheat harvest in mid to late March, have the potential to yield over 1,000 kg/ha, contributing much needed income to individual farmers and supporting national food security. The research, however, also highlights the fine line that exists between crop success and failure, predominantly as a result of adverse climatic conditions and poor crop management. While the impacts of weeds, insects and pest management on crop production can be reduced through farmer education, management for climatic conditions is more problematic, requiring farmers to take a broader perspective of the farming system and the place of mungbean within it.

Analysis of the seasonal rainfall records for 1949–2009 (Bangladesh Meteorological Bureau) shows the high incidence of late growing season (May–June) rainfall and cyclonic activity that can decimate crop production. Furthermore, successful crop establishment can be jeopardised by dry soil conditions, which systems simulation suggests may occur in up to 60% of years under rainfed conditions.

While the picture may appear bleak for the successful sequence cropping of mungbean, the crop should not be ruled out, as long as certain seasonal and management criteria can be met, including:

- use of short-duration mungbean varieties available in Bangladesh (BARI Mung 6 and BINA Mung 7)
- planting of the crop no later than the end of March
- utilisation of an 'opportunity' approach to cropping in which planting is considered only if the opportunity occurs within the designated planting window when soil moisture conditions are suitable.

If these criteria cannot be met, then consideration should be given to growing an alternative crop like jute and/or broadcasted/transplanted aus or, if mungbean is the preferred farmer choice, then mungbean should be grown instead of Rabi-season wheat.

Introduction

While pulses constitute an important component of the Bangladesh diet, and historically have been a major part of the farming system, the area under cultivation has declined from 689,000 ha in 1995–96 to 337,000 ha in 2005–06 (Ministry of Agriculture 2007). During this period, the area planted to mungbean (*Vigna radiata*) has declined from 55,000 to 32,000 ha with a commensurate reduction in grain production from 32,000 to 17,000 t/year. Mungbean is the third most important pulse in terms of area and tonnage (after grasspea (*Lathyrus sativus*) and lentil (*Lens culinaris*)) and first in terms of price (Asaduzzaman et al. 2008). Over that same decade, improved agronomic practice and the introduction of new short-season varieties have resulted in an increase in the national average yield from 0.58 to 0.75 t/ha (Ministry of Agriculture 2007). However, despite economic analysis indicating that the returns from mungbean, when grown using best-management practice (Shah and Maula 2010), are similar to boro rice and wheat (Chapter 4.1, this volume), farmers continue to prefer Rabi-season cereals which are considered less risky options.

Historically, mungbean production in southern Bangladesh has been as a Rabi-season crop following the harvest of transplanted (T.) aman rice. Land preparation and planting are undertaken in December or January with the crop growing through the Rabi season using residual stored water, supplemented in some seasons by in-crop rainfall. Irrigation is generally unnecessary in this scenario, and available water resources are freed up for the production of boro rice which is considered the nation's pre-eminent Rabi-season food-security crop. Through the efforts of the Bangladesh Agricultural Research Institute (BARI), longer season mungbean varieties have been replaced by a range of shorter duration, higher yielding varieties that better fit the requirements of the rice-based farming system (BARI 2003). Farmers gained exposure and experience to BARI Mung 6, the latest of these releases, in the aftermath of Cyclone Sidr which struck the south in November 2007, when seed was provided to affected farmers as part of the government aid response to the disaster (Wikipedia 2009a).

The research being described in this report investigates the potential for BARI Mung 6, which reaches maturity in 55–58 days (BARI 2003; Rahman et al. 2009), to be grown as part of a cereal (rice and wheat) based cropping system. In this sequence, Kharif-2 rice (Table 1; Figure 1) is followed by wheat, planted as the Rabi season commences in November/December, and later by mungbean planted in March or April as a Kharif-1 season crop. Hypothetically, this sequence appears to provide an opportunity to contribute to food security and farmer income through crop intensification. This paper describes the potential benefits and the risks associated with such a sequence.

Research

Detailed agronomic research into mungbean production was not a component of this Australian Centre for International Agricultural Research (ACIAR)-funded project. It was considered that BARI had undertaken sufficient research and development on the recently released short-season variety BARI Mung 6 that additional work was not required to determine its suitability for southern Bangladesh (BARI 2003). Consequently, research focused on investigating its potential use as part of the rice/wheat-based farming system. This was undertaken as a component of the seed multiplication trial (SMT) program described in other sections of this report, in which wheat was grown after Kharif-2 rice and followed by mungbean in the subsequent Kharif-1 season (Table 1; Figure 1). During the three seasons in which mungbean was trialled (2008, 2009 and 2010), 153 farmers participating in the SMT program planted approximately 1,000 m^2 of BARI Mung 6. Seed and preseason training were provided to growers along with in-season technical support. Farmers were encouraged to store a proportion of their production for subsequent planting and to sell to neighbouring farmers to increase the dissemination of seed within the broader farming community.

Figure 1. Proposed annual cropping sequence in which wheat and mungbean are grown in the Rabi and Kharif-1 seasons in sequence with transplanted (T.) aman rice grown in the Kharif-2 season

Table 1. Description of the three main climatic/cropping seasons of southern Bangladesh

Season	Period	Conditions
Kharif-1	March–May	Pre-monsoon—increasing rainfall
Kharif-2	June–October	Monsoon—heavy rainfall
Rabi	November–February	Dry season—occasional rainfall

Outcomes

Crop yield

Of the 153 farmers who grew mungbean in sequence with wheat during the 2008, 2009 and 2010 Kharif-1 seasons, only 27% (42 farmers) achieved yields of significance (Figure 2). Mungbean production on the remaining 111 farms failed due to a range of agronomic, management and environmental factors including poor crop establishment, lack of irrigation water at sowing, drought, tidal flooding, weeds (see Figure 8) and insect damage (Hossain M.A. et al. 2009).

In 2008, the most successful season for production, a mean grain yield of 921 kg/ha was achieved for the Barisal district, with yields ranging between 521 and 1,443 kg/ha (dry weight basis) across the 12 fields harvested (Figure 3). In Bhola, a mean yield of 646 kg/ha was achieved (ranging from 412 to 1,276 kg/ha) across the five fields harvested. Of the 13 fields planted in the Noakhali district (Figure 4), only two were harvested. They achieved yields of 282 and 446 kg/ha. The above yields were achieved from areas in which all weeds were removed. In areas where weeds were allowed to flourish, mean yields for the three districts of Barisal, Bhola and Noakhali declined by 16, 39 and 5%, respectively (Figure 3).

On 25 May 2009 Cyclone Aila (Wikipedia 2009b) hit the south of Bangladesh, resulting in significant loss of life and damage to crops. Many mungbean crops that were nearing maturity were destroyed. Consequently, of the 76 crops planted in five districts in March and April 2009, only 17% (13 fields) reached maturity and were harvested. In the districts of Noakhali and Jhalakati, all crops were destroyed. The extreme conditions reduced yields (Figure 5). In the district of Bhola, 3 crops from 20 reached maturity, with an average weed-free yield of 385 kg/ha (range from 137 to 581 kg/ha). Results for the district of Patuakhali were similar, with a mean weed-free yield across six fields (from 14 planted) of 596 kg/ha (range from 383 to 792 kg/ha). Where weeds were allowed to grow, yields dropped on average by 62% in Bhola and 18% in Patuakhali. Figure 5 provides some insight into the yield potential of the crops at Bhola in 2009 where a mean plant biomass yield of 1,580 kg/ha (dry weight) was recorded and yet only 385 kg/ha of grain was harvested. While it is not possible to be definitive about the reason for such a low harvest index (HI), it can be speculated that the cyclonic conditions experienced as the crop neared maturity were a major contributor. This conclusion is reflected in reported studies undertaken in Asia and Australia where the impacts of waterlogging, late-season rainfall and high and low temperature effects on grain quantity and quality are well recorded (Garrity and Pernito 1996; Yeates 2000; Khattak et al. 2006).

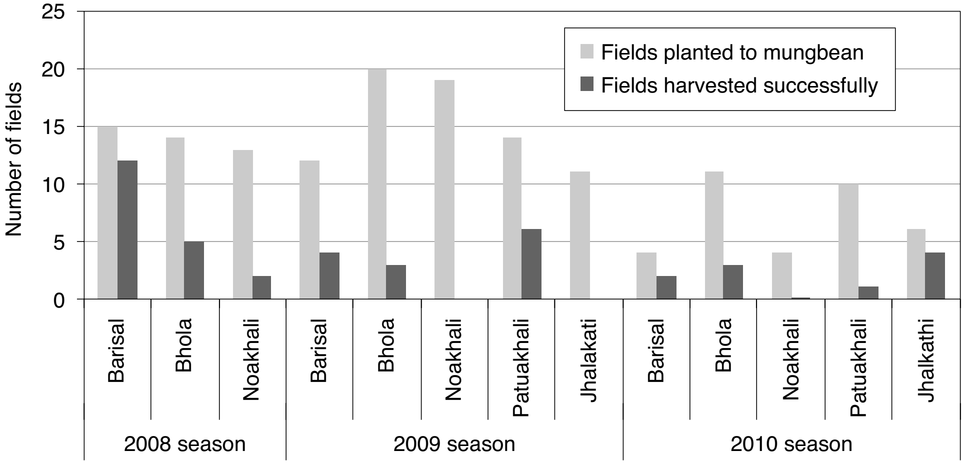


Figure 2. Number of farmer fields planted to mungbeans during the 2008, 2009 and 2010 seasons and the number that could be successfully harvested and from which economically significant yields were achieved

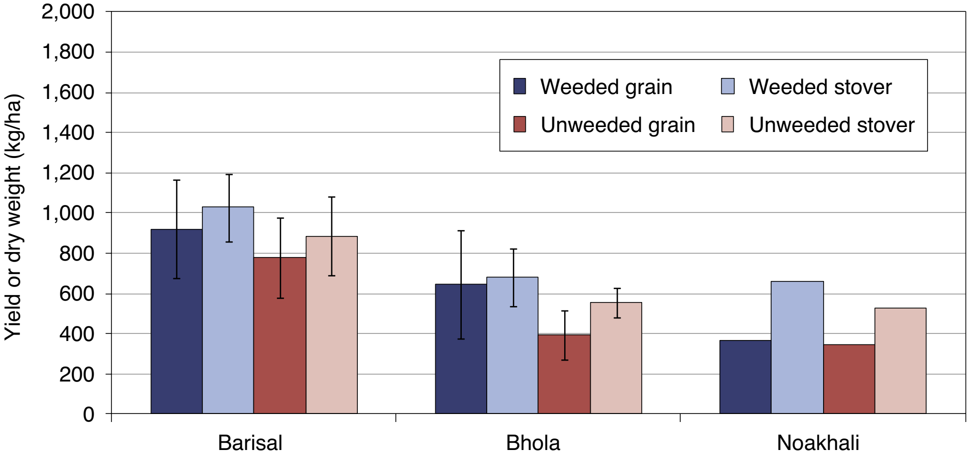


Figure 3. 2008 mungbean grain yields achieved in the districts of Barisal, Bhola and Noakhali from 19 fields (of 42 planted) where the crop was successfully established and grown through to maturity—also shown is the impact of weeds on both grain and crop stover (non-grain dry matter) yields for the three districts

Figure 4. Md Monsur Ali of Senbagh, Noakhali, in his BARI Mung 6 crop grown after wheat in 2008 (Photo: J. Kabir)

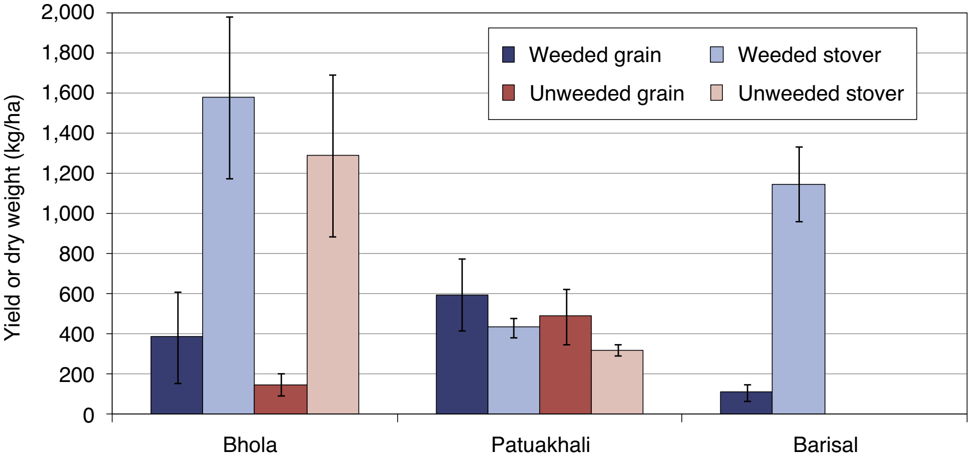


Figure 5. Mungbean grain yields in 2009 in the districts of Bhola, Barisal and Patuakhali from 13 fields (of 46 planted) where the crop was successfully established and grown through to maturity—also shown is the impact of weeds on both grain and biomass yields for Bhola and Patuakhali districts

Impact of time of sowing on mungbean production

In the 2008 season in Noakhali, only two crops reached maturity and were harvested. This was a result of the hot and dry conditions present at the time of planting and heavy rainfall in June (584 mm) that damaged crops as they neared maturity. In contrast, crops grown in the Bhola and Barisal districts were successfully planted in late March or very early April with 12 of the 15 crops in Barisal and 5 of the 14 in Bhola growing through to maturity and achieving yields of over 400 kg/ha. In 2009, all mungbean crops planted after the end of March in the districts of Bhola, Jhalakati and Patuakhali failed. This was as a result of Cyclone Aila, which hit the region on the 25 May. In Patuakhali, all crops planted before the end of March were harvested, while at Bhola around 50% reached maturity with the remainder succumbing to a variety of problems including poor establishment, waterlogging after planting and insect damage.

The examples cited above provide a sobering picture of the potential for environmental factors to reduce mungbean production, both at the time of planting and later in the season as the crop nears maturity. Further analysis of time of sowing, which includes all 118 SMT sites (in five regions) planted to mungbean during 2008 and 2009, provides further evidence of the importance of establishing the crop as early as possible (Figure 6). Analysis of the impact of March sowing (52 fields) and April sowing (66 fields) on grain yield shows that the potential for significant yield drops dramatically for plantings undertaken after the end of March, with grain yield achieved in only 6% of years. Furthermore, for crops planted in March, there is still a 48% chance of crop failure. However, the odds do improve for March plantings, with 49% of crops achieving yields of more than 380 kg/ha and 20% achieving yields of more than 800 kg/ha (Figure 6). It should be noted, however, that these data represent only two seasons, which may or may not sufficiently represent the longer record. Nor does this analysis consider inherent farmer variability in crop and pest management.

The analysis of the Barisal March–June weather records for 1949 to 2009 (data provided by Bangladesh Meteorological Department) also supports the view that later plantings are risky. The record shows that in 25% of years (15 of the 60-year record) no rainfall was received during March (Figure 7). The record also shows that at least 30 mm was received in 50% of years and at least 80 mm in 20% of years. Given that these data do not provide information on the rainfall distribution, it can be assumed that, in at least 25% of years, dry soil conditions would have made mungbean establishment difficult, unless supplementary irrigation was available. While the logical farmer response would be to postpone planting until sufficient sowing moisture was available, the issue of later crop maturity

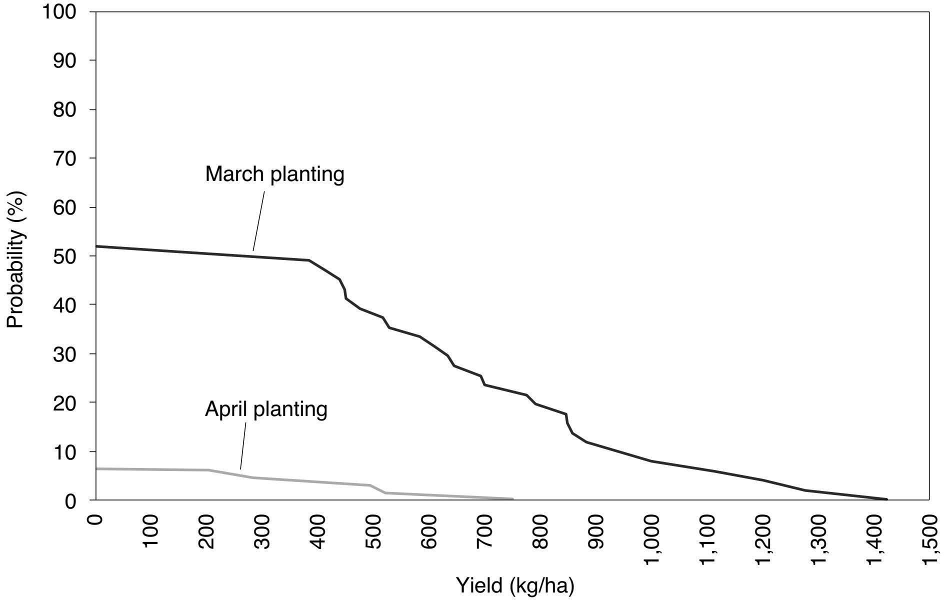


Figure 6. Probability distribution of mungbean yield (kg/ha) by month of sowing (March, April) for 118 crops grown across five regions of southern Bangladesh during the 2008 and 2009 seasons

and the potential for spoilage through early monsoonal rainfall or cyclonic activity would need to be seriously considered. Analysis of the climate record supports this observation with rainfall in May being recorded in 58 of the 60 years. In 50% of years more than 180 mm fell and in 20% of years more than 280 mm. The situation gets even more tenuous for a mungbean crop maturing in mid June (from a late-April planting), with a 96% probability of receiving at least 160 mm and a 50% chance of at least 394 mm (Figure 7).

Pests and diseases

Farmer concerns that they lacked the skills to manage pests and diseases resulted in the provision of training in pest management for both farmers and extension staff employed by the Bangladesh Department of Agricultural Extension and the non-government organisation PROSHIKA. Despite this training, pests remained a problem, causing significant yield losses for the remainder of the project. The issue was further exacerbated in 2008 when large areas of BARI Mung 6 were planted across southern Bangladesh as part of government efforts to assist farmer food security post–Cyclone Sidr (Wikipedia 2009a). These crops, planted in January 2008, were maturing in March, coinciding with the planting and early vegetative stages of the crops being grown by farmers collaborating in the SMT program. This resulted in a carryover of insects between plantings and resulted in increased insect and disease pressure.

Weeds were also a major problem for the majority of the 153 crops grown during the 3 years of research (Figure 8). Figures 3 and 5 provide examples of the effects of poor weed management on crop yield. Uncontrolled weeds reduced grain yields from between 5 and 62% during the 2008 and 2009 seasons.

Systems implications

For mungbean to be seen by farmers as a reliable, viable option in rice–wheat systems, several issues need to be considered. The most important is the timing of crop planting. As discussed above, there is a significant risk of crop spoilage as a result of late-season rainfall in crops planted after March. However, there are also difficulties associated with crop establishment in March, particularly if soil water has not been replenished subsequent to the previous crop. While supplementary irrigation would enable the timely establishment of the crop, this is often not an available option. In southern

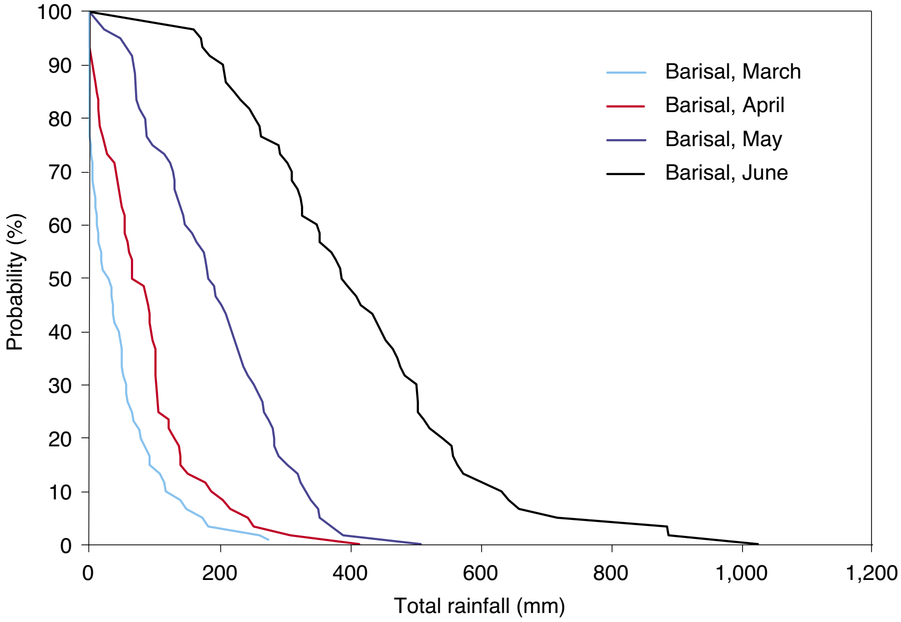


Figure 7. Rainfall probability distribution for March, April, May and June for 1949 to 2009 for Barisal, southern Bangladesh

Figure 8. Australian Centre for International Agricultural Research (ACIAR)-project Scientific Officer Md Farhad inspects a mungbean crop on Bhola which is overgrown by weeds (photo: PLP)

Bangladesh, 71% of irrigation water is sourced from surface storages and canals (Chapter 2.2, this volume). By March–April, supplies are likely to be running low or the water quarantined for use in boro rice production and not available for use on what is considered a crop of secondary importance. It is therefore proposed, where irrigation is not available, that a more opportunistic approach to mungbean production be considered in which the decision to plant is made only when there has been sufficient rainfall to encourage successful crop establishment, and then only if the opportunity occurs before the end of March.

It has been argued by others that the inclusion of a shorter season T. aman rice variety in the cropping sequence would allow the subsequent wheat crop to be planted earlier, which would then flow through to the earlier planting of mungbean. However, the reality in southern Bangladesh, as a result of the later finishing monsoon season, is that the time required for the soil to dry before land preparation and planting of the wheat is likely to be more important than the growing duration of the rice cultivar. The late finishing monsoon and resultant delays to wheat planting are reflected in the data from the SMT program where it is not uncommon for wet conditions to delay planting well into December (Chapter 3.3, this volume). The resulting knock-on effects then delay mungbean planting, constraining it to a narrow window of opportunity in mid to late March.

Given the issues associated with producing mungbean as part of a rice/wheat system, many farmers will consider the risk of successful mungbean production, after Rabi-season wheat, as being too great. They will opt for the potentially safer option of growing mungbeans as an alternative to wheat or, if the irrigation water resources are available, increasing their boro rice production.

Comparing the alternatives

Use of the APSIM model (Keating et al. 2003) provides insight into the benefits and constraints of these options. In Figure 9, a mungbean yield comparison is made for three scenarios:

1. mungbean planted instead of wheat on 15 January and irrigated once with 60 mm of water (to represent the situation where the farmer decides to forgo wheat production and opts to plant mungbean after the harvest of Kharif-2 rice)
2. mungbean planted after wheat harvest on 20 March with one irrigation application of 60 mm (to represent the situation where mungbean is planted after wheat and irrigation water is available for one application at planting)
3. mungbean planted after wheat harvest on 20 March in a soil that had either:
   - 25 mm of plant available water in the top 15 cm (to represent the situation where sufficient rain had fallen in early March to allow crop planting on 20 March) or,
   - during the period 20–31 March, received 10 mm of rainfall over the course of 1 day. The occurrence of this event then triggers the planting of the crop (to represent the situation where the farmer has no irrigation water and has to wait for 10 mm of rainfall, over 1 day, before planting).

Note that the output yields provided in this analysis are optimal for the prevailing weather conditions in each of the 40 years of simulation, with plants nutritionally non-limited and constraints to production, such as poor agronomic practice, weed and insect infestation or physical damage from hot or dry conditions or excess rainfall, not taken into consideration.

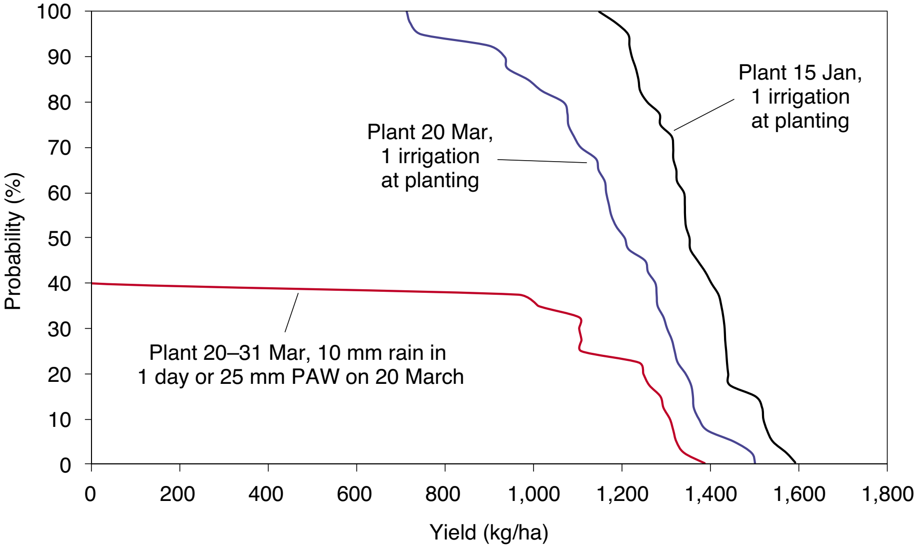


Figure 9. Agricultural Production Systems Simulator (APSIM) simulation showing mungbean yield (kg/ha) probability distribution for three scenarios at Bhola: (1) planted on 15 January with an irrigation of 60 mm water that day; (2) an irrigated crop planted on 20 March; (3) a rainfed crop either planted on 20 March when 25 mm of plant available water (PAW) was present in the top 15 cm of the soil profile, or when 10 mm of rainfall fell over one day between 20 and 31 March

The analysis indicates that mungbean, planted as a Rabi-season crop in mid January has a yield range of between 1,150 and 1,600 kg/ha (dry weight) with a 50% chance of achieving a yield of at least 1,350 kg/ha. This compares with a crop planted after the harvest of wheat on 20 March and irrigated once, which has a yield range of between 713 to 1,500 kg/ha with a 50% chance of achieving a yield of at least 1,200 kg/ha.

The overall shift of the yield distribution for a crop planted in January, compared to one planted after wheat in March, reflects the differences in soil water available for crop production. The Rabi-season crop will generally have access to a full profile of soil water (approximately 140 mm plant available water, plus in-season capillary rise) (Chapter 2.2, this volume) after the monsoon season, whereas the crop planted in March is dependent on Rabi-season rainfall and soil water remaining after the wheat crop. Field research indicates that plant available soil water in this scenario, in the top 60 cm of the profile, can vary from almost zero to around 60 mm depending on the seasonal conditions during the Rabi season and the productivity of the preceding wheat crop (Chapter 2.2, this volume).

The comparison between the two treatments where irrigation was available to establish the mungbean crop, and the real-life scenario faced by many farmers of having to rely on rainfall for mungbean establishment after wheat, paints a less positive picture. In 60% of years, the rainfed crop was a total failure, due to a lack of planting opportunities between 20 and 31 March. In 35% of years, however, it was still possible to achieve yields of at least 1,000 kg/ha, with a maximum simulated yield over the 40-year period (1967–2007) of 1,392 kg/ha. What this analysis indicates is that if the opportunity arises for a crop to be planted before the end of March, there is a good chance of significant yield, as long as good agronomic management is practised and catastrophic weather events do not intercede.

Conclusions

Mungbean grown in sequence with rice and wheat in southern Bangladesh can be an important part of the farming system if a strategic approach is taken to reduce the risk associated with its production. Mungbean, grown as part of a rice/wheat system, should be seen as an ‘opportunity’ crop. If conditions are right, i.e. in the 40% of years where simulations suggest good yields are achievable, then the opportunity should be taken to grow the crop. However, if soil-water conditions before the end of March are not conducive to establishment, then an alternative crop such as aus (Kharif-1) rice should be considered. Mungbean should not be considered for planting after the end of March, due to the potential risk from catastrophic weather events later in the season. If farmers have a preference for growing mungbean compared to wheat, then it would be logical that it be grown as a Rabi-season crop (Figure 10).

Underlying all of the assumptions about the ‘fit’ of mungbean in the farming system, and the yields that are achievable, is the premise that farmers have the expertise to grow the crop successfully. This is currently not the case. If mungbean’s potential to contribute to farmers’ livelihoods and national food security is to be realised (either as a Rabi-season crop or in sequence with wheat), then a major extension effort is required to educate farmers on the agronomy of the plant and the importance of weed and pest management.

Future opportunities

While outside the scope of the current research, it is considered that the potential to establish crops under drier starting conditions, through the use of improved tillage technologies, could benefit the overall efficiency of the farming system, including crop establishment and yield. Currently, tillage for seedbed preparation is undertaken using a bullock-drawn wooden country plough or a two-wheeled tractor and rotary hoe. The seed is then broadcast, and may or may not be covered with soil. Moving to a reduced tillage system, or a system in which tillage and sowing are done in one pass, reduces the down time between crops, increases weeding efficiency through placement of seeds in rows, and improves germination and crop establishment through improved seed/soil contact. Moving to a mechanised row-based system also provides the opportunity for the relay cropping of mungbean and other crops into the inter-row space of the preceding crop before harvest. This has the potential to improve the timeliness of crop establishment, which in turn reduces the potential for later-season damage from catastrophic weather events.

Activities promoting the use of two-wheeled tractors as a power source for smallholder-farming systems are underway in South and South-East Asia. These activities are supported by both national

Figure 10. Farmer Abdul Motin inspects a crop of Rabi-season mungbean on his farm at Hazirhat, Noakhali, in March 2009 (photo: NPD)

and international research organisations including the International Maize and Wheat Improvement Centre (CIMMYT) and ACIAR (Haque et al. 2004; Justice et al. 2004; Esdaile et al. 2009; Hossain I. et al. 2009; Hossain M.I. et al. 2009; Roy et al. 2009). Consequently, while the current research indicates that the production of mungbean after wheat is somewhat constrained by soil moisture and climatic conditions, improvements brought about by increased and appropriate mechanisation are likely to provide benefits into the future, not only for this component of a particular farming system but for crop production in general in southern Bangladesh.

References

Asaduzzaman M., Karim M.F., Ullah M.J. and Hasanuzzaman M. 2008. Response of mungbean (*Vigna radiata* L.) to nitrogen and irrigation management. American–Eurasian Journal of Scientific Research 3(1), 40–43.

BARI (Bangaldesh Agricultural Research Institute) 2003. Technology search. At <http://www.bari.gov.bd/index.php?option=com_advancedsearch&view=advancedsearch&id=926&page_no=0>, accessed 20 April 2011.

Esdaile R.J., Bell R., Hossain I., Sinath P. and Vial L. 2009. Final report on the development of conservation farming implements for two-wheel tractors (power tillers) in Cambodia, Lao PDR and Bangladesh. Australian Centre for International Agricultural Research: Canberra.

Garrity D.P. and Pernito R. 1996. Mungbean response to surface drainage when grown as a pre-rice crop on waterlog-prone ricelands. Agricultural Water Management 29, 299–314.

Haque E.M., Meisner C.A., Hossain I., Justice C. and Sayre K. 2004. Two-wheel tractor operated seed drill: a viable crop establishment and resource conservation option. In ‘Proceedings of the CIGR (International Commission of Agricultural Engineering) International Conference, Beijing, China, 11–14 October 2004, Vol. 2’. China Agricultural Science and Technology Press: Beijing.

Hossain I., Esdaile R.J., Bell R., Holland C., Haque E., Sayre K. and Alam M. 2009. Actual challenges: developing low cost no-till seeding technologies for heavy residues; small-scale no-till seeders for two wheel tractors. Pp. 171–177 in ‘Proceedings of Fourth World Congress on Conservation Agriculture, New Delhi, India, 4–7 February 2009’.

Hossain M.A., Prodhan M.Z.H. and Sarker M.A. 2009. Sowing dates: a major factor on the incidence of major insect pests and yield of mungbean. Journal of Agriculture and Rural Development 7(1&2), 127–133.

Hossain M.I., Islam M.S., Meisner C.A., Bodruzzaman, M. and Hossain I. 2009. Minimum tillage one pass seeder for sustaining cropping intensity and profitability in rice–wheat cropping system. International Journal of Sustainable Agricultural Technology 5(6), 32–37.

Justice S., Haque E.M., Meisner C.A., Hossain I., Ganesh Sah, Tripathi, J., Rashid M.H. and Amin M.R. 2004. Giving South Asia farmers a choice: a single drill for reduced and strip till crops for 2-wheel tractors. In 'Proceedings of the CIGR (International Commission of Agricultural Engineering) International Conference, Beijing, China, 11–14 October 2004'. China Agricultural Science and Technology Press: Beijing.

Keating B.A., Carberry P.S., Hammer G.L., Probert M.E., Robertson M.J., Holzworth D., Huth N.I., Hargreaves J.N.G., Meinke H., Hochman Z., McLean G., Verburg K., Snow V.O., Dimes J.P., Silburn M., Wang E., Brown S., Bristow K.L., Asseng S., Chapman S.C., McCown R.L., Freebairn D.M. and Smith C.J. 2003. An overview of APSIM, a model designed for farming systems simulation. European Journal of Agronomy 18, 267–288.

Khattak G.S.S, Saeed I. and Muhammad T. 2006. Breeding for heat tolerance in mungbean (*Vigna radiata* (L.) Wilczek). Pakistan Journal of Botany 38(5), 1539–1550.

Ministry of Agriculture 2007. Handbook of agricultural statistics, December 2007. Government of the People's Republic of Bangladesh: Dhaka. Accessible at: <http://www.moa.gov.bd/statistics/statistics.htm>.

Rahman M.A., Mia A.A., Mahmud F. and Afrin K.S. 2009. Multivariate analysis in some mungbean (*Vigna radiata* L. Wilczek) accessions on the basis of agronomic traits. International Journal of Agriculture Environment & Biotechnology 2(3), 230–234.

Roy K.C., Haque M.E., Hossain I. and Meisner C.A. 2009. Development of tillage machinery for conservation agriculture in Bangladesh. Agricultural Mechanization in Asia, Africa & Latin America 40(2), 58–64.

Shah M.M.R. and Maula A.K.M.M. 2010. Development of IPM based management tactics against insect pests of mungbean. International Journal of Sustainable Agricultural Technology 6(3), 8–11.

Wikipedia 2009a. Cyclone Sidr. At <http://en.wikipedia.org/wiki/Cyclone_Sidr>, accessed 13 December 2009.

Wikipedia 2009b. Cyclone Aila. At <http://en.wikipedia.org/wiki/Cyclone_Aila>, accessed 13 December 2009.

Yeates S.J. 2000. Prediction of weather damage of mungbean seed in tropical Australia. Part I: relation between seed quality, weather, and reproductive development. Australian Journal of Agricultural Research 51(5), 637–648.

4.4 Economics of Rabi crops and common rotations

Md Jahangir Kabir and H.M. Rawson

Abstract

Comparing yields achieved by Bhola farmers in their average, best and worst seasons with yields under optimal management for equivalent seasons, simulated by the Agricultural Production Systems Simulator (APSIM), showed that farmers should be able to increase productivity of their various crops substantially by using better agronomy. Rabi crops, in descending order of their farmer yields, are ranked boro rice, wheat, followed distantly by the legumes mungbean, cowpea and grasspea. But in terms of their farmer gross margins, which is the difference between the value of goods and cost of inputs, crop rankings changed to wheat-based cropping first, followed by grasspea, boro rice, mungbean and last by cowpea. Under optimal management (APSIM output) Rabi mungbean-based cropping became an outstanding choice based on economics, equating with boro and wheat in poor seasons and beating them in good seasons.

In terms of the most profitable annual rotations that farmers could use, wheat/mungbean/transplanted (T.) aman rice was best, followed by wheat/aus rice/T. aman, then by grasspea/aus/T. aman and mungbean/aus/T. aman. The boro/fallow/T. aman combination was poorest. Where weeds, disease and pests were controlled and other aspects of agronomy were optimised through computer simulation, the wheat/mungbean/T. aman rotation was by far the most profitable rotation. But mungbean must be grown under perfect agronomy for good results, something that farmers seldom achieve. It must also have water available to establish the crop after wheat, a commodity that many farmers do not have unless there is sufficient rain in late March, after wheat is harvested.

Introduction

In a previous paper in this section dealing with the economics of Rabi cropping (Chapter 4.1), comparisons were made between those crops grown at the paired trial and non-trial villages targeted by the project in Noakhali and Bhola. Attention was drawn to the different yields that might be achieved by farmers who owned their property, those who were owner-tenants and the poorest category of farmers who were tenants on the land. Crops examined were wheat, potato, chilli, boro rice, grasspea, sweetpotato and peanut, with specific comparisons made between wheat and other key crops—cowpea, chilli, grasspea and boro rice. Crop choices by farmers varied depending how much capital they had to spend on the crop and whether they had sufficient money or a loan to enable them to buy the seed and all the fertilisers that are needed for wheat before land preparation. Boro rice, although being more costly to grow overall than wheat, requires inputs steadily throughout the season and these can be purchased in small amounts from intermittent sales of other commodities or from earnings. Variables examined were effects on gross margins of varying fertiliser prices and the value of the commodity at market. Gross margin is the difference between the value of goods and services produced by a farm (the outputs) and cost of resources used in production (the inputs). Costs are itemised in Chapter 4.1 (this volume).

The current chapter considers the economics of crops grown on a farm of 250 decimals (1 ha; 2.5 acres), the average area for the south, and compares farmer yields and gross margins for a good Rabi season, a normal or average season, and a poor season. Costs are assumed to be the same regardless of the season being good or bad and were based on prices in February 2008. Yields were also calculated using the Agricultural Production Systems Simulator (APSIM) model (Keating et al. 2003) to estimate productivity in the varying seasons when optimal crop agronomy and inputs were used. For APSIM, the seasonal conditions modelled were the best 20% of years from the long-term weather data for Bhola, the worst 20% of years and the overall average years. Simulated potential wheat yields for Bhola from 1981 to 2007, assuming either one irrigation at 20 days after sowing (DAS) or no irrigation, are in Chapter 4.2 (this volume). In the same chapter, wheat yields from other southern regions are compared with those on Bhola, thus putting the current results into a wider context.

As well as comparing different years and yields achieved by farmers and modelled by APSIM, the current chapter introduces mungbean grown both in Kharif and Rabi seasons to compare with Rabi wheat, cowpea, grasspea and boro rice. Mungbean research in the south is detailed in Chapter 4.3 (this volume). Finally, this chapter compares different annual sequences of crops common in the region for their costs and gross margins.

Yields of various crops

The outstanding crops for yield were wheat and boro rice (Figure 1). Those crops in bad seasons produced more than twice the yields of the three legumes in their best seasons. Boro rice also maintained 1 t/ha better yield than wheat in the poorest (driest/hottest) seasons, primarily because it could depend on a supply of water, although in reality most Bhola farmers do not have adequate irrigation water for boro. Mungbean performed better when grown in the Rabi season than as a Kharif crop sown after wheat, averaging just under 1 t/ha in the best seasons. That is less than one-third the yield of wheat and one-quarter that of boro rice. Superficially, therefore, the legumes are a poor cropping choice. They have a high risk of rain and insect damage but are widely grown because they cost relatively little to produce.

APSIM calculated higher yields (Figure 2) than farmers achieved within their real constraints. And because water was non-limiting for boro even in poor seasons, it could maintain a high yield of around 5 t/ha. The potential for the legumes doubled or rose by 50% depending on the season. All increases compared with farmer reality indicate that farmers do not practise optimal agronomy.

Comparative gross margins and costs of various crops

Farmers in a normal Rabi season obtained the highest gross margin from wheat-based cropping (Tk17,000 for a 250 decimal farm), followed by grasspea, boro rice, mungbean and last by cowpea (Tk8,400) (Figure 3). The high production cost for boro rice and its relatively poor price at market reduced its gross margin—a disappointing outcome for such a

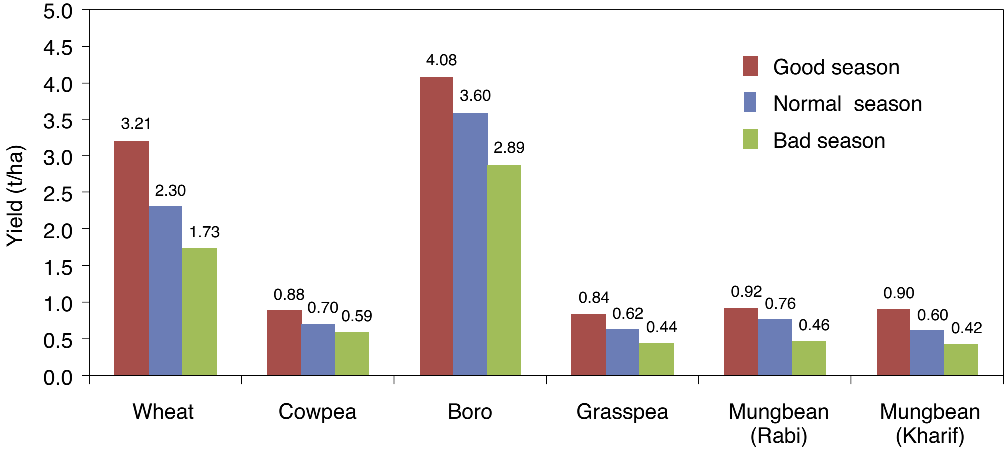


Figure 1. Comparative Bhola farm yield for major crops wheat, cowpea, boro rice, grasspea, mungbean (Rabi-grown) and mungbean (Kharif-grown) for good, average and poor seasons

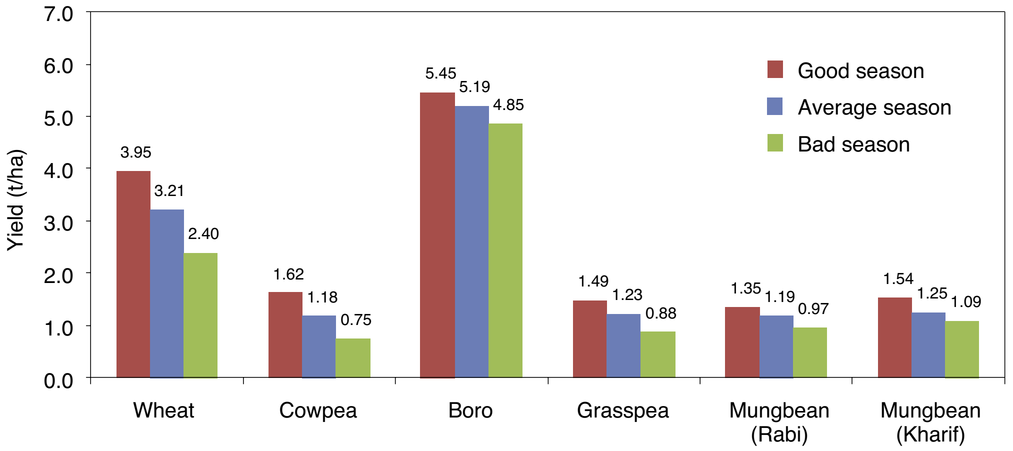


Figure 2. Comparative Agricultural Production Systems Simulator (APSIM)-simulated Bhola farm yield for major crops wheat, cowpea, boro rice, grasspea, mungbean (Rabi-grown) and mungbean (Kharif-grown) for good, average and poor seasons

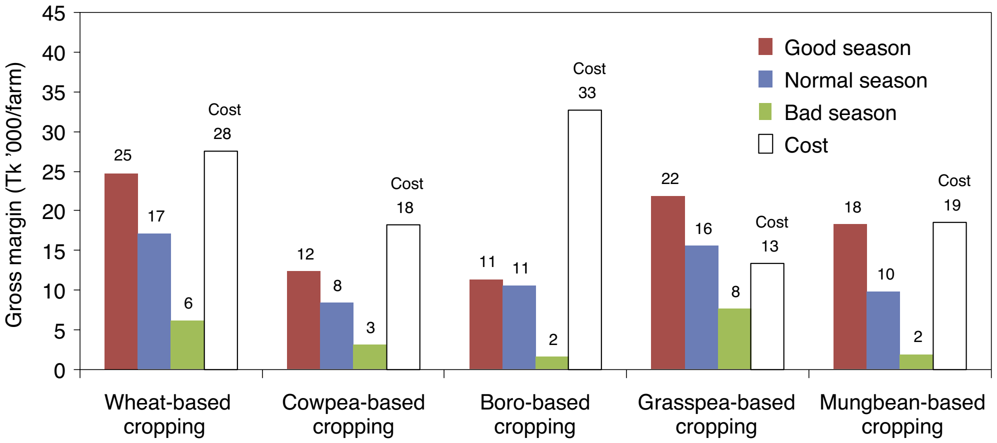


Figure 3. Farm gross margins and costs (Tk '000/1 ha farm) for wheat, cowpea, boro rice, grasspea and mungbean–based Rabi cropping in good, average and poor seasons

high-yielding crop. In bad seasons, grasspea with its minimal costs had the best gross margins, followed by wheat. Mungbean was a poor option in bad years but an excellent option in the 20% or so good seasons.

With disease, insects and weeds controlled and optimal agronomy (Figure 4), Rabi mungbean–based cropping became an outstanding choice, equating with boro and wheat in poor seasons and beating them in good seasons. In good seasons, there was little to choose between wheat, cowpea and boro–based systems. But APSIM does not reflect current reality, only an outcome to be aimed for.

Comparative gross margins and costs of various crop sequences

A crop rotation of wheat/mungbean/transplanted (T.) aman rice was the most profitable sequence for the conditions of a farmer's normal year, realising gross margins of Tk37,000 for a 250 decimal farm (Figure 5). Wheat/aus rice/T. aman was a close second followed by grasspea/aus/T. aman and by mungbean/aus/T. aman at Tk28,000. The boro/fallow/T. aman combination was poorest.

The optimised system calculated by APSIM (Figure 6) was again different from farmers' reality. Including mungbean in the sequences produced the best outcomes. So wheat/mungbean/T. aman had the highest gross margin (Tk88,000/250 decimal farm)

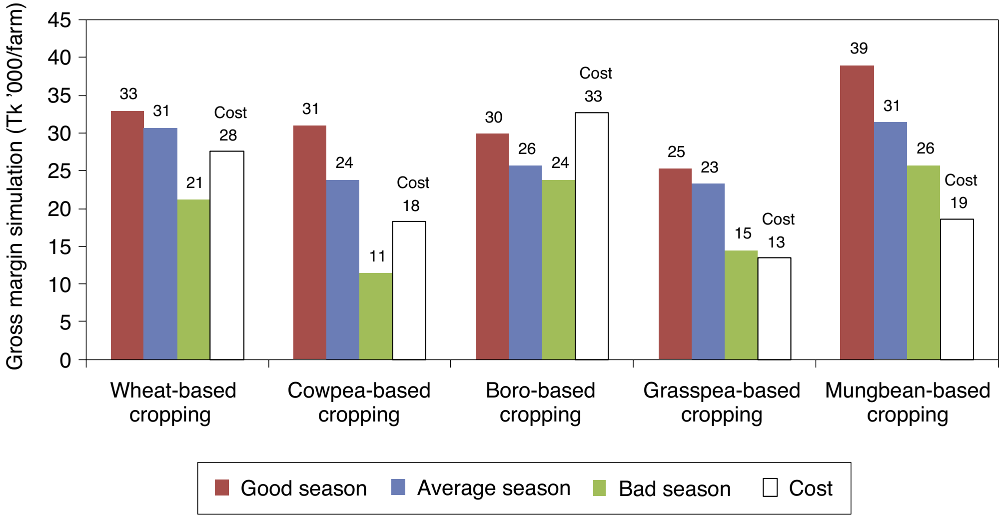


Figure 4. Agricultural Production Systems Simulator (APSIM)-simulated farm gross margins and costs (Tk '000/1 ha farm) for wheat, cowpea, boro rice, grasspea and mungbean–based Rabi cropping in good, average and poor seasons

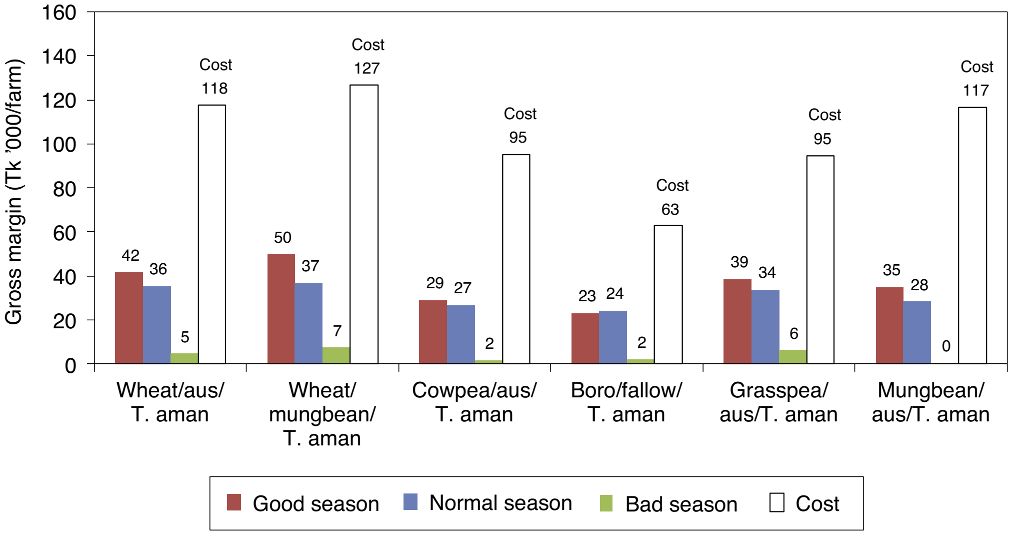


Figure 5. Farm gross margins and costs (Tk '000/1 ha farm) for common crop sequences in good, average and poor seasons

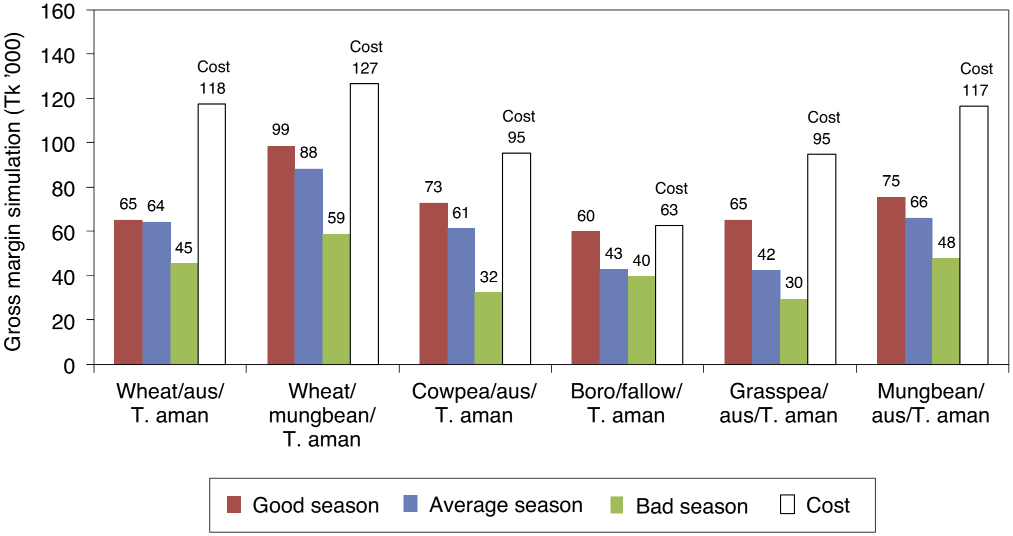


Figure 6. Agricultural Production Systems Simulator (APSIM)-simulated farm gross margins and costs (Tk '000/1 ha farm) for dominant crop sequences in good, average and poor seasons

followed by mungbean/aus/T. aman (Tk66,000), wheat/aus/T. aman (Tk64,000), cowpea/aus/T. aman (Tk61,000) and boro/fallow/T. aman (Tk43,000/250 decimal farm).

Both the farmers' reality and APSIM-calculated output indicate that a wheat/mungbean/T. aman sequence is the most profitable rotation. Despite that, the actual proportion of land area cropped under this rotation in the region is negligible, possibly because farmers do not know how to best manage the crops. The other possibility is that mungbean has occasionally failed because of inadequate water in the soil profile or because of problematic climate events (Chapter 4.3, this volume) and farmers have become wary of the risks. Traditionally, farmers do not cultivate mungbean in the Kharif season in this area. Large differences in gross returns between the farmers' experience and APSIM calculations indicate farmers can increase their profits substantially by upgrading management of their crops.

Reference

Keating B.A., Carberry P.S., Hammer G.L., Probert M.E., Robertson M.J., Holzworth D., Huth N.I., Hargreaves J.N.G., Meinke H., Hochman Z., McLean G., Verburg K., Snow V.O., Dimes J.P., Silburn M., Wang E., Brown S., Bristow K.L., Asseng S., Chapman S.C., McCown R.L., Freebairn D.M. and Smith C.J. 2003. An overview of APSIM, a model designed for farming systems simulation. European Journal of Agronomy 18, 267–288.

Section 5

Future of Rabi cropping in southern Bangladesh

5.1 Farmers' livelihoods: reality and options

Iqbal Alam Khan and Sharmin Afroz

Abstract

Previous chapters in this volume have described the potential for development of a wheat industry in southern Bangladesh to significantly improve the livelihoods of farmers. Those chapters have indicated that the climate, soils and water in the form of shallow watertables accessible to wheat roots are sufficient to produce economic and sustainable yields of wheat using the new heat- and late-planting-tolerant varieties married to technologies developed under the current Australian Centre for International Agricultural Research (ACIAR)-funded project. But are farmers ready for this possibility?

The current chapter provides a snapshot of how owner farmers, owner-tenant farmers and tenant farmers within their communities in Bhola and Noakhali are currently balancing their household budgets using their traditional farming practices, essentially without wheat, and assesses whether they might be ready to adopt changes to their traditions. The personal data were collected from farmers and assessed using the livelihoods framework of Ellis (2000), introduced here and used also in the following chapter.

It finds that existing livelihoods of farmers depend on their existing level of capital assets and ability to transform one form into others. Choices of crop, for example, are dependent on the relative availability of resources that can be transformed into, first, household food security and, when that is satisfied, into profits, and when they are plentiful into infrastructure to support future business. In one village with plentiful water and where regional food security equated with rice, wheat was of only marginal interest as a profit commodity because it was not in high demand at local markets. By contrast, where water was scarce and food security could rely on wheat, because the community ate wheat bread, it could supply both a portion of essential food security and then profit. Wheat uses little water compared with boro rice.

The same general patterns of livelihood applied for owner farmers, owner-tenants and tenant farmers with an intensity gradient in activity being from the richer (owners) to the poorer (tenants). Those who had more did more and had more opportunities presented to them by the community. Extrapolating from these patterns, it is speculated that the owner farmers will generally be first to take advantage of new technology and the others will follow. But regardless of the farmer category, the knowledge of how to successfully grow a new crop must be passed to all in any community. Small failures of individual farmers, although due to ignorance, will rapidly stop any adoption of a new method because the perception of risk within the community will rise. The new technology will be judged to be bad rather the individual within his longstanding social network. Hands-on, simple step-by-step training will assure success.

Introduction

One of the major socioeconomic challenges of the Australian Centre for International Agricultural Research (ACIAR)-funded study, outlined in Chapter 1.1 (this volume), was to assess the contribution of wheat and other Rabi-season crops to the profitability of farming systems and farm household incomes. It was also required to measure the impact of changes in Rabi-season cropping on the livelihoods of landowners and employed landless labourers, with attention to impacts on women. Employment in Rabi-season crop production provides landless labourers, including women and children, with an alternative to seasonal migration and less preferred livelihood strategies. It also affects the livelihoods of those involved in post-crop production, in harvesting, processing and transport of grain. In short, Rabi cropping affects not only on the prime producers of the crops but a large number of associated workers with flow-on into the larger communities. This chapter identifies and examines prevailing livelihood options and socioeconomic impacts during Rabi-season cropping in four selected villages traditionally not producing wheat crops during Rabi. The villages were paired into those with ACIAR-funded wheat trials intended to test wheat and its acceptance in the region, and those following their traditional agricultural practices. Village pairs were located in Noakhali and Bhola (see map in Chapter 1.1, this volume). The ACIAR-funded trials were run throughout the south of Bangladesh but these chosen villages were intended to give a snapshot of what might be happening more broadly. Assessing livelihoods in a community is difficult. This and associated socioeconomic chapters all follow the simplifying framework developed by Ellis (2000) which is described below.

Understanding rural livelihoods analysis

Rural livelihoods analysis is a conceptual framework rather than a research method for collecting data. It encourages researchers to view the adoption of specific livelihood activities such as Rabi-season cropping in the context of the assets, mediating processes and activities that combine to shape rural livelihoods (Ellis 2000). Extension programs designed to support landowners in their efforts to adopt more productive, profitable and/or sustainable land uses are only one of many mediating processes that influence rural livelihood strategies (Figure 1). These influences interact, and an integrated conceptual framework is useful for identifying which aspects need to be monitored to guide effective support for landowners in specific contexts.

The rural livelihoods framework includes the concept of social capital assets, both as reciprocal claims on, and support from, others in the local community who enhance the capacity of farmers to adopt new or altered practices. It can also include the social networks and institutional processes via which new ideas, opportunities and resources are identified and accessed in the continual process of locally inventing and adapting innovations.

Rural livelihoods analysis was developed to investigate the causes of poverty, and locally relevant strategies for combating it (Carney 1998; Ellis 2000; Ellis and Freeman 2005), including in Bangladesh (Khan and Seeley 2005). It is often closely aligned with impact research into the livelihoods of rural women (Sultana 2005 and see her Chapter 1.3, this volume). Its use to analyse the adoption and impact of specific farming systems interventions is relatively new and

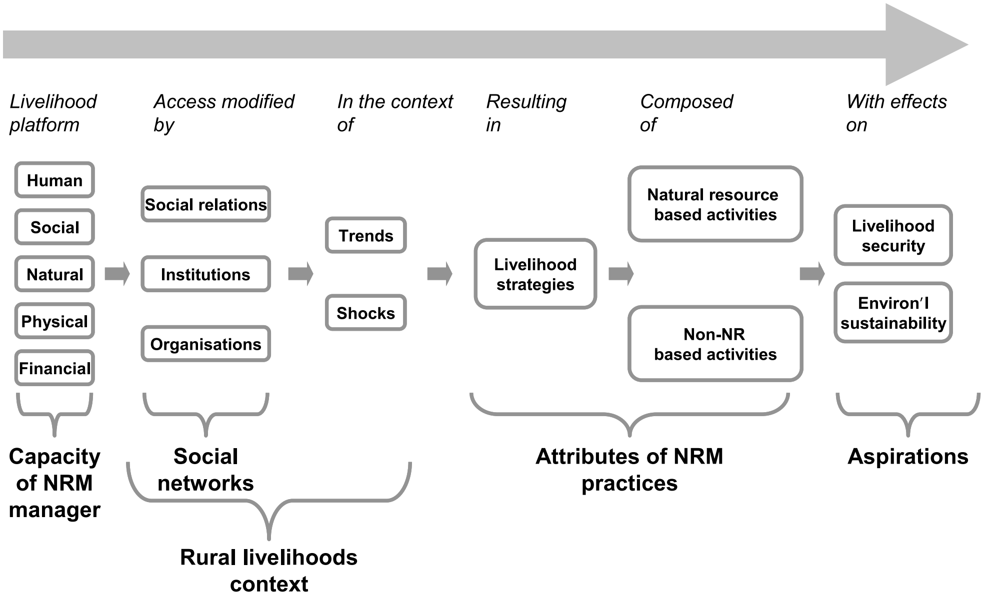


Figure 1. A framework for policy analysis of rural livelihoods (NRM = natural resource management) (Source: modified from Ellis 2000)

undeveloped. Cramb and Purcell (2001) used rural livelihoods analysis to explore the adoption of alternative forages by smallholders in Vietnam. In Australia, rural livelihoods analysis has been used to understand interactions between the capacity of farm households and the adoption of sustainable farming practices (Nelson et al. 2006). The current project was an opportunity to use innovative participatory rural appraisal (PRA) methods aligned with rural livelihoods analysis to understand what happens to individuals and communities during the adoption of new farming practices.

The rural livelihoods framework (Figure 1) developed by Ellis (2000) views livelihood strategies as comprised of activities that are continuously invented, adapted and adopted in response to changing access to five broadly defined types of capital including:

- human capital—the skills, health and education of individuals that contribute to the productivity of labour and capacity to manage land
- social capital—reciprocal claims on others by virtue of social relationships, the close social bonds that facilitate cooperative action and social bridging, and linking via which ideas and resources are accessed
- natural capital—the productivity of land and actions to sustain productivity, as well as the water and biological resources from which rural livelihoods are derived
- physical capital—capital items produced by economic activity from other types of capital that can include infrastructure, equipment and improvements in genetic resources (crops, livestock)
- financial capital—the level, variability and diversity of income sources, and access to other financial resources (credit and savings) that together contribute to wealth.

From the perspective of rural livelihoods analysis, the balance between these five types of capital is equally, if not more, important to the adaptive capacity of landowners than the amount of any one type of capital considered in isolation (Carney 1998; Ellis 2000) (Figure 2). This is because the five capitals often complement each other in the process of generating livelihoods. For example, minimum levels of human and social capital are necessary to effectively make use of natural, physical and financial capital. Viewing improvement of livelihoods as a balance between the capitals is also useful for capturing the transformative nature of the capitals (Ellis 2000).

An important strategy for generating both current and future livelihoods is transforming one form of capital into another. Natural capital, for example, can be transformed into physical and financial capital via economic activity, while financial, social and physical capital can be transformed into human capital by increasing access to education. As discussed by Ellis (2000), financial assets are not productive forms of capital in their own right, but contribute to current and future livelihoods capacity through their convertibility into consumption or other assets (Nelson and Khan 2007).

Prevailing livelihood status

Status of capital assets

Livelihood includes the capabilities, assets and activities required for a means of living. The idea of livelihood embodies three fundamental attributes—first, the possession of human capabilities (such as education, skills, health, psychological orientation); second, access to tangible and intangible assets; and third, the existence of economic activities. The interaction between these attributes defines what livelihood strategy a household pursues. The livelihood capital status and the livelihood strategies in southern Bangladesh are described below.

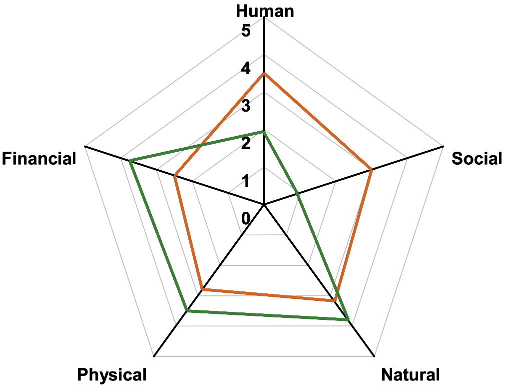


Figure 2. Livelihoods capacity depends on the balance between the five capitals (human, social, natural, physical, financial) from which rural livelihoods are derived. (Source: after Carney 1998) This example could represent the livelihoods capacity of two households, or two regions, industries, or nations.

Human capital

Human capital includes physical and intellectual skills and capabilities that enable an individual to perform tasks effectively and lead a productive life. Human capital highlights the importance of labour, health, education and skills as assets to achieving livelihood (Ellis 2000). In ACIAR-funded wheat trial villages and non-trial villages (where wheat was not trialled) in Noakhali, the average family size was 6.6 and 6.0, respectively, while it was 5.5 and 6.2, respectively, for Bhola district trial and non-trial villages, slightly higher on average than the national family size of 5.6 (BBS 2006). Labour is a vital asset for households, but labour alone cannot sustain livelihoods, except when enhanced through education, training and other skills, it becomes an effective tool for poor households to improve livelihoods. Education and training contribute to the earning capacity of individuals over their lifetime. Education prepares a workforce for productive participation in the economy as well as providing other national benefits. Individuals with higher education or training could traditionally count on higher wages, lower unemployment, better mobility and more demand for their labour over the course of their working life. The project data (Figure 3) show that the literacy rate in the trial villages was significantly higher than in non-trial villages for all three farmer categories (owner, owner-tenant, tenant). While owner males were generally more literate than owner females, gender education levels of tenant farmers were more similar. The awareness of the importance of children's education was reflected through a significant percentage of primary school enrolment in both districts, although less so in Noakhali than Bhola; percentages were marginally higher for trial villages. Owner farmers all had their 6–10-year-old children enrolled for primary school with fewer enrolments by owner-tenant and least for tenant farmers (Figure 3). Few farmers of any category reported that they got training under the ACIAR wheat-extension program (Figure 3).

Financial capital

Financial capital, put plainly, refers to money and financial assets such as loans, deposits, shares and household possessions that can be converted into other assets (Ellis 2000). The financial asset is not useful for the household unless it has been converted into other assets or into consumption. Loans are essential to poor rural households as normally they have few savings. Credit represents a form of economic empowerment that can enhance the competence of rural households. Farmers in the project used several sources of funding including non-government

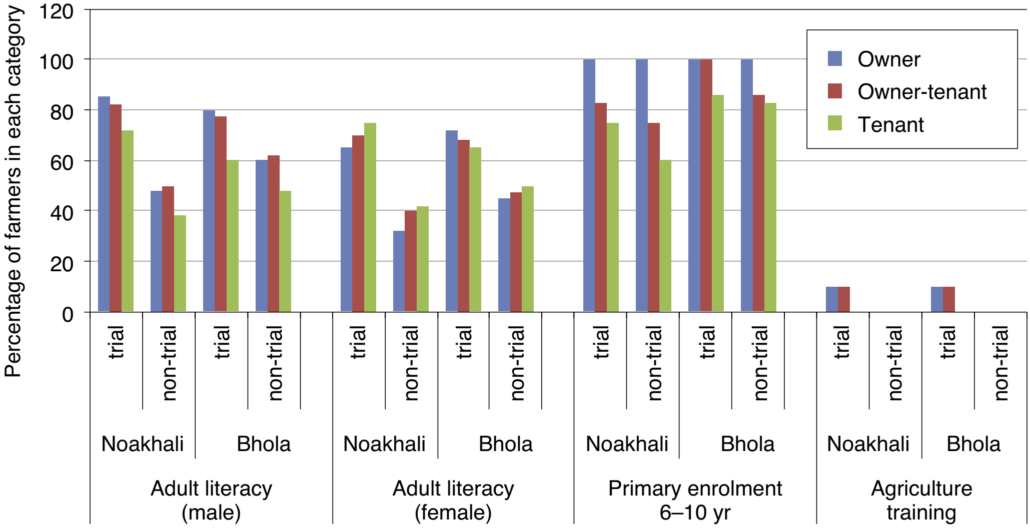


Figure 3. Human capital: household literacy, schooling and agriculture training for farmers in the owner, owner-tenant and tenant groups, assessed as percentage of farmers (wheat trial and non-trial villages in Noakhali and Bhola compared)

organisations (NGOs)/cooperatives, relatives, friends, neighbours, landlords and commercial banks. For the owner-farmer group, relatives were a reliable source of loans with 40% (Noakhali) to 50% (Bhola) coming from that source (Figure 4). Loans from friends and neighbours came as the second preferred source (20–30%). Commercial banks in the trial villages in Noakhali and Bhola provided 30% and 20% loans to the owners, respectively, while it was 10% for the non-trial villages. Commercial banks were not a source of loans for the tenant group. NGOs/cooperatives were the most popular lenders for owner-tenant and tenant farmers regardless of their village, with 40–60% of those farmers using that source. Far fewer owner farmers (10–20%) used this source for loans (Figure 4). Owner farmers did not take loans from mahajan/landlords, but that source was relatively important for owner-tenants and tenants even although rates of interest are extremely high; tenants often cannot access alternative sources.

Farmers also reported how they used their loans. In both districts, most money is invested in agriculture as more than half of villagers are dependent on it. Percentages were higher in both villages in Noakhali compared to Bhola. A total of 35–38% of the trial village farmers in both districts spent their loans on household daily necessities while it was far less in non-trial villages (17–21%). In the trial village in Noakhali, 8% of the loans were invested in business whereas it was double that in the non-trial village. By contrast, in Bhola, the trial village invested more in business than the non-trial village. Farmers also used their loans for repairing houses and purchasing livestock.

Social capital

Social capital includes formal and informal relationships (social resources) from which various opportunities and benefits can be drawn by people in pursuit of their livelihoods. Social capital is a mutual relationship within and among households and communities. Relationships are based on trust and reciprocity. More precisely, social capital pays more attention to family networks, kinships and close friends that the household will depend on in times of crisis. These relationships can be seen as an investment in future livelihoods (Krishna 1999; Ellis 2000).

The trial villages in both districts enjoyed membership of more community institutions than the non-trial villages with the saving-credit organisation being most popular. The tenant group followed

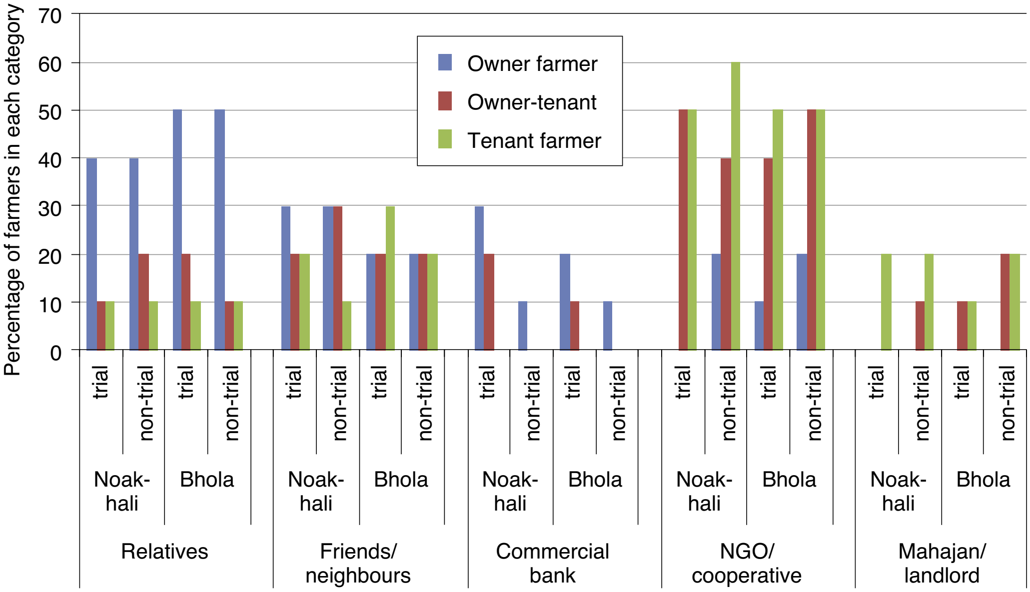


Figure 4. Financial capital: sources of loans for farmers (wheat trial and non-trial villages in Noakhali and Bhola compared)(NGO = non-government organisation)

by owner-tenant group had a higher percentage of membership in this institution than the owner group. Farmers' organisations were the second most popular institution but preferred more by owner farmers than owner-tenant farmers in both districts. Tenant farmers did not have membership in other institutions apart from 20% in a farmer organisation in the Noakhali trial village. Ten per cent of the owner farmers in each village in Noakhali and 10% in the trial village in Bhola were members of youth organisations. In the trial village in Noakhali, 10% of the owners and owner-tenants are members of religious groups. The percentage is slightly higher for owners in the non-trial village (20%) than in the trial village. In Bhola, 20% of the owners and owner-tenants are members of religious groups. The percentage is slightly higher for owners (30%) and was slightly lower (10%) for owner-tenants in the non-trial village.

Farmers reported that the agriculture services available were inputs such as subsidised fertilisers, technical assistance, microcredit and training. The data (not shown) indicate that the non-trial villages in both districts got no services for agriculture other than microcredit. More owner farmers took advantage of all types of services than owner-tenants and tenants in trial villages in both districts. For example, 50% of owners followed by 40% of owner-tenants and 10% of tenants got agricultural inputs in the trial village in Noakhali. On the other hand, more tenants accessed microcredit in both villages in both districts compared to the percentages of owner-tenants and owners. Farm owners are less likely to engage with a microcredit organisation.

Natural capital

Natural capital includes the land, water and biological resources that farm households use to generate livelihoods. Poor people especially depend on these natural assets for their livelihoods. Narayan et al. (2000) state that 'to be poor is to have no land or less access to land'. As such, it is ownership of, or access to, whatever is valued as a natural asset that defines people's status; the non-existence of it undermines the ability of the poor to provide for themselves. Natural capital is constantly changing, and its productivity can be enhanced or degraded through human and other influences. From the perspective of rural farmers, biophysical productivity of land, availability of water, the area of forest and livestock can be the important measures of natural capital.

The project showed who owned and had access to land. The non-trial villages in both districts had more area of cultivated land than the trial villages (Figure 5). In any village, the owners had access to the greatest area of land followed by the owner-tenant group and tenant group. Apart from this cultivated area of land of the owner and owner-tenant group they mortgaged out, leased out or share-cropped out their land. The tenants mortgaged, leased or share-cropped land that was not their own.

Livestock is a key element in rural livelihoods. Livestock is one form of saving that can be used during difficult times. Marginally more farmers in Noakhali had livestock than in Bhola (Figure 6). Most farmers owned cattle, although the percentage of tenant farmers with cattle was lower. Virtually all farmers had poultry. Up to half the tenant and owner-tenant farmers kept goats but owner farmers were little interested.

Water bodies are a necessary natural resource for farmer livelihoods. The respondents of both districts commented about the scarcity of water bodies and emphasised that if their village had more ponds and canals they could be used for irrigation; these provide much less expensive water than tube wells. In both districts the reported patterns of access to water bodies were quite similar (Figure 7). For example, the owners, owner-tenants and tenants owned ponds individually and also jointly. They also had access to ponds owned by others and some of them had access to canals. Tenants were most likely to use water from others' ponds; the degree depending on the social relationships that existed among neighbours. In both districts the number of individually owned ponds in the trial villages was lower than jointly owned ponds. Few farmers used canals because they are considered very small; even those living alongside canals could access that water easily only in the monsoon.

Physical capital

Physical capital assets include buildings, irrigation canals, roads, tools and machinery; in effect, the basic infrastructure—e.g. transport, shelter, communication and irrigation system, producer goods and other means—that enable people to pursue their livelihoods. Infrastructure changes the physical environment that helps people more easily meet their basic needs and so be more productive. Producer goods include the tools and equipment that people use to function more productively.

Paved houses are not common in rural areas. Most owner, owner-tenant and tenant farmers have semi-paved or unpaved houses (Figure 8). In both districts, trial villages had more paved and semi-paved houses and owner farmers were more likely to have a paved house. Only 10% of tenant farmers in the trial village in Noakhali had a paved house. On average, of farmers in the Noakhali trial village, 23% lived in paved houses, 50% in semi-paved and 27% in unpaved houses. In the non-trial village, equivalent numbers were 7% paved,

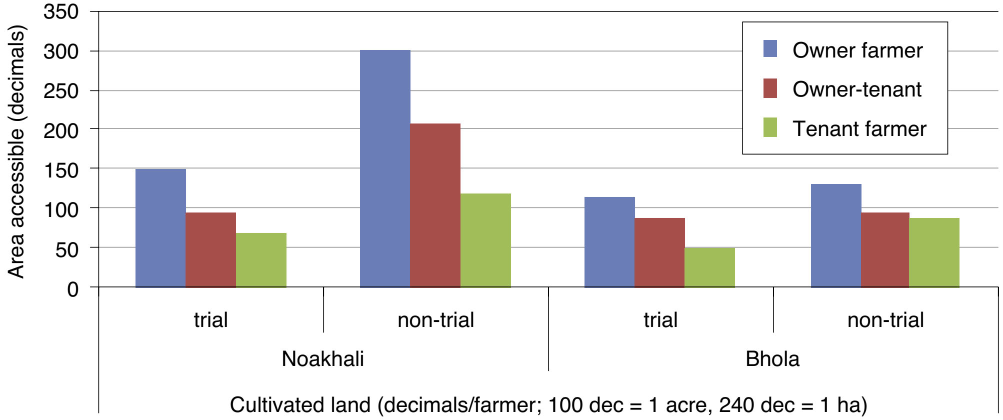


Figure 5. Natural capital: amount of cultivated land to which farmers of different categories had access (wheat trial and non-trial villages in Noakhali and Bhola compared)

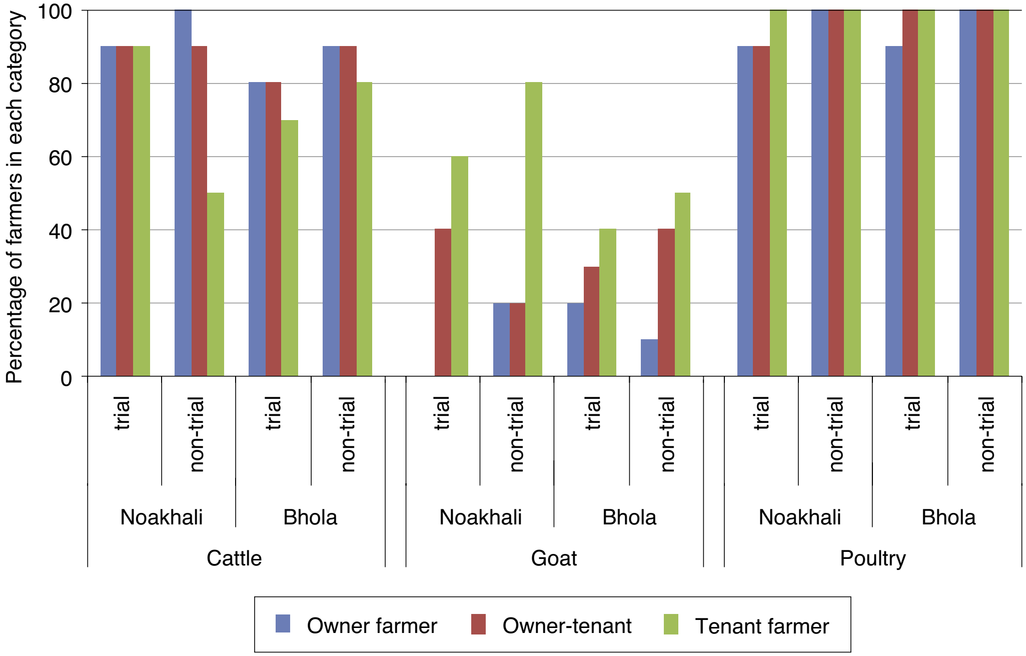


Figure 6. Natural capital: animals owned by farmers (wheat trial and non-trial villages in Noakhali and Bhola compared)

27% semi-paved and 66% unpaved houses. In Bhola, 10% of houses in each village were paved, 40% in trial and 33% in non-trial were semi-paved and 50% and 57%, respectively, were unpaved.

Through availability and access to modern farm machinery, the lives of farmers can become less arduous. The villagers surveyed in both districts had poor access to modern machines like tractors, power

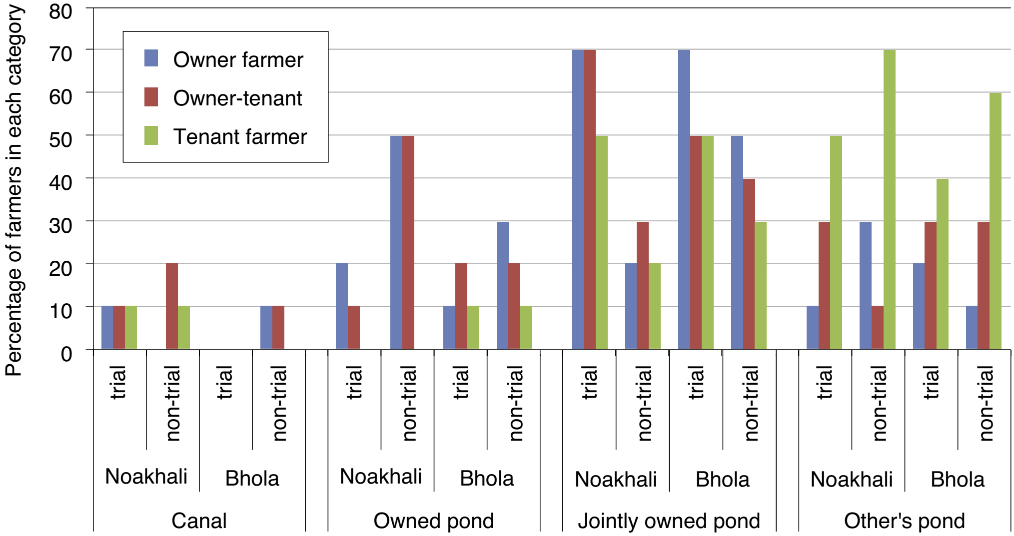


Figure 7. Natural capital: where farmers got their water (wheat trial and non-trial villages in Noakhali and Bhola compared)

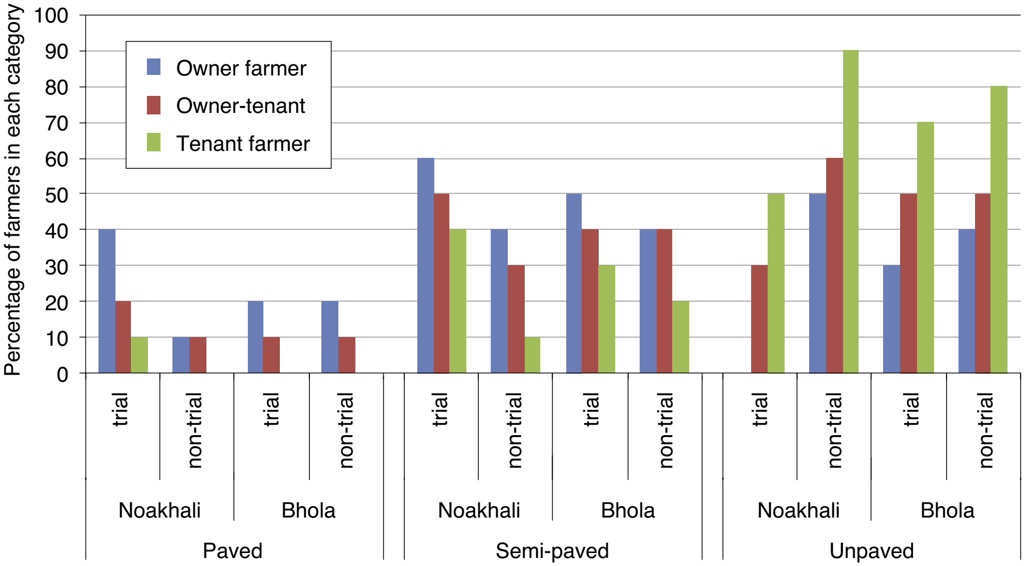


Figure 8. Physical capital: the houses farmers live in (wheat trial and non-trial villages in Noakhali and Bhola compared)

tillers and threshers. Less that 1% of farmers in both villages in both districts owned these machines. Normally they hired them from other farmers.

Trends and shocks

High population density and positive population growth exert considerable and increased pressures on the already intensively used natural resource base. Natural calamities (drought, salinity, excess rain, monsoonal flooding, tidal flooding, cyclones and disease) caused occasional shocks with widespread impact in the communities surveyed. In addition, individual households were subjected to the range of individual and social shocks that typically affect the rural poor (accidents, sudden illness and loss of access rights), with immediate effects on the livelihood viability of the individuals and households concerned.

Farmers' livelihood strategies

The ownership of, or access to, different levels and combinations of different assets or forms of capital determines the livelihood of rural people and directs their life strategies.

The data collected in the current project showed that more than half of the household members in all villages were involved in agriculture and the proportion exceeded 70% in the non-trial village in Bhola (Figure 9). Other occupations were distributed in no clear pattern among villages, although commercial and transport featured and 5–8% of the farmers worked as agricultural labourers for others. A significant percentage (16%) of household heads in the non-trial village in Bhola reported they were a service holder.

Household income is crucial for rural households as they have few savings and limited access to loans. The farmers of the trial villages earned marginally more than non-trial villages while the owner farmers and owner-tenant farmers in Noakhali had more income than their equivalents in Bhola. In all cases, the ranking for farmers' income was owner > owner-tenant > tenant (Figure 10).

Farmers' preferred livelihood options

Choices

Around 50% of farmers actually had agriculture as their livelihood preference and if it was not their first preference it was their second (Figure 11). So, particularly in Noakhali, farmers were happy to be farmers. In both trial and non-trial villages there was interest in employment in transport, or rickshaw pulling, mainly for transporting agricultural goods or people, and in commercial activities associated with agriculture. Interest in commercial activities was high in the trial village in Bhola (31%) mainly because it is located close to the centre of upazila headquarters where there

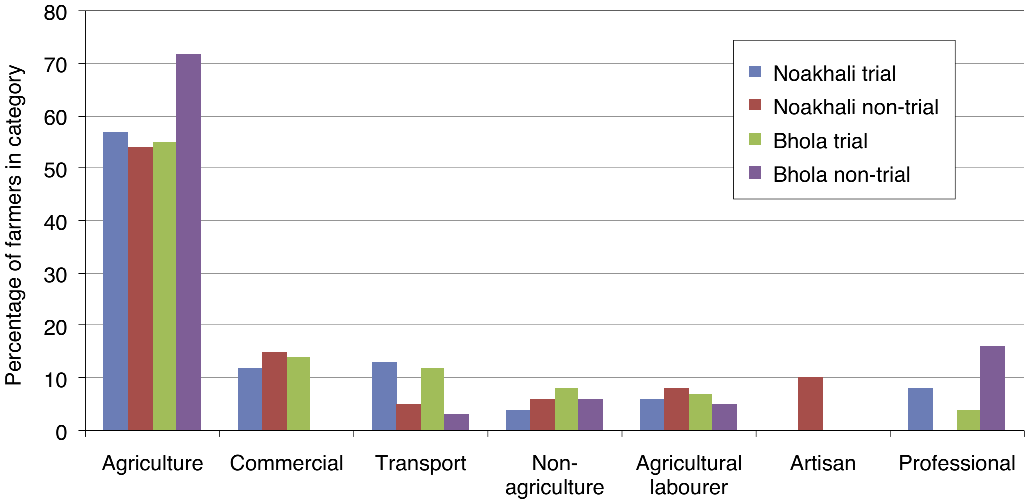


Figure 9. The main occupation of the household head (wheat trial and non-trial villages in Noakhali and Bhola compared)

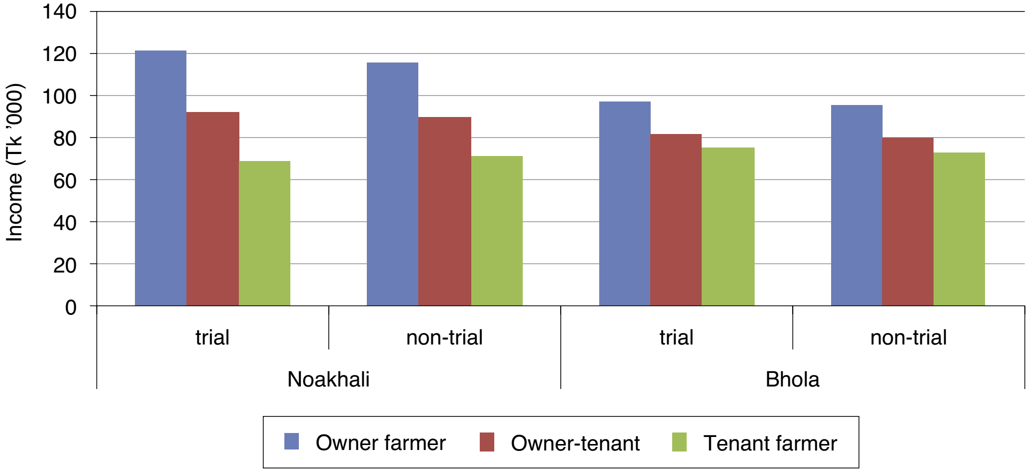


Figure 10. Household income (wheat trial and non-trial villages in Noakhali and Bhola compared)

are many opportunities. Similarly, in the trial village in Noakhali 33% of farmers expressed their interest in fisheries and livestock; that village had easy access to water. The non-trial village, which is short of water, had few farmers interested in fish (9%).

Less than 10% of respondents in Bhola were interested in working in fisheries and livestock. In the non-trial village most people preferred agriculture (>70%), probably because the village is in a remote area with lands that can be cultivated. Non-agricultural activities are their second preference (36% of respondents) followed by a 26% preference for commercial activities.

Limitations of choices

The respondents also identified the positives and negatives of livelihoods to explain their final choices. Two issues were important. They first assessed the opportunities presented by the livelihood and then the security offered. They emphasised the following issues:

Food security/household consumption

They chose those options that ensure their food security, firstly for their main staple, rice, which they eat every day. The respondents who work as agricultural labourers or in transport have a daily income if they are able to work, so they can meet daily food requirements through this income. Similarly, the respondents who had fisheries and livestock met their demand for household food.

Income security

Income security was another vital concern for the respondents. They preferred commercial activities because that ensured a reliable income as well as being an extra income source outside agriculture. Agricultural labour and transport workers noted that if they are able to work they are able to ensure daily income, which provides daily food security. In addition, professionals have a fixed income for the month or the year, which helps them to lead their lives in a planned way. In agriculture, fisheries and livestock, the more wealthy farmers reported that they were able to make profits from these options.

Social interaction/status

In choosing livelihood options, people were also concerned about their social status and social relationships. The respondents who were engaged in professional or commercial activities reported that they have higher social status than others. Additionally, these options create more chances to interact with people who help them find new opportunities in their lives. Professionals and transport workers have fixed and daily income so they feel that they are self-dependent and can lead their lives their own way.

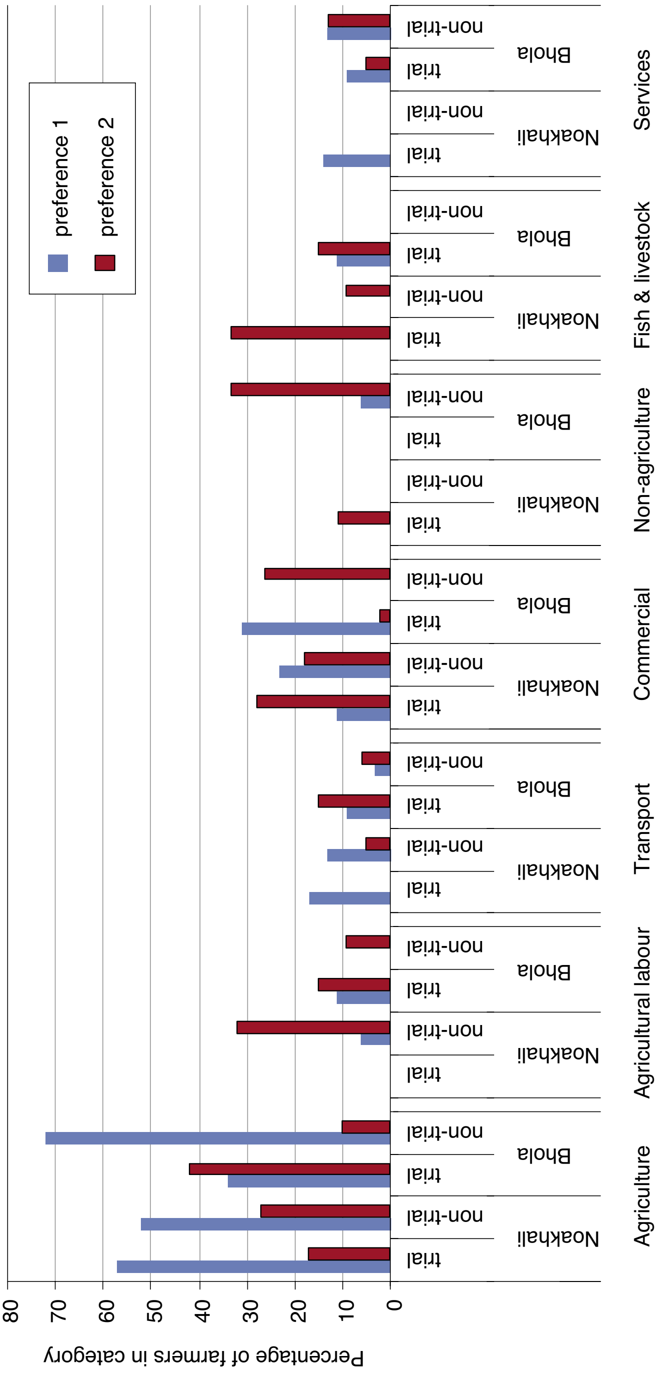


Figure 11. Farmer preferences for their livelihood (wheat trial and non-trial villages in Noakhali and Bhola compared)

Limitations of preferred livelihood options

Low profit

In agriculture, the respondents pointed out that the input costs of agriculture, such as for fertiliser, pesticide, seed and irrigation as well as for labour, have increased and continue to rise. As a result they have declining profits. On the other hand, the respondents who were engaged in fisheries and livestock and commercial activities reported that they did not have enough capital for investment. They showed that large-scale investments returned more profit. Those who are poor have a shortage of capital so cannot invest.

Risk

The respondents faced risks in almost all their livelihood options but they are varied in nature. Agriculture, fisheries and livestock have risks due to natural disasters, diseases and pests. Those involved in commercial activities may lose their invested money. Transport workers have very laborious work and they may have accidents, resulting in injury and sickness and possibly an inability to continue in that work. Agricultural labourers pointed out that they become unemployed in lean seasons. Professional workers explained that they do not have the opportunity to do their preferred work within their village so have to live elsewhere. As a result, they cannot maintain close family ties, leading to loneliness and mental stress.

Workload

Excessive workload was identified as a downside for most of the livelihood options. Within these options, agricultural labour and transport workers considered their work extremely laborious.

Lack of respect

Agricultural labour and transport workers reported that they get less respect than others. Generally they are landless people and do not have money to invest in business work.

Choice of Rabi crops

This topic is introduced in Chapter 1.2 (this volume) and the findings are summarised here.

In Noakhali, where adequate water is available (the trial village), boro rice is the choice of almost all farmers. Farmers also cultivated wheat and vegetables but most of them stated that these are their second preference. In the non-trial village where water is scarce, no crop preferences dominated. Farmers were comfortable with a range of low-water-use crops like sweetpotato, chilli, pulses, vegetables and peanut in that order of preference. Diversification meant security. Pulses (31% and 23%), chilli (19% and 15%), vegetables (15% and 0%) and peanut (12% and 19%) were identified as second and third crop preferences, respectively.

In Bhola, chilli was the preferred Rabi crop (37%) in the trial village because the production cost and initial investment are very low but the yield is high and profitable. Wheat followed chilli, as wheat breads were commonly eaten and so ensure food security. Potato is a preferred Rabi crop for the same reason as that of chilli. Boro was not of interest because of water limitations and production costs. Chilli also comes first in the second preferences of the respondents (21%), along with pulses.

Issues while choosing crops for cultivation

Food security/household consumption

This is one of the main reasons for cultivating a crop. In the Noakhali trial village, 90% of the farmers preferred boro rice and all of them reported that this crop assured their food security. In Bhola, because food preferences lean somewhat towards wheat, that provides some food security so wheat ranks more highly. Other crops like vegetables, chilli and pulses are used for daily household consumption and the remainder is sold.

Profit

Concern about profit comes after food security. In the wheat trial villages, farmers reported that they preferred wheat and vegetables as they are profitable. In the non-trial village, as their crops did not ensure food security, they preferred those crops that gave them more profit with low investment. For example, pulses have low input cost and provide good profit.

High market demand

Farmers are concerned about market demand so prefer crops that sell well throughout the year. Most of the farmers are poor so they wanted to cultivate those crops that they can sell whenever they need money. Farmers reported there is a lower chance of prices falling for high-market-demand crops, so they have a low risk of loss.

Traditional practices

The choice of crops to grow is also influenced by their traditional practices. Respondents explained that they preferred those crops that they cultivated traditionally because they are familiar with the practices. They did not need any technical advice from others to grow them. Furthermore, they preserved the seed for planting the following season, so knew the quality of that seed, whether it be good or bad. If they grew non-traditional crops, on their first experience they could not be sure of the quality of the seed they would buy. If it was possibly bad, their risk was high.

Conclusion

This chapter outlines the existing livelihoods of farmers and debates some of their future options. It shows that farmers who own their land are most wealthy in all forms of capital while tenant farmers, although earning up to 70% of owners, were least capable in their livelihoods because of need for loans, low social status in the community so least able to call on assistance, and least able to access lands for increased production. Farmers generally grew crops that first provided them with food security and after that was met they diversified into considerations of profit. The balance of the two depended on their overall capital. But a combination of the two equated with more certainty of livelihood. Crop choices depended on these things but also on natural capital. When water was plentiful, boro was an obvious choice; when it was limited, other crops moved up the preference scale. As climates change and natural capitals change with them, crop choices will also change to ensure the farmers maintain their livelihoods. But the owner farmers with their greater capital flexibility will lead the changes. There are some indications that less wealthy farmers may be diversifying into other ways of collecting capital to supplement their basic farming activities.

Acknowledgments

The authors are deeply grateful to the farmers and landless labourers, both men and women, of the four study villages in Bhola and Noakhali districts for sharing their opinions and livelihood details. We are also grateful to Dr Rohan Nelson who initiated this socioeconomic component of the ACIAR-funded project. Special thanks to Mr Jahangir Kabir and Ms Himu Bain for their prime contribution in collecting and processing the field data.

References

BBS (Bangladesh Bureau of Statistics) 2006. Statistical yearbook of Bangladesh. Government of the People's Republic of Bangladesh: Dhaka.

Carney D. 1998. Implementing the sustainable livelihoods approach. Pp. 8–9 in 'Sustainable rural livelihoods: what contribution can we make?' ed. by D. Carney. Department for International Development: London.

Cramb R. and Purcell T. 2001. How to monitor and evaluate impacts of participatory research projects: a case study of the forages for smallholders project. CIAT Working Document No. 185, Centro Internacional de Agricultura Tropical: Cali.

Ellis F. 2000. Rural livelihood diversity in developing countries. Oxford University Press: Oxford.

Ellis F. and Freeman H. 2005. Comparative evidence from four African countries. Pp. 31–47 in 'Rural livelihoods and poverty reduction policies', ed. by F. Ellis and H. Freeman. Routledge: London.

Khan I.A. and Seeley J. 2005. Making a living: the livelihoods of the rural poor in Bangladesh. The University Press Limited: Dhaka.

Krishna A. 1999. Creating and harnessing social capital. Pp. 71–93 in 'Social capital: a multifaceted perspective', ed. by P. Dasgupta and I. Serageldin. The World Bank: Washington, DC.

Narayan D., Chambers R., Shah M.K. and Petesch P. 2000. Voices of the poor: crying out for change. Published for the World Bank, Oxford University Press: New York.

Nelson R. and Khan I.A. 2007. Exploring the socioeconomic dimensions of Rabi season cropping in Bangladesh: preliminary findings and proposal for project variation. Australian Centre for International Agricultural Research (ACIAR) Project SMCN/2005/146: Expanding the area for Rabi-season cropping in southern Bangladesh. ACIAR: Canberra.

Nelson R., Webb T. and Byron I. 2006. Prioritising social and economic information for natural resource management policy. Australian Bureau of Agricultural and Resource Economics/Bureau of Rural Sciences (ABARE/BRS) report to the National Land and Water Resources Audit: Canberra.

Sultana N. 2005. The role of dowry and early marriage in shaping the livelihoods of poor rural women. Pp. 177–192 in 'Making a living: the livelihoods of the rural poor in Bangladesh', ed. by I.A. Khan and J. Seeley. The University Press Limited: Dhaka.

5.2 Impact of intensified Rabi cropping on social dimensions of livelihood

Iqbal Alam Khan and Sharmin Afroz

Abstract

In order to achieve improved food security, agriculture, which is the main livelihood source of rural people, has been gradually modernising in much of Bangladesh. But southern Bangladesh, due mainly to its difficult climatic environment, has largely remained with its well-proven traditional cultivation practices. This paper examines the impact on rural livelihoods, specifically those of owner, owner-tenant and tenant farmers, of the introduction of a new Rabi crop, wheat, into southern Bangladesh. It uses the livelihood framework developed by Ellis (2000), explained in Chapter 5.1 (this volume), as the basis for analysis. It describes the interacting complexity of the rural village structure and how and which components benefit from intensified Rabi-season cropping. Generally, owner farmers benefited most and tenant farmers least, in part because of their initial differences in capital, which influenced their access to loans, education and support from agricultural government agencies. Tenant farmers make up 60–70% of the farming community.

The roles of men and women in farming households changed their dominance from male for land preparation, irrigation and harvesting to female for kitchen-related activities, child rearing and winnowing and related postharvest duties. Other activities were more evenly shared. But the degree of sharing increased from owner households to tenants; tenants were most sharing and included children more in general duties. When it came to who made the decisions, according to surveys of the men, males slightly dominated, although again this was more the case for owners and least for tenant households. And again males dominated in general crop decisions like what crop to grow, when to plant and when to harvest. So when it comes to intensification of Rabi crops, men are the gender that needs to be convinced, although that decision will increase the load on women and children who play a major part in harvesting Rabi crops; men harvest other crops.

Surveys of women put a different slant on how work was allocated between males and females and who made the decisions. Women considered that men overall were half as important in decision-making as they althought they were and that they, as women, were four times as important as men ranked them. Women also considered that most decisions involved at least some sharing, and certainly more sharing than was conceded by men. Women also regarded their extensive work in all categories of farming were duties that were part of their household activities rather than employment.

All farmers had many suggestions as to how new crops should be introduced into communities for there to be successful adoption of the crop into the traditional farming systems. These suggestions, detailed here, ranged from the design and size of on-farm trials and community demonstrations, to restructuring agricultural loans for new crop introductions, training packages and methods of dissemination of information, and local availability of critical infrastructure. They emphasised that whole communities should be targeted with changed farm packages not just a few selected farmers, as scepticism by the traditional majority would quickly extinguish change with its perceived risks.

Introduction

An estimated 800,000 ha of agricultural land remains uncultivated in southern Bangladesh during the dry (Rabi) season. This is primarily because irrigation resources are very limited due to the general unsuitability of the area for deep and shallow tube wells. Other constraints have added to the perception that the area is too risky for wheat in a rice–wheat rotation because: sowing of wheat is delayed well beyond the date considered optimal in the north because local Kharif rice varieties can be long duration; later drainage of monsoon waters can delay the start of cultivation; and cultivation takes time with bullock-drawn ploughs. Additionally, the area is hotter than the north, with a shorter potential season, and some of the soils are saline.

Recently these southern lands have been reassessed for cultivation of wheat because some of the constraints have been overcome. By applying techniques to shorten the time between rice harvest and wheat planting and by using surface-stored water for limited irrigation, 3 years of on-farm trials at five sites showed average wheat yields exceeding 2.5 t/ha are possible, even without irrigation in some locations. Trials were funded by the Food and Agriculture Organization of the United Nations (FAO) (2003–05) and the Australian Centre for International Agricultural Research (ACIAR) (2005–06) and done collaboratively with the Bangladesh Agricultural Research Institute, Wheat Research Centre (BARI-WRC), the International Maize and Wheat Improvement Center (CIMMYT), Department of Agricultural Extension (DAE) and On-Farm Research Division (OFRD). Modelling in the ACIAR study, using historical local weather data and the Agricultural Production Systems Simulator (APSIM), indicated that wheat, mungbean and maize can be grown with low-risk, long-term economic feasibility, particularly if surface floodwater, stored over from the Kharif season, is sufficient for one in-crop irrigation. The study estimated that the potential for new wheat production from southern Bangladesh may approach 1 million tonnes (t)/year—average total wheat production for Bangladesh is currently much less than 2 million t/year.

The aim of this project was to improve the livelihoods of farmers in southern Bangladesh by introducing crops, such as wheat, onto currently fallow lands during the post-rice Rabi season. Following the livelihoods framework, introduced in Chapter 5.1 (this volume), which views capital in the categories of human, social, natural, physical and financial, this chapter investigates the impact of intensification of Rabi-season cropping on rural livelihoods. From this point of view, the findings focus on the livelihoods of rural people in the southern coastal belt of Bangladesh, especially those whose livelihood is affected by Rabi-season cropping. It also discusses the separate and joint roles of men and women in farming and, in the light of new cropping sequences including wheat now becoming an option, who makes the decisions about cropping in the households of owner, owner-tenant and tenant farmers.

Impact on capital assets

Generally, a successful Rabi-season crop means more profits. This financial benefit directly influences the magnitude of change in other capital assets. The farmers' experiences of impact of intensified Rabi-season cropping, including wheat, on livelihood is detailed below. The data are all based on farmer surveys done in paired villages in which there was either an ACIAR-funded wheat trial (trial village) or no change to standard Rabi cropping patterns (non-trial village). Such paired villages were surveyed in Noakhali and Bhola districts.

Financial capital

After a good Rabi season, financial capital increased considerably in all villages surveyed. According to farmers, the most significant change was a rise in the ability to store food for a crisis and secondly being able to save money. All three groups of farmers (owners, owner-tenants and tenants) in both districts benefited but it was the owner farmers who generally benefited most and the tenants least in their abilities to store more food and save money (Figure 1). There was no consistent overall evidence that trends in this good season were different in trial villages, with their occasional wheat plots, and non-trial villages, although in Bhola, food storage appeared to increase more in the trial village.

Social capital

All farmer groups in all villages enjoyed an increase in their social life following a successful Rabi cropping season. Only 10–15% of farmers said their social lives did not change. All interacted with their neighbours more and visited relatives, but invariably it was the owner farmers who increased

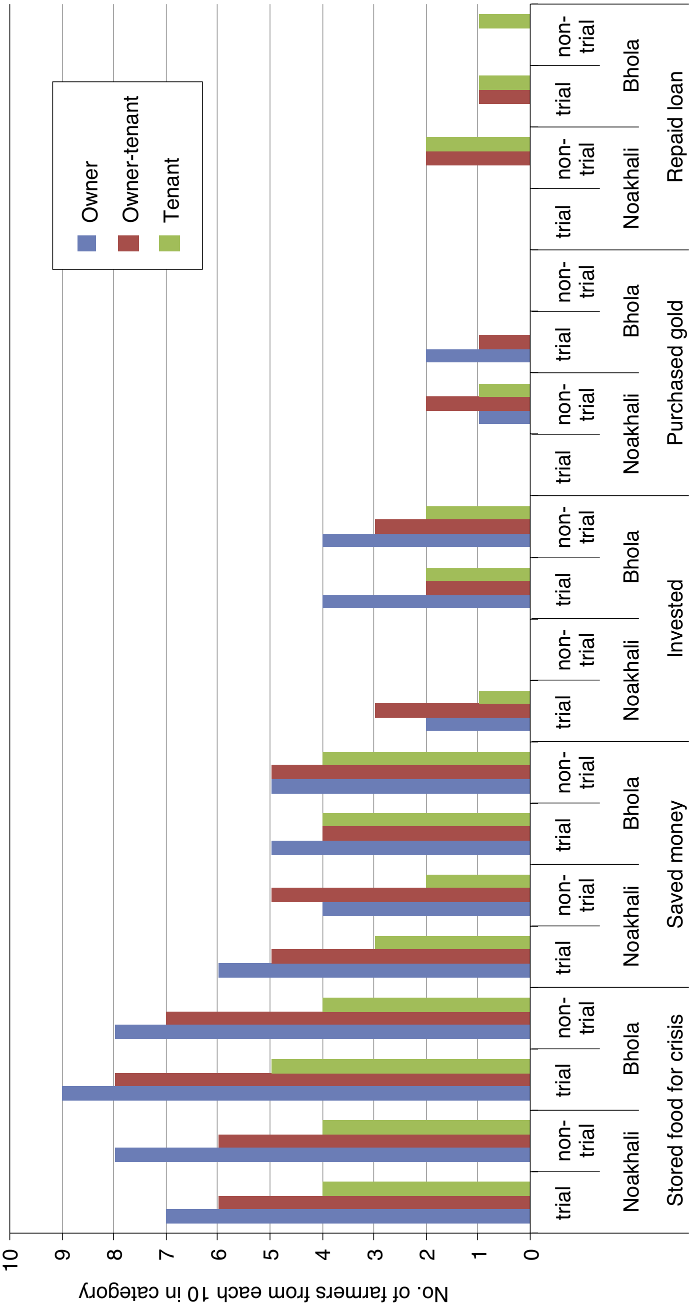


Figure 1. How owner, owner-tenant and tenant farmers used their financial capital after a good Rabi-season crop—farmers were from Noakhali or Bhola and in a village with or without an Australian Centre for International Agricultural Research (ACIAR)-funded wheat trial

their social activities more than the owner-tenant farmers and much more than tenant farmers.

A few owner farmers (20–40%) considered that the good Rabi crop had increased their social status in the community while only half the number of tenant farmers felt that way. There was a small trend for all social indicators to be higher in the trial villages.

Physical capital

Many surveyed farmers in the Noakhali and Bhola villages did not see much change in their physical capital as a result of harvesting a good Rabi crop in a single season (Figure 2). This is because building physical capital is a long-term and continuous process. However, between 40 and 70% of owner farmers did see some change and similarly 10–30% of tenant farmers registered change. In the trial village in Noakhali, 3 of 10 owner farmers bought machines and two purchased land; one owner-tenant farmer purchased machinery (a power tiller) and land; and two tenant farmers repaired their old houses. In the trial village in Bhola, three owner farmers purchased machines, one bought a power tiller and another repaired the house while two others bought land. One tenant farmer also bought land while two fixed their houses. In non-trial villages in both districts, fewer farmers were able to enhance their physical capital although house repair was the most common activity.

Overall it seemed there were benefits of the trials although these were more slanted towards those farmers who already had greater capital.

Human capital

After a good Rabi-season crop, human capital improved considerably in all villages studied. Improvements were more noticeable in trial villages where the biggest effect was on the ability to send children to school, particularly for the owner group—7 of 10 farmers in Noakhali and 9 of 10 farmers in Bhola district. But all farmer categories and villages did benefit somewhat in increased schooling. Tenant farmers in all groups benefited most from the good season by being able to work hard instead of being underemployed. Owners and owner-tenants claimed they increased their knowledge from the good season and there was evidence that many learnt from the field days in the trial village in Bhola. Tenant farmers in non-trial villages gathered little knowledge. Despite differences between categories, there were few farmers who did not have some improvement in their human capital resulting from a good Rabi season (Figure 3).

Overall impact on financial, social, physical and human capitals

Figures 4 and 5 describe the overall impact on livelihood capital as a result of a successful Rabi cropping season. The findings show that the impact on livelihood capital is more encouraging in Bhola district as the farmers of Bhola are more used to cultivating wheat. This in turn enables them to gain more financial benefit, which they are able to invest in other forms of livelihood capital. Similarly the graphs show that the farmers from the trial village gained more positive impact in their livelihood capital than those from the non-trial village. The trial village attracted more extension services. They got trial plots as well as free seed, fertiliser and technical assistance. On the other hand, due to the project's chance selection of a trial village close to upazila headquarters, that village enjoyed more facilities for their farming activities; the non-trial village was less central.

Among the three categories of farmers, the owner farmers achieved most and tenants least in all types of livelihood capital from the good season. The owners reported that as they were able to get more financial profit, they were able to use this capital to increase other forms of capital, such as social capital. With their profits the farmers were able to buy gifts for their family and relatives. They invited their relatives to their house and visited them more regularly after a successful Rabi-season crop. And they used financial capital to increase human capital by, for example, spending more on children's education.

By contrast, the tenant farmers reported that because they have to share a big proportion of their crop with the land owner, they accumulate less financial profit so are unable to increase other forms of livelihood capital. Tenants had the least increase of physical capital compared to owner and owner-tenant groups. Tenant farmers have few savings and as a result they are dependent on loans for their cropping activities. Some of their profit is also used to repay loans. Farmers in all categories referred to their low increase in physical capital because it needs a big investment. In the course of one year, successful Rabi farmers were not able to save sufficient money to be able to invest in physical capital; they needed to have several good cropping seasons.

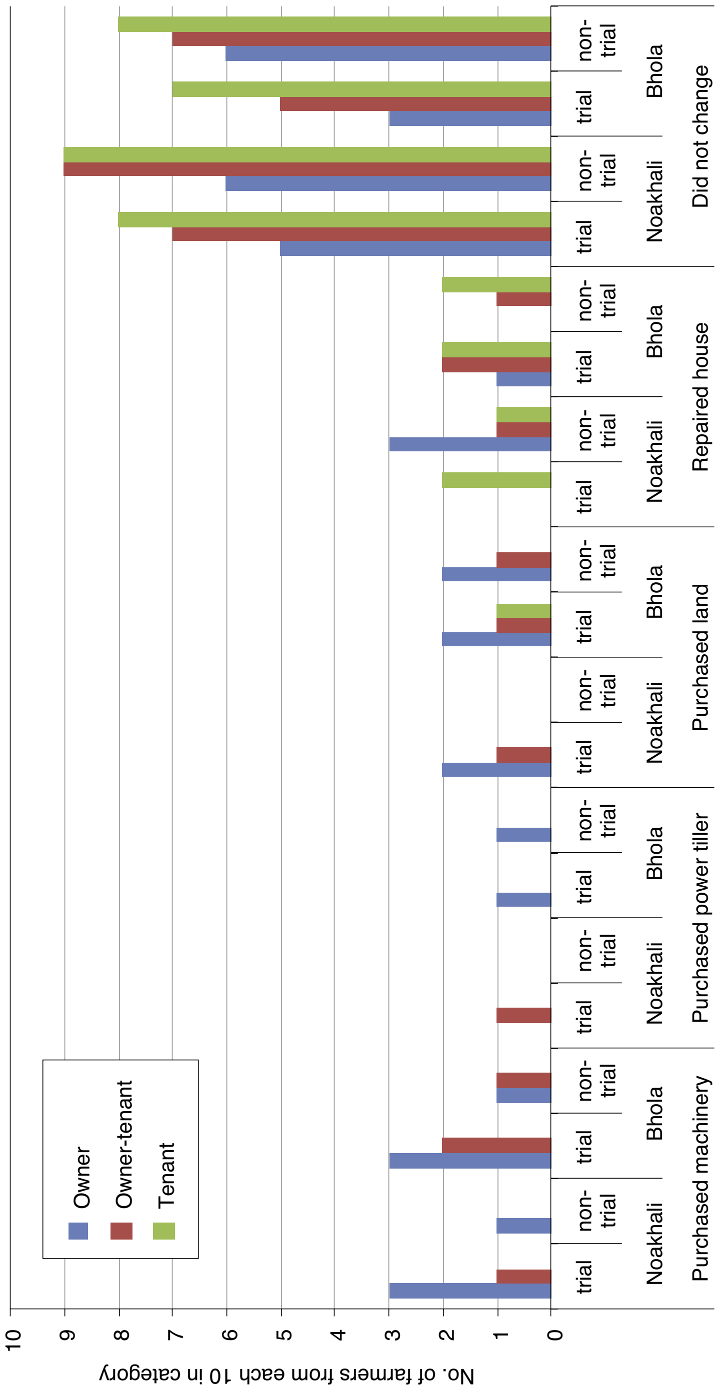


Figure 2. How a good Rabi-season harvest affected farmers' physical capital—Noakhali and Bhola farmers in a village with or without a wheat trial

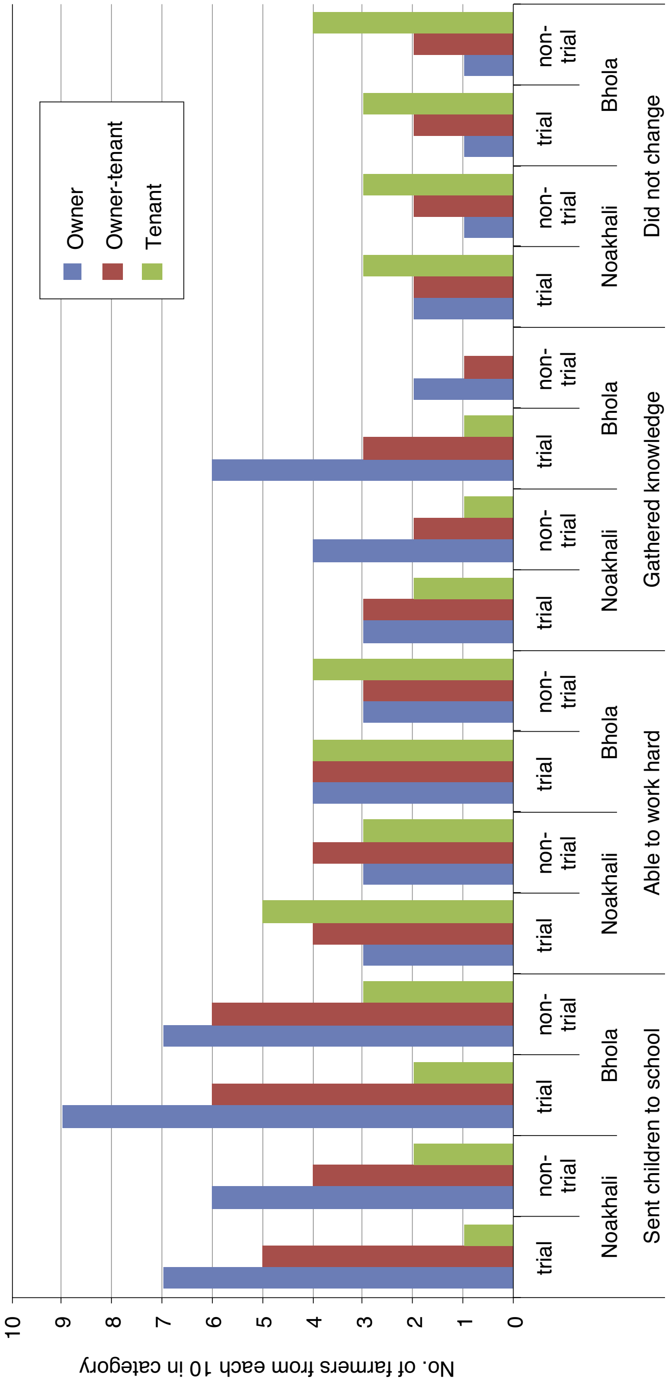


Figure 3. How a good Rabi-season harvest changed human capital—Noakhali and Bhola farmers in a village with or without a wheat trial

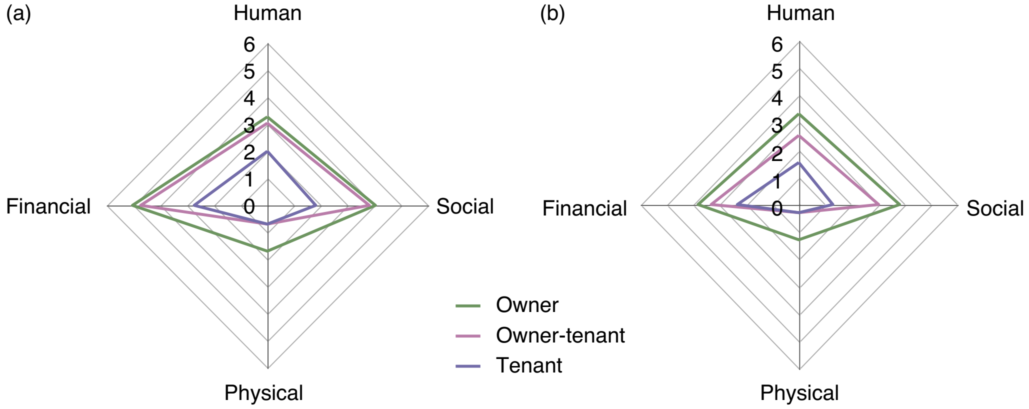


Figure 4. Overall livelihood impact on capitals in (a) trial and (b) non-trial villages in Noakhali district

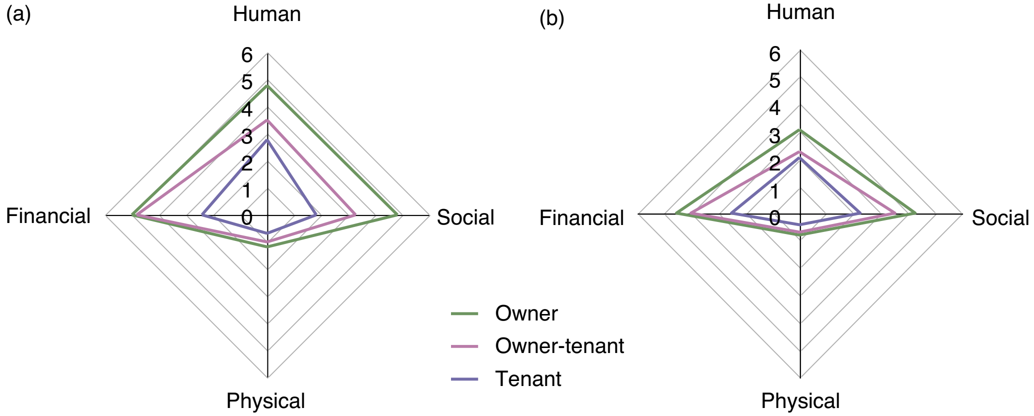


Figure 5. Overall livelihood impact on capitals in (a) trial and (b) non-trial villages in Bhola district

Use of capital assets in strategising livelihoods

The livelihoods capital status of these communities indicates that the human capital is an important trigger for economic and social wellbeing (Figures 4 and 5). In southern Bangladesh the data indicate weak human capital in terms of formal education and technical training. Such weak human capital presents a challenge to technical interventions that demand high-quality (educated) labour.

The social capital in rural livelihoods is developed through informal networks and connectedness (vertical patron/client linkages or horizontal linkages between individuals with shared interest). Social capital is particularly important for poor and vulnerable people or households, for whom it can provide an informal safety net for coping with shocks, or enable them to compensate for a lack of other types of capital. In the rural situation, those people who participate less in formal groups find it more difficult to achieve their livelihood objectives.

Financial capital is one crucial component of household livelihood assets; it can be used for direct achievement of livelihoods outcomes, or it can be converted into other forms of capital. But it is least available in a rural economy. Building financial capital in remote communities is constrained by limited opportunities to access financial services. The diversification of income sources is a survival strategy in rural areas that have few opportunities. Natural capital is defined as natural stocks from which resources and services for livelihoods are derived and is an essential capital for the farming economy.

The livelihood strategies within the rural economy in the Rabi season are dependent on the livelihood capitals that are mainly associated with agriculture; more than 50% of respondents in the current study had agriculture as their main occupation. Traditionally, rural livelihood strategies have been viewed as being solely based around agricultural production. However, there is increasing recognition that rural people are diversifying their strategy portfolios in response to changing needs or to control risk. Further, this research has suggested that beneath this diversity and complexity there is a long-term trend away from agriculture and towards non-farm activities.

Owner and owner-tenant farmers are in a relatively secure position due to having different types of livelihood capitals support. The tenant farmers had a 33% lower average income than owners (Figure 6), which is consistent with their generally marginalised socioeconomic status, and consequently had fewer opportunities for economic activity. The crop preference in the communities depends on different types of issues like food security, profitability, extension services, traditional practice and risks.

The present study of impact of intensification of farm production, i.e. the effects of a good Rabi season, on different categories of farmers shows that the livelihoods capital assets are strongly interlinked. That is, any change in one capital asset directly influences the magnitude of change in other capitals. By extension, the variability in different capitals governs the livelihood options for farmers in rural areas. For example, investment in child education will upgrade the human capital within the household. Equally, the availability of financial capital is directly related to the capacity of a household to cope with or mitigate risks and shocks. However, investments of savings or credit in productive activities help to improve overall wellbeing. As well, social capital can help increase people's incomes and rates of savings by improving the efficiency of economic relations. Social networks can also facilitate the development and sharing of innovation and new knowledge leading to increased human capital.

A successful Rabi-season crop leads to an improvement in a whole range of different livelihood capitals in which the owner farmers benefited most and tenants least and the trial villages overall benefited more than villages without trials. The owner has more livelihood capitals support of their own as well as receiving more agricultural extension support by virtue of their position in the community. The trial villages get more extension services associated with the presence of trials, and due to their fortuitous more central geographical locations. In this context, building the livelihoods capacity of an area through introducing a new crop such as wheat should be based on holistic programs that encompass livelihood support and poverty mitigation and alleviation strategies.

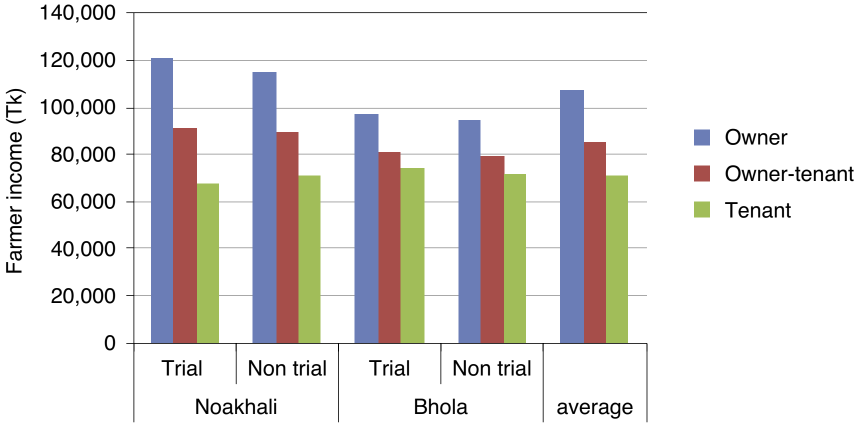


Figure 6. Annual income of owner, owner-tenant and tenant farmers in Noakhali and Bhola trial and non-trial villages

The farmers made many suggestions as to how this might be done that will be presented later. But first, holistic programs for change should understand the roles that women and men, together and separately, play in farming. Their needs may be very different.

The roles of women and men and who makes decisions

Some aspects of gender in farming were discussed in Chapter 1.3 (this volume) but the examples were restricted to Noakhali. Here the Noakhali and Bhola villages are compared. Because the patterns of men's and women's roles were generally similar between trial and non-trial villages, their averaged data are presented here. The first set of responses, illustrated in Figures 7 and 8, are those of the 'farmers' in three categories, owner farmers, owner-tenants and tenants, who were predominantly men. Later, Figure 11 illustrates the differing opinions of the men and women in the two Bhola villages as to who made decisions.

Gender roles in farm and household activities

There are some clear patterns (Figure 7). Men are solely in control when it comes to preparing the land for a crop. They are almost exclusively in control of irrigation although male tenant farmers in Bhola shared hand watering with the women and children. So, where machinery might be involved, men were boss. Women are solely in charge of kitchen-related activities and dominated child rearing, although children helped somewhat in this as did men. Women also were key in winnowing and seed handling (Figure 9).

The other clear pattern was that there was a progressive increase in sharing the duties from owner to owner-tenant to tenants and the tenants tended to use their children most, maybe because women were also present. There were apparently no activities where men and children worked together in the absence of women, except for possibly a few cases involving sowing and transplanting. There was a tendency for there to be more sharing in the non-core roles in Noakhali than on Bhola. So while males dominated the animal care activity on Bhola it was very much shared in Noakhali. But overall, men owner farmers did most of the crop production alone while men tenant farmers shared roles.

An interesting finding from the point of view of intensifying Rabi crop production was that harvesting of the non-Rabi crops was a male activity, but harvesting in Rabi was very much shared between men, woman and children. Figure 10 shows children starting to harvest a wheat crop without adult supervision.

Which gender made the decisions in the farming households?

All important decisions were shared between men and women, although on balance men dominated (Figure 8). As with activity sharing, tenants were more likely to share their decision-making within their family than were owner farmers. This is strongly reflected in who chose the crops to grow. For both Noakhali and Bhola, owner farmers 70:30 male:female made that decision whereas for tenants the ratio fell to 60:40. Similar patterns held for when to plant, when to harvest and when to hire labour.

Females played a strong decision-making role when it came to the marriage of their children and this was more so in Bhola than in Noakhali, although marginally less so for tenant farmers. Buying and selling property and decisions on borrowing money were shared equally.

From the viewpoint of intensification of Rabi cropping and changing rotations, it appears that it is men who should be convinced, although according to the following surveys, women would probably disagree with that conclusion.

What women said about their work roles

The foregoing discussion of the roles of men and women in the various farming households was based mainly on data collected from interviews with males so might be slanted towards their viewpoint. Additional data were collected from the females with similar questions being asked. Of the farmer spouses, 80–90% were fully engaged in agriculture with only a few being employed in other activities like handicrafts, tailoring, agricultural labour for hire, banking and a small number who were too old to work. In overview they considered that they did a higher proportion of the work than might be reported by the males; the male view is what the social system likes to believe. They were able to conceptually generalise work roles by the sexes into men being involved in the larger scale paid activities away from the household, like broad-scale land preparation and broad-scale harvesting, while women did the many smaller unpaid jobs that could be done near the dwellings. These included the postharvest

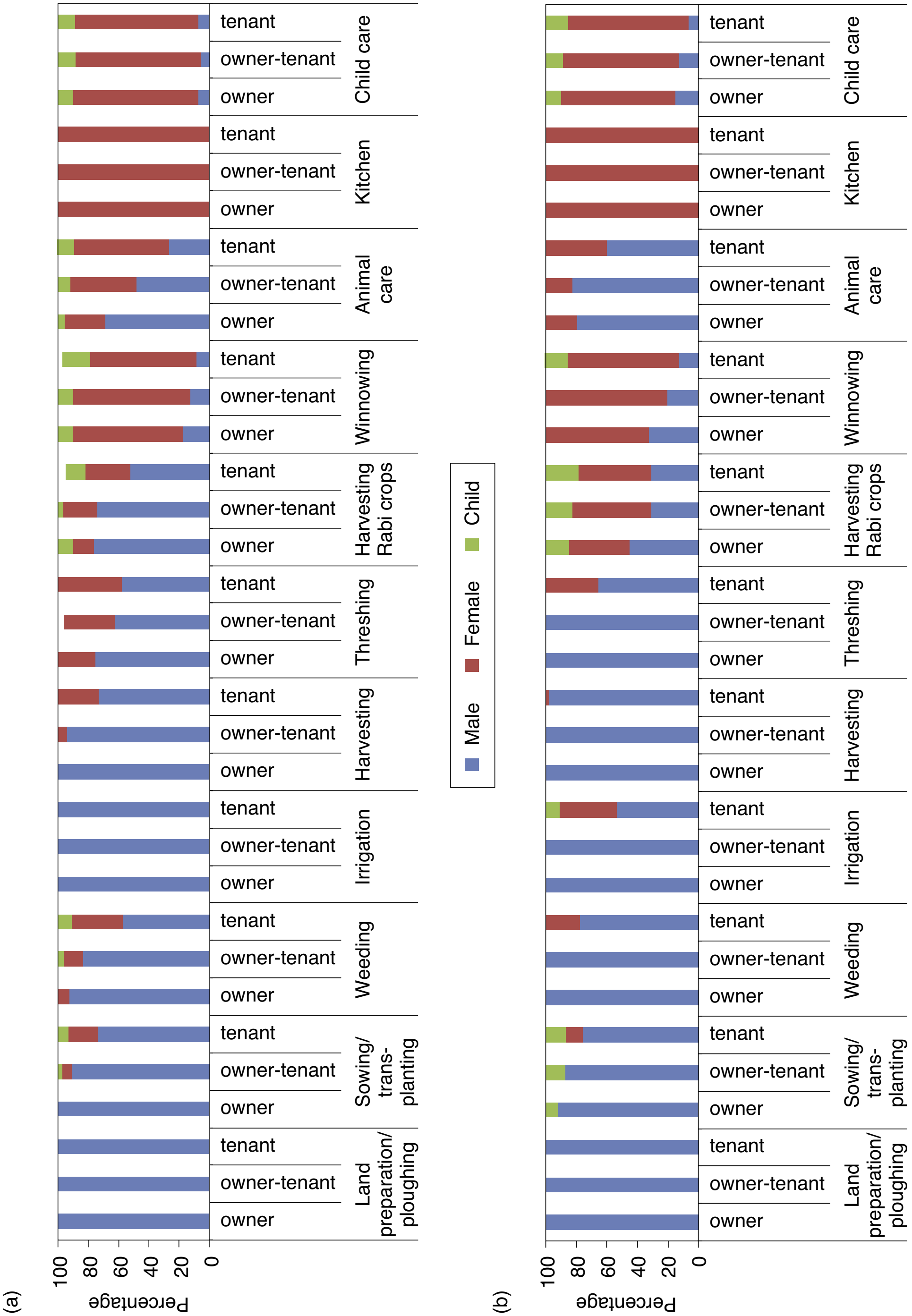


Figure 7. Roles of men and women in farm and household activities in owner, owner-tenant and tenant households in (a) Noakhali and (b) Bhola villages

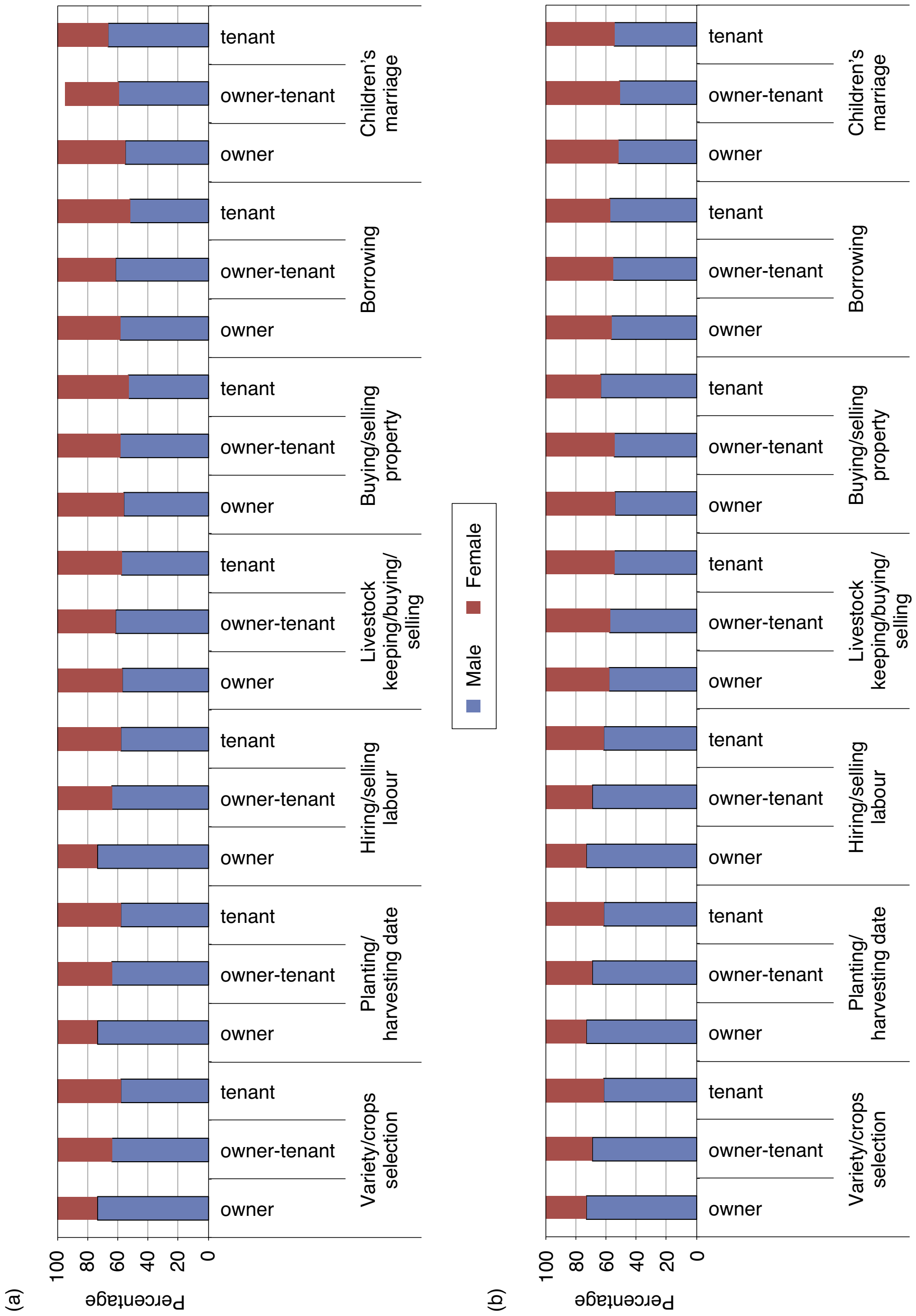


Figure 8. Balance of decision-making between men and women in farm and household activities in owner, owner-tenant and tenant households in Noakhali (a) and Bhola (b) villages—values of 50 for red and blue mean decisions are shared equally between men and women, more blue means more male 'control'

Figure 9. Winnowing is women's work (Photo: H.M. Rawson)

activities that could be done at home, the growing of vegetables primarily, although not exclusively, for household consumption, that could be done near the home and care of small farm animals and poultry, again done near the home. Men looked after the larger plantations of vegetables that were not near the homestead cluster.

Women, although they do engage in many forms of work, generally do not regard that work as their occupation but rather as part of their household activity. So all postharvest activities like grain boiling and drying, raising crop seedlings for later transplanting, tree planting, fish production and livestock production and care are not regarded as occupations but as necessary household chores. However, some of these chores were shared. For example, food bought from the market for livestock was the man's role, as was washing of the cattle (Figure 11). Similarly, some vegetable production activities were shared.

Men and women's views of each other's contribution to making decisions

Men althought they had the major role in decision-making, at least as great as that of their women, in all areas except the activities described above as being exclusively women's roles (Figure 12). Interestingly, women considered that men overall were half as important in decision-making as they thought they were and that they, as women, were four times as important as men ranked them. Women also considered that most decisions involved at least some sharing, and certainly more sharing than was conceded by men. For example, on selecting crops to grow, women said the decision was 55% shared while men ranked that at 16% shared. With regard to marketing, buying and selling, the actual presence at the market was the man's job and so choice of activities at point of sale/purchase was exclusively male. However, the woman knew what was needed by the household, which she ran, so she instructed the male what to purchase and what to sell to keep the household commodities and budget in balance. He was her agent. Similarly, with regard to land transactions and loans, the man did the action while the woman knew and communicated to him what was required, so again the male was, in part, her agent.

Remarkably, opinions shown in Figure 12 were more or less the same between trial and non-trial villages and within a 2% range in all categories when averages of trial and non-trial villages were compared for Noakhali and Bhola. Noakhali villages are superficially very different sociologically, but not by this measure.

Figure 10. Children harvesting their wheat (grown next to chilli) in Noakhali, Char Bagga, 2004 (Photo: H.M. Rawson)

Figure 11. Cow washing, a role for men (Photo: H.M. Rawson)

At first sight of the data, it appears that either women were overplaying their importance or men were vastly overplaying their power in the household (and see Chapter 1.3, this volume, for other opinions from women). However, because men were the active agents representing the household in the community, they were presumably scoring their decision-making role on this level whereas women were scoring roles from their perspective within the household.

Suggestions from farmers for expediting the adoption of wheat

The farmers pointed out that under the ACIAR-funded project, trial farmers got free seed, fertiliser, irrigation, training and technical advice whereas non-trial farmers got only technical advice, and that was not regular. Farmers also commented that although including wheat into their traditional crop rotations is financially beneficial they did not adopt it due to the lack of other required livelihood capital support. They identified the regular availability of extension services as being a critical first requirement for communities to adopt wheat.

Enhancing human capital

Intensive training on wheat cultivation

Training is an important component towards adopting wheat because wheat is a new crop for many areas of Bhola and Noakhali. Two or three trial farmers were trained to grow wheat in every village which is a negligible percentage of total households; there are about 1,000–1,200 households in each village. With these large numbers it is impossible for two to three trial farmers to teach proper methods of wheat cultivation to all farmers in the village. So if 20–25% of farmers of the village are trained (200 farmers) then it will be very effective for them to take up wheat cultivation.

Special training on seed preservation

Correct seed preservation is essential if a crop is to be grown from last year's seeds. Most farmers do not know how to preserve wheat seed so should be trained. If the farmers do not have their own seed for planting, they regard the cost and inconvenience of buying it too big a burden and not worth the investment. With their own preserved seed available they will be likely to cultivate wheat.

Include tenant farmer and women in training programs

Most farmers in a village (60–70%) are tenant farmers and they reported that they are not included in training programs. The broad adoption of any new crop is dependent on targeting this largest group of farmers, not just the more wealthy. In addition, women are engaged in crop cultivation, particularly in postharvest activities like seed preservation. For this reason, extension officers should include women in training sessions. In addition, if they arrange training sessions within the village, women can easily participate.

Practical training for wheat cultivation

The trial farmers mentioned that after getting training, if they do not get the opportunity to do the activities themselves, they forget the training after some months and certainly by the following season. Trial farmers reported that DAE officers did all the hands-on work in the trial plots. As a result they have forgotten many things about cultivation practices like how much fertiliser to apply. They said that training sessions must have hands-on practical classes, giving farmers the opportunity to work in a trial plot under the supervision of DAE personnel. This will raise the confidence of the farmers about cultivating their own new crop the next year.

Provide training handbook

Farmers mentioned that sometimes they forgot what they had learned in the training, e.g. process of seed preservation, recommended dose of fertiliser. So it will be more effective to them if trainers provide them, during training, with a training handbook with instructions and pictures about wheat cultivation.

Provide technical advice for every type of farmer

Farmers often complained that extension field workers did not provide equal technical services to all types of farmers. Tenant farmers particularly were under-serviced. Extension officers mainly provided services to those farmers who had good relations with them or to political people or landowner farmers. Technical advice for all types of farmers should be provided.

Arrange field days for all types of farmers

Farmers complained that only trial and selected other farmers are invited to field days. Many farmers do not know what field days are, so they

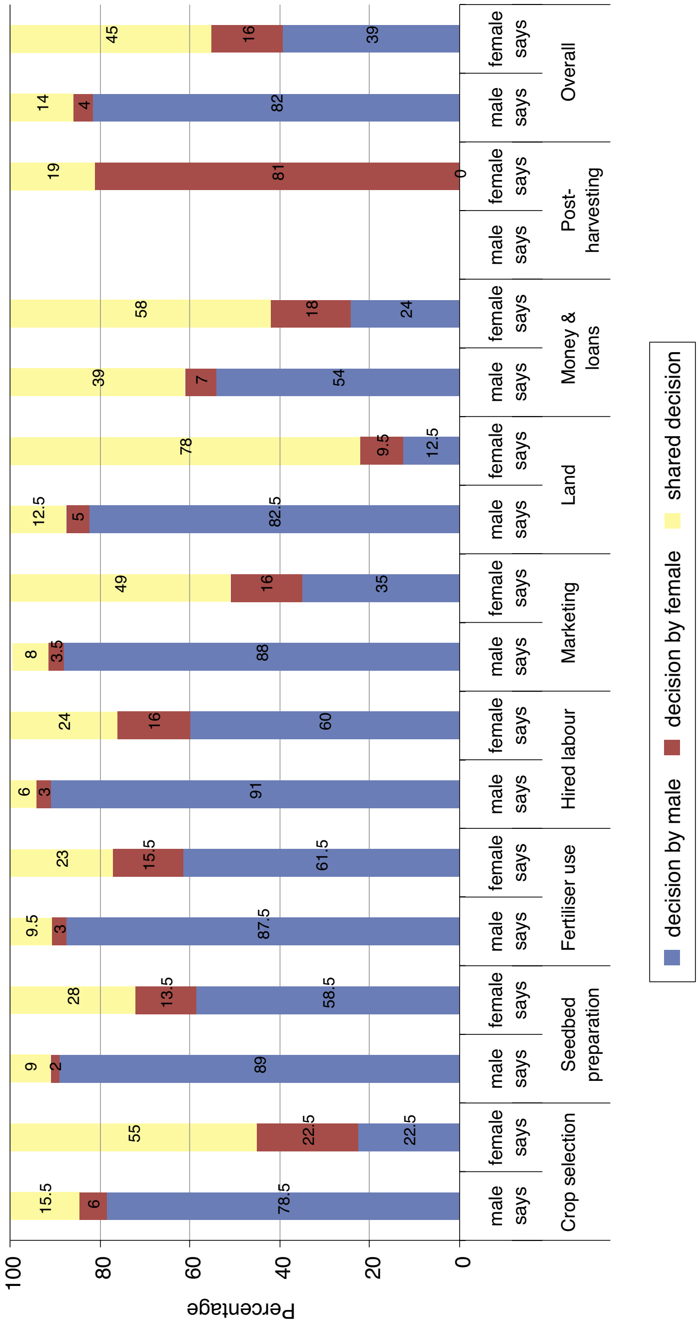


Figure 12. Percentage of decisions about different activities that are made by men and women in the farming community according to the men and according to the women who were interviewed separately. These data are averages of trial and non-trial villages in Bhola. The patterns were very similar in Noakhali.

cannot realise how important they are as a channel of information about wheat cultivation. So to adopt wheat widely, all farmers in the vicinity should be encouraged to attend field days.

Enhancing physical capital

A greater number of trial plots

As discussed above, only two or three farmers got a trial plot, training and other technical support in each village of about 1,000–1,200 households—a very small proportion. As a result, most farmers are not encouraged to grow wheat, due to lack of information. A large number of trial plots should be supported in each village so many farmers become involved and knowledgable about wheat cultivation and will be interested to grow wheat.

Trial plots should be big, as then they will attract many farmers

Trial farmers said that the small size of plots (25 decimals; 1,000 m^2) does not attract the attention of all farmers of the village. Big plots of 50–75 decimals would be more visually attractive to villagers who would then be more encouraged to grow wheat.

Ensure trial plots for tenant farmers

Generally, tenant farmers do not get a trial plot. The extension officer and others think that tenant farmers do not have the ability to work on trial plots. They think they will consume their seed due to poverty or cannot apply inputs at the optimal time due to less education. But most, about 50% of farmers of the village, are tenants and they are very interested to grow wheat. So trial plots for tenant farmers should be provided.

Distribute free seed

If it is not possible to provide more trial plots and training in a village then at least free wheat seed should be distributed among the farmers. Then cultivation of wheat will increase.

Supply inputs (seed, fertiliser) before required

Farmers said if they do not get input support at the proper time, they do not get good yields and they lose interest in growing wheat again. So inputs must be provided at the proper time.

Provide threshing machine support

All farmers said threshing of wheat is very laborious but threshing machines are not available in their village—machines should be provided by the government or non-government organisations (NGOs) (see Figure 13).

Enhancing financial capital

Supply adequate loans for all categories of farmers

Loans are essential to enable most farmers to cultivate wheat. Most village farmers have little available money so they have to take loans with high interest from Mohajan (private loans organisations) or NGOs. Sometimes they could not apply fertiliser and other inputs at the optimal time or at recommended levels due to lack of capital. For this reason, they have harvested low yields.

Easy-terms government loans

To overcome this problem the government should provide loans in agriculture on easy terms; the rate of interest for government loans generally is low compared to those from Mohajan or NGOs. Government can provide loans with easy repayment conditions such as allowing farmers to make repayments after harvest of their crops or later when they are sold. Such government loans would be a key incentive for farmers to grow wheat.

Loans for tenants

Generally, government gives loans to farmers who own land. But more than 50% of farmers in a village are tenants who are excluded from government loans. Government should include tenant farmers in the agricultural loan policy.

NGO loans for cropping

NGOs usually provide loans for business, housing, purchasing equipment and livestock, but they provide few loans for production of crops. If NGOs did provide loans for different crops at their required time it would be helpful for adoption of a new crop. They should also reassess their rates of interest for agricultural loans and introduce repayment policies that are targeted specifically at encouraging the adoption of a new crop.

Figure 13. Threshing can be hard work (Photo: Dinajpur in 2005 by H.M. Rawson). The work here is shared between men and women as in Noakhali and as by tenant farmers in Bhola (see Figure 7)

Subsidies on inputs

The price of inputs like fertiliser is increasing and the seed cost of wheat is higher than that of any other crop. For this reason, many farmers cannot afford to grow wheat. Government should provide subsidies on inputs like wheat seed and fertiliser so that farmers can grow wheat on large areas of land.

Enhancing social capital

Relationship between extension officers and farmers

Most farmers complained that extension field workers did not visit their field regularly and that relationships between field workers and farmers are not good. Extension field workers should build up good relations with all types of farmers, visit their fields regularly and provide advice according to their crop problems. Frequent, timely advice will lead to good yields.

Make farmers aware of the advantage of rotations including wheat

Most village farmers do not know what benefits they will get if they adopt wheat. Extension field workers should develop awareness among the farmers about the advantages of wheat like its profitability, short duration and the possibility of mungbean rotations.

Demonstrate the food value of wheat

Rice is the staple food in Bangladesh. The farmers who have grown wheat buy rice by selling their wheat. In this case, extension workers can motivate the farmers to use wheat as a substitute for rice. If people can change their food habits and learn the high nutritional value of wheat, they will be more likely to grow it.

Enhancing natural capital

Proper utilisation of fallow land

Generally farmers do not grow crops like boro rice on high land because it is not possible to hold water in the land. So farmers keep much of this land fallow. But farmers can easily grow wheat on this fallow land because it needs little irrigation to cultivate, just one or two irrigations. Motivational programs should be developed to encourage farmers to use their fallow land fully.

Proper land selection for proper crop

Some farmers do not rationalise which land is suitable for which crops; they are commonly influenced by what their neighbours are growing and where. They face loss by inadequately matching land to crop. Training about soil and land type, suitability of crop and sowing time would minimise their production risks. Training via radio and television and mobile phone support would realise good benefits.

Conclusion

Using the livelihoods framework, explained in Chapter 5.1 (this volume), to assess the ACIAR-funded project's impact, an attempt was made to understand the changing nature of capital assets and their interactions that work to determine farmers' livelihood strategies in a given context. We demonstrate how introduction of a new crop, specifically wheat, should occur considering not only economic aspects, but also the social fabric of communities and the structure of extension services, with some services particularly targeted at women.

Reference

Ellis F. 2000. Rural livelihood diversity in developing countries. Oxford University Press: Oxford.

Section 6

Conclusions

Intense interest in a wheat field laboratory in a Noakhali saline area
(Photo: H.M. Rawson)

6.1 Increased Rabi-season cropping in southern Bangladesh: an overview of this ACIAR project

Peter S. Carberry

Abstract

This Australian Centre for International Research (ACIAR) technical report details the program of technical and extension activities that supported farmers in southern Bangladesh to trial new crops during the post-rice Rabi season. This final chapter summarises the conduct and impacts from the 6 years of research effort. In brief, crops such as wheat were grown successfully using existing resources throughout southern Bangladesh on lands that were previously left fallow during the dry Rabi season. Today, there is sufficient evidence that farmers will continue to adopt wheat and mungbean crops into their system given adequate support from local research and extension agencies. A key conclusion from this successful research for development project is that supporting people and institutions is critical to make such investments succeed.

Introduction

Rarely today, amongst fears of food insecurity and diminishing arable lands due to pressures from urban development, mineral and gas resource extraction and environmental conservation, does opportunity emerge to successfully increase cropping intensity by bringing underutilised lands into new crop production. Especially so in a country such as Bangladesh where population numbers and density would suggest all lands are utilised to their arable capacity. Yet this study both raised and tested the proposition that the farming lands in southern Bangladesh could increase food production through the introduction of new crops during the post-monsoon Rabi season. The conclusions, as reported over the series of previous chapters, are definitive. Crops such as wheat can be grown successfully in southern Bangladesh and produce food from farms that were left fallow or underutilised during Rabi. Importantly, this development can proceed without the requisite investment in irrigation infrastructure that was essential to the prior decades' intensification of crop lands across the Indo-Gangetic Plains.

This chapter concludes a series that reports the findings from a program of activities targeted at providing the technical and extension support for farmers in southern Bangladesh to introduce new crops, such as wheat and mungbean, onto their lands during Rabi. While briefly collating the main findings from this study, this final chapter attempts to critically assess the conduct and impacts from 6 years of research effort as represented by an ACIAR-funded project. The current state of this effort and the prospects of continued progress are evaluated. Finally, the chapter acknowledges the people and institutions whose ambition, energy and aptitude facilitated what can only be viewed as a successful research for development investment.

Project activities and findings

Between 2007 and 2011, an ACIAR-funded project utilised livelihoods analysis (Chapters 1.1–1.3, 5.1, 5.2), resource inventory assessment (Chapters 2.1–2.3), on-farm trials (Chapters 3.1–3.6) and systems modelling and economics (Chapters 4.1–4.4) to assess the production potential for crops, to develop appropriate agronomic practices and to promote their adoption in several districts in southern Bangladesh. The project achieved significant outcomes against all three of its objectives restated here from Chapter 1.1 (this volume):

1. delineate and characterise the areas where Rabi-season cropping is feasible on currently fallow lands with or without supplementary irrigation
2. finetune agronomic practices specific to each potential region and socioeconomic grouping, especially in the efficient utilisation of limited water resources and fertilisers
3. encourage farmer uptake of emergent cropping practices through training and support of the regional change agents who have ongoing commitment to supporting smallholder farmers.

First, the physical and social characteristics of potential Rabi-cropping areas of southern Bangladesh areas were characterised to provide a basis for the development of appropriate agronomic practices and adoption processes. Technically, the most significant finding was the presence of shallow watertables at most sites, which positively supplemented water availability for crop use and allowed for reasonable yields. Spatial data and field monitoring suggest that watertables will contribute to Rabi crop production in a number of districts of southern Bangladesh. Somewhere in the order of 850,000 ha across southern Bangladesh, much with shallow watertables, are available for Rabi-season crop intensification. From a social perspective, a key insight was that women are involved in the decision-making on crop selection and undertake much of the postharvest threshing and cleaning—this finding led to changes in the project's training program, with an increased emphasis on whole-of-family training. The livelihoods surveys reinforced the reality that, for farmers to adopt new crops, they have to be sure in their own minds that the risks (financial, human, social, natural and physical) are no greater than with the existing land use.

Second, the project developed agronomic practices that resulted in farmers in southern Bangladesh reliably producing wheat yields of over 3 t/ha with a single irrigation and 2 t/ha as rainfed crops. These practices have been assessed and validated in over 400 farmer-run trials in seven southern districts over five seasons. The agronomic packages provide recommendations for variety choice (Chapter 3.6), land preparation and sowing, fertiliser rate and irrigation scheduling (Chapters 3.3, 3.4 and 3.5). Specifically, seven new wheat varieties with improved environmental adaptation were trialled across the region and found to have high yield potential. For southern environments where higher growing-season temperatures are common and soil salinity is an issue, promising wheat cultivars were screened from 63 lines that are potentially suited to very late planting (heat) and for saline conditions (Chapter 3.6). The project promoted the use of the short-season mungbean variety BARI Mung 6, the area of which is expanding within the regions where the project operated (Chapter 4.3). The project produced the manual 'How to grow wheat in southern Bangladesh and fit it into a timely annual sequence with other crops' and also its Bengali version 'Bangladesher Dakhinanchale Gom O Porabarti Fasoler Uthpadon Kolakousol', which summarises these agronomic recommendations for farmers, extension agents and researchers.

Third, farmers are being supported in their uptake of emergent cropping practices through training and support of the regional change agents, from both government and non-government organisations (NGO), who have ongoing commitment to supporting smallholder farmers. Over 700 farmers, 180 regional extension personnel and 60 researchers were trained in wheat agronomy and management by the Wheat Research Centre (WRC) and project scientists. Farmer interviews suggest that the project has been successful in those villages that collaborated in the project—reports indicate participating farmers continued to grow wheat after cessation of project activities and they sold wheat seed to non-participating neighbours. There is some evidence of farmers further afield also adopting wheat and mungbean production.

As a direct consequence of project activities, Rabi-cropping of wheat and mungbean in southern Bangladesh is now regarded as a viable option by local farmers, government extension services and NGOs.

Impacts

Over 700 participating farmers, regional extension officers and researchers were trained in wheat and mungbean agronomy and management during the course of the project. In those villages that directly participated in the project, the socioeconomic surveys found that wheat was profitable for farmers and could attain higher gross margins compared to leaving the land fallow, or growing low-producing crops or even boro rice. Specific farmers in these villages now have the knowledge and skills to continue to grow wheat and fully utilise their lands during the Rabi season. Furthermore, these surveys suggest that the financial capital and food security of farmers in these villages has increased as a result of this intervention.

While the participating farmers who benefited directly are relatively few, the seeds for growing impact have now been sown. Before the project began, the prospects for Rabi-season cropping in the south were severely discounted due to oft-stated reasons of high temperatures and salinity, but most critically because irrigation development was stymied through fears of saltwater intrusion if tube well development mirrored that from the country's northern agricultural development. The most significant impact from this project is that agriculture in southern Bangladesh is now seen with new eyes. Farmers, public researchers and extension officers, NGOs and government policymakers all recognise the new prospects for producing crops such as wheat in the south without the need for new irrigation infrastructure. The challenge now is to support the utilisation of the land and water resources in southern Bangladesh through sensible use of surface water and shallow watertables to produce adapted crops such as wheat, maize and mungbean during the Rabi season.

At the time of writing, a number of initiatives had commenced to support the continued expansion of cropping in southern Bangladesh. Critically, these are being led by government agencies, which have adopted new priorities for supporting agriculture in the southern regions.

Unresolved issues

Scaling out to all farmers in southern Bangladesh the knowledge and opportunities for Rabi-season cropping is clearly the priority for further investment. Alongside such knowledge extension there also have to be systems to support the uptake of the new technologies. Local systems that supply seed for the new adapted varieties require development, as well as farmer access to the required inputs and necessary finances to complete the agronomic package. As a critical step, the WRC is already mobilising its efforts to supply the new varieties and, in collaboration with government and non-government extension agencies, the associated agronomic training in the south.

The physiology and agronomy of wheat were well explored during the course of the project (Chapters 3.1–3.6). However, several issues were identified and explored but remain unresolved. Notwithstanding that soil nitrogen samples were collected in all project trials, the nitrogen dynamics of the rice–wheat system remain largely unknown. Laboratory delays in analytical analysis and high sample variability in results hindered the attempts at quantifying the crop's response to soil nitrogen. A key hypothesis from the project is that the recommended irrigation at 20 days after sowing is more for the benefit of leaching top-dressed nitrogen into the root zone than for supplementing crop water status. This needs confirmation. Likewise, the interaction between multiple irrigations and nitrogen supply requires further exploration and explanation.

The mechanisms that instil salinity and high temperature tolerance in some wheat germplasm are areas for further research, especially with drivers such as climate change. Additionally, Chapter 3.6 also recommends that experimental approaches that elicit such tolerance be honed to provide unambiguous results.

Collating the data and analyses from 6 years of project study into this ACIAR technical report is a significant achievement.

People and institutions

The activities and achievements reported here result from the investment by motivated people and supporting institutions. The key people can be found listed as the authors of chapters in this volume and it is my onus here to provide due attribution to these researchers for whom this project has represented a significant personal investment over several years.

Drs M. Saifuzzaman and A.B.S. Hossain over the full life of the project, and Dr M.A. Sufian in its establishment, provided the combination of technical knowledge, local know-how and unmitigating drive that is essential to successful implementation of research for development projects. The research credentials of these leading scientists and their colleagues are testament to the professional capacity housed within the WRC, Bangladesh Agricultural Research Institute (BARI), the On-Farm Research Division (OFRD), Department of Agricultural Extension (DAE) and CIMMYT's in-country office.

Most trials were conducted on farms by farmers new to wheat cultivation in southern Bangladesh. Yet these trials were overwhelmingly successful in attaining not only good yields but also results ably subjected to scientific analysis (Chapters 3.1 to 3.6). These results indicate how good Bangladeshi farmers are and it is to their credit that Bangladesh produces so much food from its limited resources. Highly competent farmers, supplemented with support from local researchers and extension officers, are key ingredients to successful research for development activities.

While the potential that Rabi-season cropping holds for southern Bangladesh has been demonstrated, the support of policymakers is critical in ensuring that this potential is turned into longer term farming systems change through support of the necessary extension and infrastructure development activities. Dr Wais Kabir, the Executive Chairman of the Bangladesh Agricultural Research Council (BARC) has been pivotal in providing researchers with the opportunities to communicate with senior policymakers and to make the case that southern Bangladesh is ready to contribute more to national food security into the future. The non-government organisations PROSHIKA and Forum for Regenerative Agricultural Movement (FoRAM), through their consistent link to this project in Mr Q.K. Alam, have provided the project with the opportunity and resourcing to scale-out project results to many more farmers across southern Bangladesh.

Australia provided support to this effort in Bangladesh via funding from ACIAR and project leadership and technical input from the Commonwealth Scientific and Industrial Research Organisation (CSIRO). International research for development is an important means whereby Australian organisations can help support Australia's national and regional interests. Emerging global challenges such as food security and climate change are not contained within national boundaries and it is important that Australia's science investment is well connected to the global research efforts in both the developed and developing world. In addition, many benefits flow back to Australia from building international partnerships. These include direct science discoveries or methods development, indirect development of skills and capabilities within staff, and the attraction and retention of staff motivated by the research challenges involved in working internationally. These benefits are all evident in this Bangladesh project. For example, the further testing of the Agricultural Production Systems Simulator (APSIM) model for new situations, e.g. rice–wheat systems, crop production over shallow watertables and impacts of high salinity on crop growth, has led to new research investment and advancement both in Australia and internationally. Most notably amongst the involved Australians, Neal Dalgliesh, in leading this ACIAR project, demonstrated yet again he is a trusted and committed leader of a project team and Perry Poulton gave the project full support across so many domains.

It is hardly debatable whether the participants of this project could have achieved their own contribution if Dr Howard Rawson, retired physiologist/ agronomist and long supporter of Bangladesh research, had not committed the time and energy to making this effort succeed. He recognised the opportunity and helped instigate the research. He provided the intellectual rigour and analysis to understanding the research results and, in doing so, mentored all who had the good fortune of his company. In the end, he also co-wrote much of this report and is its editor.

ACIAR funding was initially sponsored through the efforts of Dr Christian Roth who remains committed to the research approach adopted here. In more recent years, Dr Mirko Stauffacher was the project's sponsor within ACIAR. Only a few weeks before the completion of this technical report, Mirko died. To Mirko, this report is dedicated for good work done.

Conclusions

There is an international imperative for the production of major food crops to increase in order to keep pace with projected food demand driven by increases in population and consumption patterns. As bringing new lands into arable production is unlikely, productivity per unit area must rise to underwrite the global supply response. This ACIAR-funded project, which aimed at expanding the area for Rabi-season cropping in southern Bangladesh, is an exemplar case of crop intensification where annual crop production can be dramatically increased on current arable lands. It is not unreasonable to expect that significant production of wheat will now come from Bangladesh's south. The project team will hold to this prediction and look forward to seeing its fruition.

Acknowledgments

To all the participating farmers, project staff and supporting institutions, thanks are given for your time, energy and resources committed to this project. Planning and implementation of the research program involved many people from Bangladesh and Australia and the efforts of all demonstrated real commitment. Our gratitude is given to the organisations ACIAR, Bangladesh Agricultural Research Institute (BARI), WRC, CSIRO, International Maize and Wheat Improvement Center (CIMMYT), DAE, On-Farm Research Division (OFRD) and the NGOs PROSHIKA and FoRAM for their support during the course of this project.

ACIAR

Research that works for developing
countries and Australia

aciar.gov.au