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2 Executive summary

A significant concern to food security in Bangladesh is that annual wheat production falls significantly short of consumer demand. Increasing the cropping intensity on currently under-utilised lands in southern Bangladesh offers the prospect of increased grain production and improved livelihoods of farmers in the region. This project provided the technical and extension support for farmers in southern Bangladesh to introduce new crops, such as wheat and mungbean, onto their lands during the post-rice Rabi season.

Between 2007 and 2011, the project utilised on-farm trials, resource inventory assessment, systems modelling and livelihoods analysis 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.

Firstly, 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 fresh ground water tables at most sites which positively supplemented crop water use. From a social perspective, a key insight was that women are key decision makers in crop selection and undertake most of the post harvest threshing and cleaning – this early finding led to changes in the project's training program. The livelihoods surveys reinforced the reality that, for farmers to adopt new crops, they have to be sure in their own mind that the risks (financial, human, social, natural and physical) are no greater than with the existing land use.

Secondly, the project developed agronomic practices which resulted in farmers in southern Bangladesh reliably producing wheat yields of over 3 t/ha with limited irrigation and 2 t/ha as rainfed crops. These practices have been assessed and validated in 285 farmer-run trials in six southern districts over five seasons. The agronomic packages provide recommendations for variety choice, land preparation and sowing, fertilizer rate and irrigation scheduling. Specifically, five new wheat varieties were trialled and found to be similar in yield and phenology. For districts with salinity, promising wheat cultivars were screened from 63 lines and are potentially suited to very late planting (heat) and in saline conditions. The project promoted the use of the mungbean variety Bari Mung-6, the area of which is expanding within the regions where the project operated. The project produced the manual "*How to grow wheat in southern Bangladesh and fit it into a timely annual sequence with other crops*" and the ACIAR Technical Report "*Sustainable intensification of Rabi cropping in southern Bangladesh using wheat and mung bean"* (*in press*) which provide information for farmers, extension agents and researchers on the potential for the integration of wheat and mungbeans into existing rice based farming systems.

Thirdly, farmers are being supported in their uptake of emergent cropping practices through training and support of the regional change agents who have on-going commitment to supporting smallholder farmers. Over 830 farmers, 305 regional extension personnel and 60 researchers were trained in wheat agronomy and management by 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 sold wheat seed to non-participating neighbours. There is some evidence of farmers further afield also adopting wheat and mungbean production.

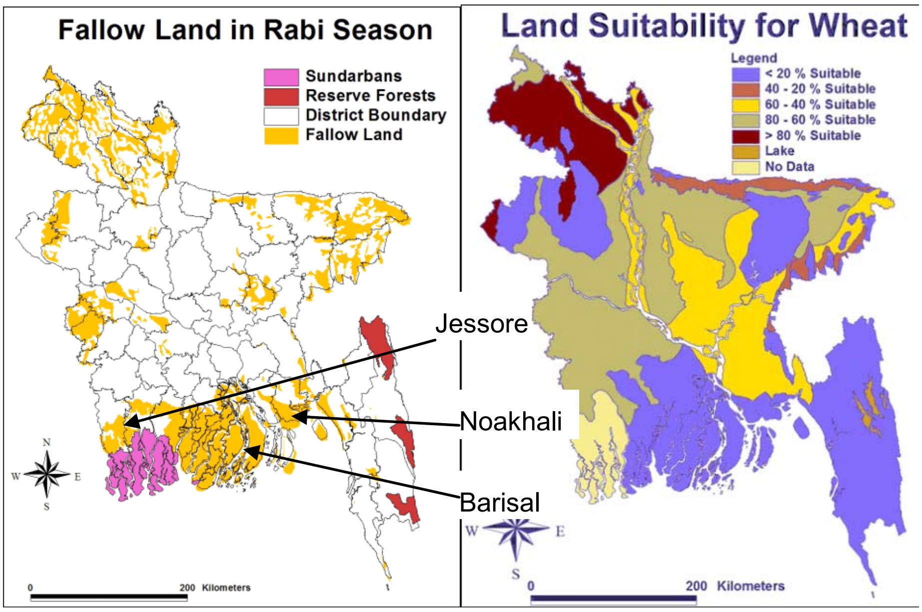
As a direct consequence of project activities, Rabi-cropping of wheat and mungbean in southern Bangladesh is now regarded as a viable option by government extension services and NGOs.

3 Background

The rationale for this project is the shortfall in wheat supply in Bangladesh – in 2006, consumption of wheat was around 4 million tonnes per annum, increasing at 3% per annum, whereas production was then less than 2 million tonnes and decreasing. The situation created serious concerns for food security and for diminishing foreign currency reserves.

The opportunity to be explored was the estimated 800,000 ha of agricultural land remaining uncultivated in southern Bangladesh during the dry (Rabi) season (Figure 1) due to a lack of irrigation infrastructure and the perception that the area is too risky for wheat production as part of a rice-wheat rotation. Sowing of wheat is often delayed well beyond the date considered optimal in the north due to late finishing long season rice varieties and later drainage of monsoon waters which delays tillage and planting operations. Additionally, the area is hotter than the north, with a shorter potential season and soils in the districts closer to the Bay of Bengal are often saline.

Figure 1: (a) Identification of fallow land during the Rabi season in Bangladesh (Bangladesh Country Almanac BCA v3.0); (b) Land suitability for wheat production in Bangladesh (Bangladesh Country Almanac BCA v3.0.).



Prior work had reassessed the south for cultivation of wheat because some of the constraints were overcome. By applying techniques to shorten the time between rice harvest and wheat planting and by using surface-stored water for limited irrigation, three years of on-farm trials at five sites showed average wheat yields exceeding 2.5t/ha are possible in some locations, even without irrigation (FAO 2003-5; ACIAR 2005-6, in collaboration with WRC/BARI, CIMMYT, DAE and OFRD). Modelling in the ACIAR scoping study, using historic local weather data and APSIM, indicated that wheat, mungbean and maize can be grown with low-risk, long-term economic feasibility, particularly if surface flood water, stored over from the kharif season, is sufficient for one in-crop irrigation. The scoping study estimated that the potential for new wheat production from southern Bangladesh may approach 1 million tonnes per annum – a significant contribution to national food security considering average total wheat production for Bangladesh is currently less than 2 million tonnes per annum.

To expand wheat production through the southern fallow lands, this current study aimed to build on the established collaboration with WRC/BARI, CIMMYT, DAE and OFRD and add a new NGO partner, PROSHIKA. This team has worked together to progress through the four steps of (i) constraint characterisation, (ii) development and demonstration of farm management packages to handle local constraints, (iii) training extension personnel in the use of packages who then (iv) train farmers in an outreach program. The pattern proceeded concomitantly in several regions starting with Noakhali, Barisal and Bhola.

Acronyms

APSIM	Agricultural Production Systems Simulator
BARI	Bangladesh Agricultural Research Institute
BBS	Bangladesh Bureau of Statistics
BADC	Bangladesh Agricultural Development Corporation
BMD	Bangladesh Meteorological Department
CIMMYT	International Maize and Wheat Improvement Centre
DAE	Department of Agricultural Extension
FAO	United Nations Food and Agriculture Organisation
OFRD	On Farm Research Department
PROSHIKA	Bangladesh NGO
WRC	Wheat Research Centre

4 Objectives

Through collaboration with researchers in Bangladesh from WRC (BARI) and CIMMYT, and building on the momentum gained from previous research undertaken by WRC/BARI/FAO/CIMMYT/ACIAR, the overall aim of this study has been to improve the livelihoods of farmers in southern Bangladesh through the introduction of wheat and mungbean onto otherwise underutilised fallow lands during the post-rice Rabi season.

Specific objectives were:

1: To delineate and characterise the areas where Rabi–season cropping is feasible on currently fallow lands with or without supplementary irrigation.

Activity 1: To quantitatively describe the environmental and socio-economic resources for prospective Rabi-cropping regions in southern Bangladesh.

Activity 2: To spatially represent suitable Rabi-season cropping areas using four defined land categories

Activity 3: To demonstrate a small group of improved wheat varieties in new areas in order to involve prospective wheat farmers in selecting their preferred cultivar and to provide seed increase locally for wheat production in following years.

2: To finetune agronomic practices specific to each potential region, land category and socio-economic grouping, especially in the efficient utilisation of limited water resources and fertilisers.

Activity 1: To collect field crop-soil-climate datasets from on-farm trials testing agronomic practices in southern Bangladesh and Australia.

Activity 2: To adapt APSIM to better simulate high temperature, water and salinity impacts on crop production in both South Asia and Australia

Activity 3: To test the feasibility of alternative agronomic practices in southern Bangladesh and Australia through long-term simulations using APSIM.

3: To encourage farmer uptake of emergent cropping practices through training and support of the regional change agents who have on-going commitment to supporting smallholder farmers.

Activity 1: To develop training programs on crop agronomy with senior scientists from WRC for delivery to research and extension staff of WRC/BARI, DAE, OFRD and PROSHIKA in the prospective new regions.

Activity 2: To support WRC, DAE and PROSHIKA in on-ground extension activities targeted at farmer uptake of Rabi-season cropping practices.

Activity 3: To evaluate the current and evolving perception of farmers and other stakeholders to Rabi-season cropping and track its on-ground adoption.

5 Methodology

The Bangladesh Wheat Research Centre's (WRC) release of a suite of new wheat varieties provided the opportunity for more sustainable Rabi-season wheat production in southern Bangladesh. The release of the short season mungbean variety BARI Mung 6 by the Pulse Research Centre further increased flexibility in Rabi-season cropping options. Whilst farmer preference is to grow Boro rice during the Rabi season, demand for irrigation water for its production often outstrips supply. Consequently, lower water-demand alternatives, including wheat and mungbean, provide opportunity in an environment where it appears that climate change is further diminishing water supply.

Agronomic and social research were conducted across districts in southern Bangladesh during the five dry (*Rabi*) seasons of project activity (2006/07, 07/08, 08/09, 09/10 and 10/11). In the first two seasons research and extension was focussed in the regions of Barisal (22.7°N, 90.4°E), Noakhali (22.8°N, 91.1°E) and Bhola (22.7°N, 90.6°E). Regions were selected based on apparent land availability and previous research which indicated potential for significant wheat production using the new improved varieties released by the WRC (Rawson et al 2007; Carberry *et al* 2008). The district of Noakhali represented potential production areas adjacent to the Bay of Bengal where the lands are more recently formed through sedimentation (*char* lands) and production potential is restricted by high seasonal salt concentrations and potential for water inundation through tidal surge. In the 2008/09, 09/10 and 10/11 seasons research was extended to encompass the districts of Patuakhali (22.33°N, 90.4°E), Jhalakathi (22.64°N, 90.2°E) and Pirojpur (N22.58°, 90.05E). These districts lie to the south and west of Barisal and were indentified as having significant fallow lands available for wheat cropping.

The partnership with WRC also provided the opportunity for participation in nationally focussed wheat research, in particular the wheat 'time of sowing' program (5.3.3) where an additional site was established in the south for comparison with the 6 northern research sites. The 3 years of data from this research, in conjunction with data from the seed multiplication program (5.2), have provided valuable information on the impact of time of sowing on yield, a potentially important issue in the south where wheat sowing is often delayed due to the late finish to the wet season.

5.1 Spatial analysis of natural resources

Spatial evaluation of the availability of natural resources required to increase crop production was seen as key to informing and supporting project activities seeking to improve smallholder livelihoods through successful introduction of alternate *Rabi*-season crops. Water availability for the production of Rabi season crops, including wheat and mungbean, was considered one of the major determinants for the suitability of land for increased Rabi season cropping. The following criteria were used in the identification of regions considered as having potential for increased cropping intensity.

- Land remaining fallow following the T. Aman rice harvest in November.
- The potential for supplementary irrigation from surface storage of monsoon rainwater.
- The contribution of near surface water tables to dryland cropping through capillary rise.
- The potential for supplementation of poor quality ground water with irrigation from surface storages.

5.1.1 Identification and mapping of regions for increased Rabi season production

A number of approaches were tested for the quantification of regional potential using the above 4 criteria. These included:

Using statistical datasets for modelling and analysis of resource availability

Analysis focused on the region south of latitude 23.5 deg N in southern Bangladesh. 20 districts from 4 divisions within this region were selected as a geographically representative subset for detailed analysis and to provide the basis for demonstrating spatial distribution and result outcomes. Examples of data accessed for this analysis include a) The Bangladesh Country Almanac (BCA v.3.0) which provides a spatial perspective on climate, soil characteristics, natural and water resources, agriculture and irrigation for the entire country (but over limited time periods) and b), data from the Bangladesh Bureau of Statistics (BBS) on district wise land utilisation and cropping area statistics and c) data from the 2005-06 Department of Agricultural Extension (DAE) census which provides an estimate of cropping area and intensity and potentially fallow land during this period, with land type classification used to assess cropping suitability.

BBS and DAE data was analysed using the following 5 up-scaling methodologies:

- estimating fallow area using current land use statistics
- estimating fallow area using cropping intensity (land utilisation)
- estimating fallow area using knowledge of local crop sequences
- estimating fallow area using cropping intensity at the district level
- estimating fallow area using boro rice planting statistics

Using satellite imagery in the identification of fallow and cropping areas

Using satellite imagery as a tool for identifying changes in broad scale land use is well accepted internationally (Poulton and Dalgliesh 2008), however its use in farming systems with small spatial scale ie small fields, has in the past been limited by image resolution. Images from the Japanese Advanced Land Observing Satellite (ALOS) (http://www.eorc.jaxa.jp/ALOS/en/about/about_index.htm) using AVNIR-2 provides observations at a 10m spatial resolution using a 70 km swath width. Interpretation of these data suggest cropping management of small scale paddocks (<0.2ha) can be captured remotely using sequenced images. Data images for a selected subset of districts in southern Bangladesh were obtained from Geosciences Australia (http://www.ga.gov.au/earth-observation.html). These data images were evaluated for the potential to use spectral signatures in the initial selection and classification of land under Rabi season fallow and under wheat cultivation. A supervised classification technique identifying four elements (ponds, trees, cropping areas and fallow land) on a regional area in Noakhali using the ENVI® imaging software was undertaken in conjunction with field ground truthing in 2009.

5.2 Rabi-season cropping demonstration

The concept of the Seed Multiplication Trial (SMT) was developed to expose farmers to the opportunities presented by the availability of alternate Rabi-season cropping options for southern Bangladesh, to support crop expansion through regional distribution of seed of the new wheat and mungbean varieties and to develop crop production data sets for use in systems analysis (Table 1). Farmer involvement in the SMT program was negotiated between the farmers, project personnel and local Department of Agricultural Extension (DAE) block supervisors. Participation was on the understanding that the grain produced was to be used by the farmer or sold to others for future production. Plots were of a commercial size (~1000 m^2) and required access to irrigation. Agricultural inputs, including seed and fertiliser and technical training and support were provided by the project through regionally located project officers and Dhaka based scientists. Participating farmers undertook pre-season training in wheat and mungbean production and seed storage techniques, followed by a post-harvest village or district meeting to discuss seasonal outcomes.

The collection of agronomic and production data was an important component of the SMT trials. These data enabled the development of knowledge of wheat and mungbean adaptation based on spatial and temporal variables including climate, geography, salinity and soil type. In the 2008 and 2009 wet (*Kharif*) seasons the crop monitoring program was expanded to include production of T. Aus and T. Aman (Transplanted Aus and Aman) rice. Availability of these data, in conjunction with regional weather records (collected from a network of electronic weather stations managed by the project) and soil water characteristics routinely collected as part of the program, provide the opportunity to explore whole of systems options for crop sequence change in southern Bangladesh using tools such as simulation modelling.

Table 1: Summary of Seed Multiplication Trial program for wheat, mungbean and rice 2007-2011. (Detailed sites included soil characterisation and monitoring)**.**

Season	District	Upazilas	Number of SMTs (1 SMT per farm)	Varieties (wheat, mungbean, rice)
2007/08 (39 wheat farms)	Noakhali	3	13 wheat (2 detailed-1 irrigated, 1 non-irrigated) 13 mungbean	Shatabdi, Sourav, Prodip, Bijoy (each variety grown on 3 farms) Bari-Mung 6 (all farms)
	Barisal	3	13 wheat (2 detailed-1 irrigated, 1 non-irrigated) 15 mungbean	Shatabdi, Sourav, Prodip, Bijoy (3 farms) Bari-Mung 6 (all farms)
	Bhola	3	13 wheat (2 detailed; 1 irrigated, 1 non-irrigated) 14 mungbean	Shatabdi, Sourav, Prodip, Bijoy (3 farms) Bari-Mung 6 (all farms)
2008	Barisal	3	16 Kharif rice (4 detailed), 3 jute	Farmer choice
	Bhola	3	20 Kharif rice (4 detailed)	Farmer choice
	Jhalakathi/ Pirojpur		16 Kharif rice (4 detailed)	Farmer choice
2008/09 (87 wheat farms)	Noakhali	4	20 wheat (6 detailed, 1 of each variety irrigated + dryland Shatabdi) 19 mungbean	Shatabdi (6 farms, 2 non-irrigated) Sourav (4), Bijoy (4), Prodip (3), Sufi (4) Bari-Mung 6 (all farms)
	Barisal	5	14 wheat (7 detailed, 1 of each variety irrigated, 2 of Prodip + dryland Shatabdi) 12 mungbean	Shatabdi (3 farms, 1 non-irrigated) Sourav (2), Bijoy (3), Prodip (3), Sufi (3) Bari-Mung 6 (all farms)
	Bhola	3	20 wheat (6 detailed, 1 of each variety irrigated + dryland Shatabdi) 20 mungbean	Shatabdi (6 farms, 2 non-irrigated) Sourav (3), Bijoy (3), Prodip (4), Sufi (4) Bari-Mung 6 (all farms)
	Jhalakathi/ Pirojpur	2	17 wheat (5 detailed, 1 of each variety irrigated except Sufi + dryland Shatabdi) 11 mungbean	Shatabdi (7 farms, 3 non-irrigated) Sourav (3), Bijoy (2), Prodip (3), Sufi (2) Bari-Mung 6 (all farms)
	Patuakhali / Barguna	3	16 wheat (6 detailed, 1 of each variety irrigated + dryland Shatabdi) 14 mungbean	Shatabdi (5 farms, 2 non-irrigated) Sourav (3), Bijoy (3), Prodip (3), Sufi (2) Bari-Mung 6 (all farms)
2009	Barisal	3	7 Kharif rice	Farmer choice

	Bhola	3	16 Kharif rice	Farmer choice
	Noakhali	3	10 Kharif rice	Farmer choice
	Jhalakathi/ Pirojpur	1	4 Kharif rice	Farmer choice
2009/10 (69 wheat farms)	Barisal		15 wheat (2 detailed, Shatabdi irrigated and non-irrigated) 4 mungbean	Shatabdi (3 farms, 1 non-irrigated) Sourav (2), Bijoy (2), Prodip (2), Sufi (2), BW1059 (2), BW1064 (2) Bari-Mung 6 (all farms)
	Bhola		15 wheat (2 detailed, Shatabdi irrigated and non-irrigated) 11 mungbean	Shatabdi (3 farms, 1 non-irrigated) Sourav (2), Bijoy (2), Prodip (2), Sufi (2), BW1059 (2), BW1064 (2) Bari-Mung 6 (all farms)
	Noakhali		15 wheat (2 detailed, Shatabdi irrigated and non-irrigated) 4 mungbean	Shatabdi (3 farms, 1 non-irrigated) Sourav (2), Bijoy (2), Prodip (2), Sufi (2), BW1059 (2), BW1064 (2) Bari-Mung 6 (all farms)
	Barguna		8 wheat (2 detailed, Shatabdi irrigated and non-irrigated)	Shatabdi (2 farms, 1 non-irrigated) Sourav (1), Bijoy (1), Prodip (1), Sufi (1), BW1059 (1), BW1064 (1)
	Jhalakathi/ Pirojpur		8 wheat (2 detailed, Shatabdi irrigated and non-irrigated) 6 mungbean	Shatabdi (2 farms, 1 non-irrigated) Sourav (1), Bijoy (1), Prodip (1), Sufi (1), BW1059 (1), BW1064 (1) Bari-Mung 6 (all farms)
	Patuakhali		8 wheat (2 detailed, Shatabdi irrigated and non-irrigated) 10 mungbean	Shatabdi (2 farms, 1 non-irrigated) Sourav (1), Bijoy (1), Prodip (1), Sufi (1), BW1059 (1), BW1064 (1) Bari-Mung 6 (all farms)
2010/11 (90 wheat farms)	Barisal	7	23 wheat	Shatabdi (2 farms), Bijoy (4), Prodip (6), BARI Gom 25 (6), BARI Gom 26 (5)
	Bhola	7	20 wheat	Shatabdi (4 farms), Bijoy (7), Prodip (4), BARI Gom 25 (5)
	Noakhali	4	20 wheat	Bijoy (2 farms), Prodip (3), BARI Gom 25 (10), BARI Gom 26 (5)
	Barguna	1	10 wheat	Prodip (2 farms), BARI Gom 25 (5), BARI Gom 26 (3)
	Jhalakathi	1	7 wheat	Prodip (2 farms), BARI Gom 25 (3), BARI Gom 26 (2)
	Patuakhali	3	10 wheat	Prodip (2 farms), BARI Gom 25 (5), BARI Gom 26 (3)

5.2.1 Wheat Production

The number of SMTs established in each season for wheat varied between seasons, 39 in 2007/08, 87 in 2008/09, 69 in 2009/10 and 90 in 2010/11 (Table 1). All sites received fertiliser at the WRC recommended rate for wheat (Urea 220 kg/ha-150 kg/ha basal/ 70 kg/ha top dressed; Triple Super Phosphate 132 kg/ha; MP 100 kg/ha; Gypsum 111 kg/ha; Boric Acid 7.5 kg/ha). Fertiliser was applied as part of the pre-sowing tillage operation with a second application of Urea 20 days after crop sowing (applied after the first irrigation). Sowing method was at the farmer's discretion with the majority broadcasting seed into rotary tilled seed beds, although a number used the traditional ox drawn country plough. The number of irrigations applied to individual fields was dependent on water availability and crop requirement. All irrigated sites received at least 1 water application at 20 days after sowing, with additional applications at heading, and grain filling where available and required. Whilst the recommended water rate per application was 100 mm, the actual applied rate was often much less. In order to develop an understanding of the impact of irrigation on wheat yield, non-irrigated sites of the variety Shatabdi were also established in each district in the first 3 years.

Whilst all sites received the same agronomic management, the level of crop and soil monitoring varied between sites. A sub-set of sites that represented the suite of wheat varieties was selected for 'detailed' monitoring. In essence this amounted to the additional monitoring of soil water and nitrate nitrogen at key agronomic points during the season (pre-sowing, post harvest and in some instances at crop anthesis) and the characterisation of soils for Plant Available Water Capacity (PAWC). In an effort to better understand the contribution of regional water tables to crop yield, detailed monitoring was further extended during the 2008/09 and 2009/10 seasons to include the measurement of depth to water table using piezometers installed within, and adjacent to the growing crop. These were measured every 15 days throughout the year or until the water level dropped below the depth of the installed tube (3 m).

Crop monitoring during the season at all sites included recording dates of sowing, crop emergence, anthesis, physiological maturity and harvest and dates and rates of fertiliser and irrigation applications. Grain and biomass yields were measured at crop maturity within three quadrat areas (each 2 m^2) representing variability in crop stand (1 located in a high yielding area and 2 in medium yielding areas), and from these and associated measurements the components of yield were calculated for every crop.

5.2.2 Mungbean production

Following the harvest of wheat in 2008, 2009 and 2010 participating farmers were offered the opportunity of growing the short season (60 days to maturity) mungbean variety Bari Mung 6 as a short term rotation crop prior to establishment of Kharif season T. Aman rice. As there was little experience of growing pulses in the south, training of extension personnel in the Barisal region employed by the NGO PROSHIKA and farmers was undertaken by the ACIAR Bangladesh Pulse Project. The workshop included both crop agronomy and weed and insect management.

A mungbean data set comprising key phenology, yield and management parameters was collected to enable the simulation of the crop as part of a rotational sequence. In 2008 (42 growers) this activity was successful in showing the potential for mungbean in southern Bangladesh as part of a rice/ wheat system, however it also highlighted the necessity for rigorous weed and insect management. Whilst many farmers again grew mungbean in 2009 (76 growers) and 2010 (35 growers), seasonal conditions conspired against a successful outcome in the majority of cases due to late planting, drought and water inundation through tidal surge.

5.2.3 Kharif season monitoring

Kharif season rice (T. Aus or T. Aman), planted following mungbean harvest, was monitored in the 2008 (52 fields) and 2009 (37 fields) seasons. This was to provide a dataset for what would likely become the typical annual rotational sequence were wheat and mungbean to become a major component of southern farming systems. In the village of Khanjapur in Barisal where jute is the main Kharif season crop, 3 fields were monitored. Having data on the annual sequence of crops provides the necessary information to validate the APSIM model to allow systems issues to be investigated. The field work was undertaken by regionally based project staff and a dataset comprising key phenology, yield and management parameters including irrigation timing and depth, fertiliser regime, plant population and farmer yield collected.

5.3 Fine tuning agronomic practice

As the main focus of wheat breeding and production in Bangladesh is in the north of the country, research and agronomic recommendations are logically focussed in this region. Consequently management recommendations are potentially less relevant to the south where the wet season tends to be longer, winter season temperatures higher, water for irrigation often in short supply and saline soils more prevalent. Consequently the focus of project research has been on the fine tuning of existing recommendations to better fit the southern reality. Specifically, focus has been on varietal adaptation to the southern environment (Time of sowing and variety trials) and the management of the crop in terms of nitrogen and irrigation (Nitrogen x irrigation trials). With large areas of the south affected by salinity there has also been an emphasis on the testing of new wheat breeding lines for salt tolerance (Salinity screening trials assessing large numbers of lines and salinity observation trials assessing identified-as-promising lines in detail) and on modification of the tillage system to improve crop establishment, timeliness of sowing and production under saline conditions (bed planting and relay cropping). Table 2 summarises the work conducted.

Planning of the research program was undertaken annually and involved Bangladesh and Australian researchers and extension specialists from the WRC, CSIRO, CIMMYT, DAE and the NGO PROSHIKA which was replaced by the NGO FoRAM in 2009. Operational plans and data books were developed and distributed to staff for use during the season. The translation of operational plans into action was the responsibility of the Bangladesh scientific staff and the team of regionally based scientific officers and their assistants who were responsible for the day to day experimental management. Whilst field staff were employed by both the WRC and PROSHIKA they worked as a single team in each of the regional locations. The social science group employed a similar structure with members employed by CSIRO, WRC and PROSHIKA (and later CIMMYT).

Table 2: Experimental program 2006 – 2011.

Season	Experiment	Location
2006/07	Variety comparisons	Barisal (2 sites), Bhola (2 sites), Noakhali (2 sites)
	Salinity observation and screening trials	Noakhali (2 sites)
	Time of sowing	Dinajpur, Jamalpur, Rajshahi, Ishurdi, Joydebpur, Jessore, Barisal
2007/08	Variety	Barisal (1 site), Bhola (1 site), Noakhali (1 site)
	Nitrogen x Irrigation	Noakhali
	Salinity observation and screening	Noakhali (2 sites)
	Time of planting (TOP)	Dinajpur, Jamalpur, Rajshahi, Ishurdi, Joydebpur, Jessore, Barisal (also TOP effects assessed for all southern zones using SMT data)
2008/09	Nitrogen x Irrigation	Noakhali
	Salinity observation and screening	Noakhali (2 sites)
	Time of planting (TOP)	Dinajpur, Jamalpur, Rajshahi, Ishurdi, Joydebpur, Jessore, Barisal (also TOP effects assessed for all southern zones using SMT data)
	Formed bed rows vs broadcast on flat	Barisal (4 sites), Noakhali (4 sites)
	Preliminary organic fertiliser assessments	Barisal (1 site), Noakhali (2 sites)
2009/10	Formed bed and mungbean relay cropping	Barisal (4 sites), Noakhali (4 sites), Barguna (4 sites)

	Salinity yield	Noakhali, Patuakhali, Joydebpur, Satkhira (2 sites at each)
	Salinity screening/observation	Noakhali, Joydebpur and Amtoli (1 site at each)
	Time of sowing x fertiliser amount	Noakhali (1 site), Barisal (2 sites), Dinajpur (1 site)
2010/11	Time of sowing x fertiliser amount	Noakhali (1 site), Barisal (1 site)
	Salinity screening/observation	Noakhali, Barguna (1 site at each)

5.3.1 Nitrogen by Irrigation

Replicated experiments in 2007/08 and 2008/09 seasons in Noakhali and Barisal investigated the potential for improving nitrogen and irrigation management in wheat production. National WRC recommendations for wheat production suggest three irrigations of 100 mm applied at 20, 50 and 70 days after sowing (DAS), and nitrogen to be applied at a rate of 100 kg/ha split into a basal application at sowing and a top dressing after the first irrigation at 20 DAS. As these recommendations are based on northern research it was considered necessary to investigate whether they were applicable for the south and whether economies, based on timing of irrigation and nitrogen rate, were possible.

In the 2007/08 season a replicated split plot design (3 replicates; main plot: irrigation timing-5 treatments; sub-plot: nitrogen rate-4 N rates applied after the first irrigation) was established on-farm at the village of Hazirhat in Noakhali and at the BARI Research Station at Rahmatpur in Barisal (Table 3).

Table 3: 2007/08 and 2008/09 Nitrogen x Irrigation experimental treatments.

Treat	Irrigation 1	Irrigation 2	Irrigation 3	N Timing (Days after sowing)	N rate (kg N/ha)
2007/08					
1	Rainfed			66%@sowing, 33%@20DAS	N0, 33,66,100
2	20DAS			66%@sowing, 33%@20DAS	N0, 33,66,100
3	20DAS	50DAS	70DAS	66%@sowing, 33%@20DAS	N0, 33,66,100
4	30DAS			66%@sowing, 33%@30DAS	N0, 33,66,100
5	40DAS			66%@sowing, 33%@40DAS	N0, 33,66,100
2008/09					
1	Rainfed			All at sowing	N0,33,66,100
2	20 DAS			66%@sowing, 33%@20DAS	N0,33,66,100
3	30 DAS			66%@sowing, 33%@30DAS	N0,33,66,100

Results from the 2007/08 experiment allowed the design for the 2008/09 trial to be simplified. A replicated split plot design was used (3 replicates; main plot: irrigation timing-3 treatments; sub-plot: nitrogen rate-4 treatments) in experiments at Hazirhat in Noakhali and at an on-farm site near Barisal township (Table 3).

In both seasons all sites received basal fertiliser at the WRC recommended rate for wheat (Triple Super Phosphate 132 kg/ha; MP 100 kg/ha; Gypsum 111 kg/ha; Boric Acid 7.5kg/ha). The land was rotary tilled and the wheat variety Bijoy sown in 20 cm rows to give an emerged population of 25-30 plants/m^2. Site monitoring during the season included recording dates of sowing, seedling emergence, anthesis, physiological maturity and harvest and recording fertiliser and irrigation rates and dates. Grain, biomass and yield components were calculated from three 2 m^2 quadrats cut from each plot at maturity.

Soil monitoring was undertaken at sowing (3 sites per replicate bulked by layer) and crop maturity (1 replicate only with 2 cores bulked by layer in each N rate x Irrigation treatment) for plant available water, Nitrate Nitrogen and Electrical Conductivity (Noakhali only) to a depth of 150 cm for the depth increments, 0-15, 15-30, 30-60, 60-90, 90-120 and 120-150 cm. Bulk density was measured at each research site to a depth of 60 cm (3 replicates) using the above depth increments. In the 2008/09 season depth to water table was measured in 1 replicate of each experiment for all 3 irrigation timing treatments. Measurements were made every 15 days during the experiment or until water level dropped below the depth of the installed tube (3 m).

5.3.2 Variety assessment

The aim of these experiments was to assess the potential of the newly released wheat cultivars under southern Bangladesh environmental conditions. These trials were conducted in the 2006/07 and 2007/08 seasons at locations in Noakhali, Barisal and Bhola districts (Table 4).

Each experiment consisted of 2 replicates of the varieties listed in Table 4. In the first season both replicates were managed using recommended WRC fertiliser and irrigation management (Urea 100 kg/ha; Triple Super Phosphate 132 kg/ha; MP 100 kg/ha; Gypsum 111 kg/ha; Boric Acid 7.5kg/ha; 3 irrigations at 20, 50 and 70 DAS).

Table 4: Variety trial locations and varieties compared.

Year	District	Location	Variety
2006/07	Barisal	Sanuhar	Sourav, Shatabdi (irrigated and dryland), Bijoy, Prodip, BAW1059
		Babuganj	As above
	Bhola	South Balia	As above
		North Joynagar	As above
	Noakhali	Bariopur	As above
		Hazirhat	As above
2007/08	Barisal	West Narayanpur	Sourav, Shatabdi, Bijoy, Prodip, Sufi, BAW1059, BAW1064
	Bhola	South Balia	As above

All plots were irrigated with the exception of 1 Shatabdi dryland plot in each replicate. In the second season the design was modified with 1 replicate receiving recommended WRC fertiliser rates and the other receiving half of the recommended rate for all nutrients. This modification to design was aimed at investigating yield potential using fertiliser rates which are more likely to be used by the farming community.

Seasonal monitoring included the recording of key phenological stages of crop development (emergence, anthesis and physiological maturity) and of management operations including sowing and harvest dates, and fertiliser and irrigation application timing. Total biomass and grain yields were measured at maturity using three quadrat areas of 1 m^2 (2 m^2 in season 2) representing variability in crop stand (1 located in a high yielding area and 2 in medium yielding areas).

Soil characterisation for plant available water capacity (PAWC) was undertaken at each site as part of the routine monitoring of plant available water and nitrate N at crop sowing, anthesis and maturity. In 2006/07 EC (Electrical Conductivity) and chloride were measured at each site at the time of crop sowing. Sampling was undertaken using the depth increments of 0-15, 15-30, 30-60, 60-90, 90-120 and 120-150 cm. Bulk density was measured to a depth of 60 cm using the above layer structure (3 replicates).

5.3.3 Time of sowing

Time of sowing trials were conducted in the major wheat production districts of Bangladesh during 2006/07, 07/08 and 08/09 seasons. These included one southern site located at Barisal. Wheat sowing dates were designed to straddle the potential sowing window for wheat from early November through to late December (Table 5). The replicated trial (3) was sown to wheat at 120 kg/ha at a row spacing of 20 cm using standard WRC fertiliser and irrigation recommendations (Urea 100 kg/ha; Triple Super Phosphate 132 kg/ha; MP 100 kg/ha; Gypsum 111 kg/ha; Boric Acid 7.5 kg/ha; 3 irrigations of 100 mm at 20, 50 and 70 DAS).

Seasonal monitoring included the recording of key phenological stages of crop development (emergence, anthesis and physiological maturity) and of management operations including sowing and harvest dates, and fertiliser and irrigation application timing. Total biomass and grain yields were measured at maturity using a quadrat area of 2.4 m^2 and three replicates.

Table 5: Time of Sowing locations, varieties and sowing dates.

Season	Locations	Varieties	Sowing dates
2006/07	Dinajpur, Jamalpur, Rajshahi, Ishurdi, Joydebpur, Jessore and Barisal	Sourav, Shatabdi, Bijoy, Prodip, BAW1059, BAW1064	8Nov, 15Nov, 22Nov, 29Nov, 6Dec, 13Dec 20Dec, 27Dec
2007/08	Dinajpur, Jamalpur, Rajshahi, Ishurdi, Joydebpur, Jessore and Barisal	Sourav, Gourab, Shatabdi, Sufi, Bijoy, Prodip, BAW1059, BAW1064	8Nov, 15Nov, 22Nov, 29Nov, 6Dec, 13Dec 20Dec, 27Dec
2008/09	Dinajpur, Jamalpur, Rajshahi, Ishurdi, Joydebpur, Jessore and Barisal	Sourav, Gourab, Shatabdi, Sufi, Bijoy, Prodip, BAW1059, BAW1064	8Nov, 15Nov, 22Nov, 29Nov, 6Dec, 13Dec 20Dec, 27Dec

5.3.4 Time of sowing x fertiliser rate

A series of trials was undertaken during the 2009/10 and 10/11 season to test the hypotheses that later sown wheat crops should require less than the recommended WRC fertiliser rate to reach yield potential. Experience over the past 4 seasons indicates that it is common for southern wheat crops to be planted later than optimal due to the late harvest of T. Aman rice. Trials were established at a range of locations (Table 6) with a replicated split plot design used (3 replicates at on-farm sites and 4 on-station; main plot: time of sowing, sub-plot: fertiliser rate). Fertiliser rate refers to the combination of fertilisers recommended by WRC (Urea 100 kg/ha; Triple Super Phosphate 132 kg/ha; MP 100 kg/ha; Gypsum 111 kg/ha; Boric Acid 7.5 kg/ha) with all components reduced to 33 and 66% of WRC recommended in the reduced application treatments (Table 6).

Seasonal monitoring included the recording of key phenological stages of crop development (emergence, anthesis and physiological maturity) and management operations including sowing and harvest dates, and fertiliser and irrigation application timing. Total biomass and grain yields were measured at maturity using a quadrat area of 2.4 m^2.

Table 6: TOS x Irrigation.

Season	Locations (3)	Time of sowing (3)	Fertiliser rate (4)
2009/10	Noakhali Barisal (2) Dinajpur (1)	29/11/09 13/12/09 27/12/09	none 33% WRC 66% WRC 100%WRC
2010/11	Noakhali (1) Barisal (1)	29/11/09 13/12/09 27/12/09	none 33% WRC 66% WRC 100%WRC

5.3.5 Salinity screening and observation

With large areas of the districts close to the Bay of Bengal subject to episodic salinity, and the south being generally hotter than the north, the evaluation of breeding lines for salinity and heat tolerance was an important component of the research program. At the time of wheat sowing in the early Rabi season, soil surface salt levels are sufficiently benign to allow successful establishment of the crop. However, as the season progresses, capillary rise results in increases in surface salt concentrations with plants having to increasingly rely on soil water containing higher levels of salt. This results in a reduction in general plant vigour and in the worst cases, plant mortality.

Areas of the Noakhali and Barguna districts have high, but spatially variable levels of salt present in the soil which can impact significantly on crop production. Salt tolerance experiments were undertaken in each of the 5 years of research. In the first 2 seasons sites were selected with high underlying salinity levels, but in the latter seasons sites with moderate levels were selected. This change was made as it was considered that wheat lines with reasonable tolerance to salt were being discriminated against in the highly saline environments. In the first year of research Barisal was used as a zero salinity control (Table 7).

Table 7: Salinity research sites and trials.

Season	Location	Screening Trial Genotype No.	Expt. Design	Observation Genotype No.	Expt. Design
2006/07	Barisal (Rahmatpur)	51	1 replicate (plots 2.5 m x 2 rows)		
	Noakhali (Bariopur)	51		22	1 replicate (plots 2.5 m x 3 rows)
	Noakhali (Hazirhat)			22	1 replicate (plots 2.5 m x 3 rows)
2007/08	Noakhali (Hazirhat)	42	1 replicate (plots 2.5 m x 2 rows)	12	4 replicates (plots 3 m x 6 rows)
2008/09	Noakhali (Hazirhat)	62	2 replicate (plots 2.5 m x 2 rows)	15	4 replicates (plots 3 m x 6 rows)
2009/10	Noakhali (Hazirhat)	26	3 replicates (plots 2.5 m x 6 rows)	12	4 replicates (plots 5 m x 6 rows)
	Barguna (Amtoli)	26	3 replicates (plots 2.5 m x 6 rows)	12	4 replicates (plots 5 m x 6 rows)
2010/11	Noakhali (Subarnachar)	26	4 replicates (plots 2.5 m x 6 rows)		
	Barguna (South Amtoli)	26	4 replicates (plots 2.5 m x 6 rows)		

Salinity screening

The screening trials were used as a broad brush evaluation to identify lines from Australia, India, Mexico, Pakistan and Bangladesh with increased salinity tolerance. Lines were compared against the newly released local varieties including Shatabdi and Prodip, which it was assumed, had some tolerance to salt and were reasonably well adapted to higher temperature environments. Due to the small amounts of seed available for evaluation it was not possible to provide replication in all trials. Dates of plant establishment, anthesis and maturity were recorded. Biomass and grain yield were measured and relative salt tolerance was assessed by ranking lines for yield. Soil EC levels were measured at sowing and crop maturity.

Salinity observation

Shortlisted lines from the screening program with apparent superior salinity tolerance to the standards, along with lines already identified through the WRC breeding program, were more intensively assessed for salt tolerance using larger plots and increased replication (Table 7). As in the screening trials, dates of plant establishment, anthesis and maturity were recorded. Biomass and grain yield were measured and relative salt tolerance was assessed by ranking lines for yield. Soil EC levels were measured at sowing and crop maturity.

5.3.6 Formed beds vs flat planting

During the 2008/09 season the use of conventional tillage practice (sown on the flat and the seed broadcast) was compared to the use of formed beds (ridges) and the sowing of wheat in rows. Attachments for the commonly used two wheeled power tiller are now available to form a ridge, to plant two rows of crop and apply fertiliser in one pass. These provide a ridge centre spacing of less than 60 cm which is appropriate for wheat. Beds improve irrigation efficiency with the ridge top remaining oxygenated during irrigation, avoiding short-term root water-logging and accompanying cessation of carbon fixation and growth. This can save 1-2 days growth per irrigation cycle compared to flat-land flood irrigation. There is also less likelihood of crop lodging during windy weather and after heavy rain. In saline areas where salt rises through capillarity in wet soil, plants on the ridge tops will not be as exposed to salt as on flatland where pooling after irrigation and light rains creates salt slicks and associated plant mortality.

Normal recommendation for wheat using 20 cm row spacing is to sow 120 kg seed/ha, though this varies with seed boldness. This can be reduced to 80 kg seed/ha with ridge planting thus saving the farmer money. Less seed is needed because the number of overall rows planted is less. However there are negative aspects as well, bed planters are expensive to buy and run and the yield differential would need to be substantial for individual farmers to invest although the purchase of machines by individual farmers and the contracting of their services would be an option.

Bed and flat planting were compared at 4 SMT sites in Barisal and 4 SMT sites in Noakhali. Planting dates were the same at any SMT for the two treatments and the area tested was approximately 1000m² at each SMT. Varieties common to the regions were Bijoy, Sourav and Sufi, while additionally Prodip was used at Barisal and Shatabdi at Noakhali. As this study was undertaken on existing SMTs the monitoring regime undertaken on both the flat and raised bed treatments was the same as described in 5.2.

5.4 Systems analysis

5.4.1 Soil monitoring and characterisation

Over the four seasons of research, soils at the 'detailed' SMT farms were monitored for water status and nutrient availability and their Plant Available Water Capacity as expressed in mm calculated.

To characterise a soil for PAWC it is necessary to measure or estimate volumetric water content at points on the water characteristic curve which equate to saturation (SAT), drained upper limit (DUL) and crop lower limit (CLL) (Dalgliesh and Foale, 1998). Due to the generally wet soil conditions at the commencement of the Rabi season cropping period and the homogeneity of the soils at each of the locations it was considered appropriate to utilise data collected as part of pre-season soil monitoring to determine DUL. A similar rationale was used for the determination of CLL with monitoring data collected at crop maturity used in conjunction with piezometer data (in 2008/09) to develop a lower limit for wheat.

A suite of 29 soils has been characterised during the life of the project which represent the districts and sites where research has been undertaken (Table 8).

Prior to wheat sowing, each of the detailed SMT and experimental sites was sampled using a 37 mm diameter driven coring tube to a depth of 1.5m. The extracted soil cores were separated into the layers from the depths of 0-15, 15-30, 30-60, 60-90, 90-120 and 120-150 cm. Three cores were taken within each SMT (~1000 m^2), bulked by layer, mixed and split into two samples for the estimation of water and nutrients. Depth to saturated layer was recorded. Soil water samples were weighed immediately after sampling, dried at 100ºC for at least 48 hours and re-weighed to estimate gravimetric water content. Soil nutrient samples were air-dried and analysed for nitrate nitrogen (NO3-N) and EC)at the BARI chemistry laboratories at Joydebpur. Bulk density (BD) was measured at two sites per detailed SMT and experimental site with three replicates taken at each site to a depth of 60 cm (using the same depth layers as above). Driven rings with a volume of 51 cm^3 were hammered into the soil, extracted, soil trimmed and dried at 100^{o}C before weighing. The BD was estimated for depths below 60 cm.

Table 8: Soil characteristics for a range of soils in Southern Bangladesh.

Season	District	Site	PAWC (Wheat) to 1.5m (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	Babugonj	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
	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
Average			146 stdev 19

5.4.2 Climate data

Long-term climate data to 2005 was obtained from the Bangladesh Meteorological Department (BMD) for 30 national climate stations with further updates obtained in 2008 and 2009. Data included daily sunshine hours (h), maximum and minimum temperatures (^{o}C) and rainfall (mm). A subset of 13 key regional stations located in the southern region of Bangladesh was selected and converted to a format suitable for use with APSIM (Table

9). These data were supplemented by measured data using single channel data loggers recording temperature and solar radiation located at experimental sites in Noakhali, Barisal and Bhola from the start of the project in 2005 to 2011 seasons. Data from the official meteorological station at BARI Headquarters at Gazipur was used for the 2005-06 season

Solar radiation (H, MJ m-2 d-1) was calculated from measured sunshine hours (n, hours) using the Angstrom equation (Angstrom 1924) where Ho is extraterrestrial radiation (MJ m-2 d-1), N' is day length (hours) and *a* and *b* are fitted coefficients.

$H = Ho(a + b(n/N'))$

A number of coefficients published in *Measurement and study of solar radiation over Bangladesh* and *Solar radiation in Bangladesh* (www.lged-rein.org.htm) for locations in Dhaka, Bangladesh were evaluated for best fit with long-term monthly mean values of solar radiation (MJ d^{-1}). To include the seasonal effect, the fit was taken for 2 periods, March to September (Kharif) and October to February (Rabi). Two sets of Angstrom coefficients for Dhaka are presented (www.lged-rein.org.htm) with the values for source 2 (Table 10) generating daily radiation values that best fit long-term mean monthly radiation data. These coefficients were then used to convert all daily sunshine hour data to daily solar radiation (Mj/day) for all 13 long-term climate sites used for simulation analysis. Additional radiation sensors were placed at the research station in Joydebpur over the 2008-09 season. Measurements of both global solar radiation (R_s) and photosynthetically active radiation (PAR) were recorded for evidence of solar dimming due to seasonal low atmospheric haze and pollutants. Atmospheric haze potentially reduces the level of sunshine hours recorded and may lead to lower calculated values of daily solar radiation affecting radiation use efficiency (RUE) models such as APSIM.

Table 9: Long-term climate stations converted to APSIM input file format and used for simulation analysis

File	Location	Station code	International ID	Latitude, Longitude, Altitude	Start of record *not all variables start in the same year
1	Barisal	11704	950	22.42N 90.21E 4m	1949
2	Bhola	11706	951	22.42N 90.39E 5m	1966
3	Chandpur	11316	941	23.15N 90.40E 7m	1966
4	Comilla	11313	933	23.28N 91.11E 10m	1948
5	Dhaka	11111	923	23.46N 90.23E 9m	1948
6	Dinajpur	10120	863	25.37N 88.39E 37m	1948
7	Feni	11805	943	23.00N 91.22E 8m	1973
8	Jessore	11407	936	23.10N 89.13E 7m	1948
9	Khepupara	12110	984	21.58N 90.13E 3m	1975
10	Khula	11604	947	22.40N 89.04E 4m	1948
11	Madaripur	11513	939	23.10N 90.10E 5m	1977
12	MaijdeeCourt	11809	953	22.49N 91.04E 6m	1951
13	Patuakhali	12103	960	22.21N 90.20E 3m	1973

Table 10: Coefficients for Angstroms equation

Source	Station	Period	a	b
1	Dhaka	Mar-Sep	0.281	0.383
1	Dhaka	Oct-Feb	0.241	0.419
2	Dhaka	Mar-Sep	0.239	0.483
2	Dhaka	Oct-Feb	0.266	0.436

5.4.3 APSIM setup

APSIM was applied to investigate the potential for Rabi season wheat and mungbean production and to evaluate cropping options in rice based farming systems. Specification of APSIM requires input data for soil, climate and information on crop management for individual sites and farming systems of interest. Soil characterisation data was obtained from detailed monitoring at SMT sites (2006-09) with 29 soil profiles now available for selection from APSoil (Dalgliesh and Foale, 1998) (5.4.1). The nearest long-term daily climate record (13 available in APSIM format) was selected along with specific crop management options. Soil profiles were set to 180 cm to enable incorporation of a water table below the rooting zone of the crop.

APSIM is essentially a point model though it has been parameterised in some systems for dealing with spatial flows at a multipoint scale. Unsaturated flow in the current APSIM water balance (soilwat2) has not been designed to operate with dynamic water tables and required parameterising outside the normal values used for dryland agriculture in order to facilitate capillary rise in these soils. Diffusivity was set high in order to achieve any significant upward flow with watertable levels adjusted using fortnightly inputs. The water balance model, APSIM SWIM (Verburg 1996) was also parameterised and tested for one site and demonstrated ability to simulate upward flows to ~2 mm d^{-1} over the cropping season. A version of the SWIM model is currently not in the APSIM release 7.1 (used in the simulation analysis) and requires further testing, evaluation and a higher level of parameterisation before it can be used for scenario analysis of local farming systems. Simulation results presented are based on a use of a modified SOILWAT with restricted drainage losses during the early Rabi while water tables are close to the surface.

The initial APSIM configuration was tested against the 2006-07 variety trials at Barisal, Bhola and Noakhali to develop a suitable wheat variety (Shatabdi) as a baseline cultivar for simulation of experimental treatments. Grain yield, biomass and soil water at sowing, anthesis and maturity are compared across all sites. Soil salinity at the Noakhali site was observed and site specific parameterisation of KL values (maximum rate of water extraction for a particular soil layer) in APSIM used. Cultivar specific phenology was developed from the time of planting trials (TOP) over 3 seasons from 2006 to 2009. Data from the 2007-08 irrigation by nitrogen trial at Bhola was used to parameterise irrigation and nitrogen treatments within APSIM. APSIM-Oryza was also configured to simulate sown and transplanted upland, T.Aus and T.Aman rice cultivars and was tested against on-farm yields from the 2007-08 SMT sites at Bhola.

5.4.4 Simulation analysis

Using simulation models to explore the potential environmental constraints to Rabi-season cropping

Systems modelling (using the APSIM model) of key crop rotational practices was undertaken using data collected from trial sites over 3 seasons (2007-09) to help identify potential constraints and limitations to farming practice and to inform discussion between project collaborators. Main data requirements consisted of long-term daily climate records for key sites; water holding characteristics of the soil, knowledge of current farming practice and current cropping systems. Long-term climate data was purchased from the Bangladesh Meteorological Department (BMD) and transformed for climatic and modelling analysis. Soils characterisation was carried out in each of the experimental regions and is described in 5.4.1. Farmer interviews as part of the socio-economic study provided a detailed description of the current farming systems and local practices. WRC, DAE and other government department's prescriptive recommendations contributed to a systems evaluation in conjunction with results of field experimentation.

Data on depth to ground water for a subset of southern regions was obtained from Bangladesh Water Resources (WARPO) and evaluated both temporally and spatially, providing a historic record of ground water availability and informing the system modelling and field experimentation components of the project. Evaluation of potential volume of surface water storage was undertaken using ground surveys, satellite imagery classification and observational assessment of Google Earth (http://www.google.com/earth/index.html) images for a case study of 300 ha at Noakhali.

Using simulation to explore the potential Rabi season cropping options

Initial validation on a subset of the experimental data has demonstrated a capability to model wheat, mungbean and to a lesser extent rice in Bangladesh farming systems. A number of cropping sequences based on farmer survey data were constructed (Table 11) and simulated in APSIM using 30 years of climate records for key sites. Simulated results are incorporated into the economic analysis in conjunction with farm survey data.

Table 11: Schematic of crop rotations available for simulation.

System	Dec Jan Feb Mar	Apr May Jun Jul	Aug Sep Oct Nov Dec
Upland_Aus		25-Mar Aus [Local] N15,20,40	
T_Aus		25-Apr T.Aus [BR3] N15,20,40	
T_Aman			1-Aug T.Aman [BR23] N25,30,50
T_Aman-boro	15Jan-15Feb Boro		1-Aug T.Aman [BR23] N25,30,50
T_Aus-wheat	20-Dec Wheat [Shatabdi] N50,50	25-Apr T.Aus [BR3] N15,20,40	
T_Aman-wheat	20-Dec Wheat [Shatabdi] N50,50		1-Aug T.Aman [BR23] N25,30,50
T_Aus-T_Aman-wheat	20-Dec Wheat [Shatabdi] N50,50	1-Apr T.Aus [BR3] N25,30,50	1-Aug T.Aman [BR23] N0
T_Aman-wheat-mung	20-Dec Wheat [Shatabdi] N50,50	1-Apr Mungbean [local]	1-Aug T.Aman [BR23] N25,30,50
Wheat	20-Dec Wheat [Shatabdi] N50,50		
Mungbean		1-Apr Mungbean [local]	
T_Aman-Mung		1-Apr Mungbean [local]	1-Aug T.Aman [BR23] N25,30,50
T_Aus-T_Aman-cowpea	15Jan-15feb Cowpea	1-Apr Mungbean [local]	1-Aug T.Aman [BR23] N25,30,50
T_Aus-T_Aman-grasspea	20Oct-15Nov Grasspea	1-Apr Mungbean [local]	1-Aug T.Aman [BR23] N25,30,50
T_Aman-wheat-0N	20-Dec Wheat [Shatabdi] N50,50		1-Aug T.Aman [BR23] N0
T_Aman-Mung-0N		1-Apr Mungbean [local]	1-Aug T.Aman [BR23] N0

5.5 Training and extension

Training workshops have focussed on providing participating farmers and government and non-government extension agents with the agronomic and management skills necessary to successfully grow wheat and mungbean. The main extension tool used by the project has been the SMT which provides a focal point for demonstration and extension of the technologies and the seed resources necessary to ensure future expansion of wheat and mungbean production. Another component of extension which is critically important to the longer term expansion of Rabi-season cropping is the briefing of policy makers on the potential for increased Rabi season cropping to contribute to national food security. Without a focus on policy makers it is unlikely that significant investment and change will take place.

5.5.1 Change agent and farmer training and extension

Prior to each season project scientists trained farmers, DAE and PROSHIKA extension personnel and regionally based scientists. Training was generally done at the district or Upazila level although in the lead up to the 2009/10 and 2010/11 seasons training was focussed at the village level to enable farmer spouses to attend (Table 12). This was an initiative resulting from the social evaluation program which highlighted the shared responsibility of women in crop decision making which in the past has not been recognised in the development of training packages. This initiative was highly successful with 115 couples attending the training in 2009/10 and 145 women (43% of farmers) attending in 2010/11. Whilst the focus of the one day workshop was on crop agronomy and management, an overview of the project and the research program was also provided. In 2008 post-harvest field days were conducted in the three districts of Barisal, Bhola and Noakhali to enable farmers and local government officials to inspect the SMT crops grown by the collaborating farmers and to promote Rabi-season cropping potential in the south. In an attempt to ensure that extension staff were kept up to date on research outcomes, regional meetings were conducted in 4 districts leading up to the 2009/10 season. These involved the DAE staff involved in day to day extension including the agricultural officers, crop production specialists and training officers, as well as local BARI scientists. In 2008, in response to a need identified by the project for improved skills in insect and weed management in pulses, scientists from the ACIAR Northern Pulse Project (LWR/2005/001) (Chris Johansen, AM Musa and Sirajul Islam) provided training in pulse agronomy to extension staff and farmers in Barisal (staff from Proshika (15), DAE (12) and BARI (1) attended).

5.5.2 Staff training

Whilst the Scientific and Technical Officers employed by the project attended the regional training days they also participated in an annual technical workshop conducted in Dhaka. These workshops were held prior to the commencement of the season (Oct/Nov) whilst Australian researchers were in-country. The aim was to ensure that the 6 Scientific Officers and 10 Technical staff understood the aims of the project and had the technical expertise to undertake their duties. The running of these meetings on an annual basis was important because of the high turnover of staff. Draft annual operational plans and field data books (developed by the scientists) provided the basis for discussion, with staff encouraged to provide their input into the planned work program. Technical training was conducted in the use of a range of equipment and techniques including hand held GPS devices, soil coring, installation of piezometers, harvest protocols and phenology measurements for wheat. A video produced by the project in 2005/06 was used to train staff in soil sampling techniques, from the preparation of equipment to the bagging and weighing of samples.

Table 12: Training and formal extension program.

Season	Location	Activity	Participants
2006/07	Barisal, Bhola, Noakhali	Pre-season district training	3 workshops with a total of 119 farmers, extension agents (DAE, BARI, PROSHIKA) and scientists attending
2007/08	Barisal	Pre-season district training	Total of 34: 15 farmers, 13 DAE, 6 WRC/PROSHIKA project staff
		Post-season field day	~80-100 farmers and officials
	Noakhali	Pre-season district training	Total of 38: 18 farmers, 11 DAE, 9 WRC, PROSHIKA project staff
		Post-season field day	~80-100 farmers and officials
	Bhola	Pre-season district training	Total of 45: 20 farmers, 17 DAE, 6 PROSHIKA, 2 project staff
		Post-season field day	~80-100 farmers and officials
2008/09	Barisal	Pre-season district training	DAE and NGO staff (Pulse agronomy)
	Barisal, Noakhali, Bhola, Pirojpur, Patuakhali	Pre-season district training	Total of 172: 94 farmers, 70 DAE and PROSHIKA, 8 WRC scientists
	Barisal, Noakhali, Bhola, Pirojpur, Patuakhali	Pre-harvest wheat field day and mungbean promotion	5 workshops undertaken

2009/10	11 locations in Barisal, Noakhali, Bhola, Pirojpur, Patuakhali and Jhalakathi	Pre-season district training	Total of 391: 269 farmers including 115 couples, 81 DAE, 41 scientists and project staff
	Noakhali, Barisal, Patuakhali and Bhola	Feedback on research results and discussion on expansion of wheat in south	DAE regional staff tasked with extension in south. Included Upazila Agricultural officers, crop production specialists and training officers + BARI regional scientists
2010/11	Barisal, Noakhali, Bhola, Pirojpur, Patuakhali and Jhalakathi	Pre-season district training	Total of 459: 334 farmers including 145 women, 114 DAE/BARI and 11 project staff

5.5.3 Development of a Rabi-season cropping manual

As part of the communication strategy developed in early 2009 a decision was made to develop a training manual on Rabi-season crop production for southern Bangladesh. The goal was to develop a document that both met the information needs of farmers but also provided more background science for extension agents and researchers. As would be expected the manual draws heavily on the research findings of the current project and previous activity undertaken by WRC and FAO. The manual was written in English by Drs' Rawson, Saifuzzaman and Shakhawat and has been translated into Bengali for distribution to farmers and their extension agents. The manual complements several other publications in Bengali produced by WRC, FAO and CIMMYT that cover production of Rabi crops for the whole of Bangladesh.

5.5.4 Publication of ACIAR Technical Report

In 2010 a request was made of ACIAR that research papers describing the results of the 5 years of social, production and systems research undertaken in Bangladesh be compiled into a technical report. The resulting report “Sustainable intensification of Rabi cropping in southern Bangladesh using wheat and mung bean” is aimed at informing researchers and extension agents of both the methodologies used in the research and its outcomes. The majority of project researchers have contributed to the 19 papers which cover the integration of new crops into an existing farming system from the perspectives of production and cropping systems, economics and the social systems in which farmers operate. Publication is expected in mid-2011 with the document targeting researchers in both Bangladesh and other countries interested in the integration of a new crop into an existing system.

5.5.5 Change manager extension

It was recognised by the project that change would not occur in southern farming systems unless there was informed knowledge at the political level and the will to promote future expansion of production in the south. A communication plan was implemented in 2009 that targeted Bangladesh policy makers and the heads of relevant government departments. Meetings were held in October 2009 between Bangladesh and Australian research staff and the Minister for Agriculture (Motia Chowdhury), the Minister for Food and Disaster Management (Dr Md. Abdur Razzaque), The Parliamentary Standing Committee on Agriculture, the Executive Chairman of the Bangladesh Agricultural Research Council (BARC) (Dr Wais Kabir) and the Director General, Dept Agricultural Extension (DAE) (Md. Sayeed Ali). The upshot of these meetings was the convening of a workshop for Ministers and senior public servants titled “Wheat cultivation in southern Bangladesh: The potential for expanding the Rabi season cropping” which was held in Sept 2010 and hosted by the Chairman of BARC (Dr Wais Kabir). Over 80 delegates attended including the Minister for Agriculture (Motia Chowdhury) and the Australian High Commissioner and a number of international aid agencies including FAO (Food and

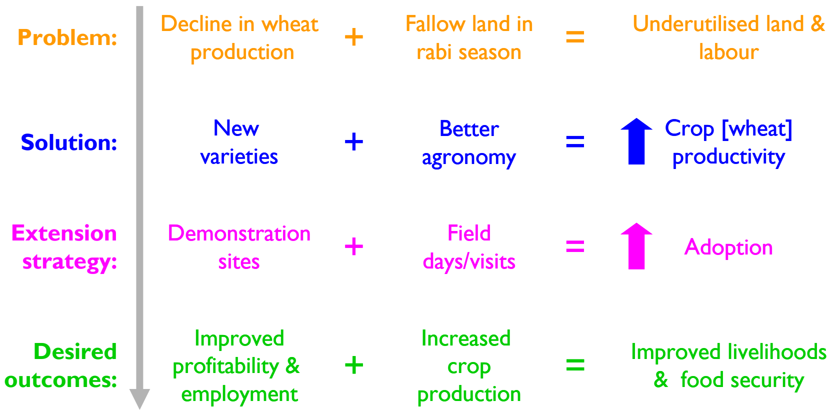
Agriculture Organisation), USAID (United States Agency for International Development) and DANIDA (Danish International Development Agency).

5.6 Socio-economic research

A starting point for the socioeconomic component of the project was the research perspective of the problem and the technical innovations and extension strategies designed to overcome it. The overall objective of the project has been 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 (Carberry 2007). Figure 2 summarizes the research logic which has been used to guide the activities of the project.

The socioeconomic component of the project potentially provided insights into some specific research questions that have been raised by the research logic of the project. In analysing livelihoods improvement, the Rural Livelihoods Framework (RLF) seemed useful. The RLF 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 asset.

Figure 2: Overall research logic for the project.



5.6.1 Rural livelihoods analysis

The RLF has become popular in examining the social and material conditions within which targeted participants seek to gain access to food, other basic needs and overall improvement of the household asset base. A household's 'entitlement' consists of endowments and exchanges. Firstly, a household is considered to be endowed with a set of resources, which conditions the range of economic options available to it.

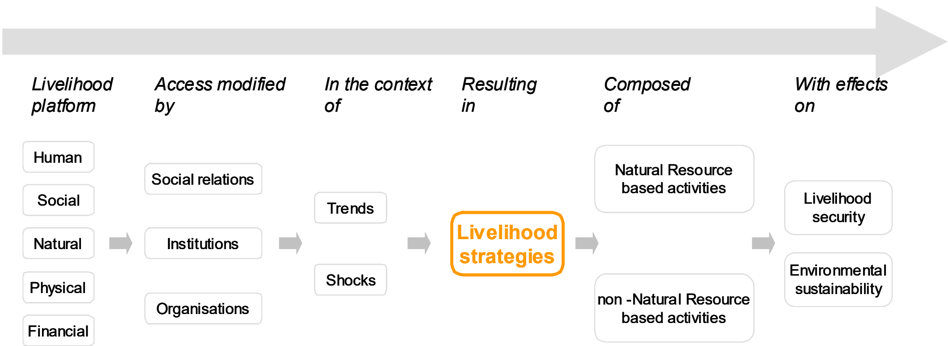
The idea of livelihood as defined above embodies three fundamental attributes: the possession of human capabilities (such as education, skills, health, psychological orientation), access to tangible and intangible assets and the existence of economic activities. The interaction between these attributes defines what livelihood strategy a household pursues.

Socioeconomic research methods are broader than traditional economic analysis of farming systems and may be required to identify and measure the impact of alternative cropping patterns on rural livelihood strategies. Adoption is a continual process of adaptation and reinvention of component technologies to meet local needs. How farmers interpreted their production situations and how they articulated their constraints and needs to researchers, as well as their desire to contribute more directly and creatively to the design and evaluation of new technologies, were all considered in the analysis. In contrast, methods to define the adaption of specific technology changes in terms of their interaction and impact on rural livelihoods are less well established. One potential approach is rural livelihood analysis (Scoones 1998, Ellis 2000- Figure 3). Rural livelihood analysis is a conceptual framework rather than a socioeconomic research methodology for collecting data. It encourages the researcher to view the adaptation of specific livelihood activities such as Rabi season cropping as enmeshed in the context of assets, mediating processes and activities that combine to shape rural livelihoods (Ellis 2000). Extension programs designed to encourage and support land mangers in their efforts to adopt more productive, profitable and/or sustainable land uses is only one of many mediating process that influences livelihood decision (Figure 3). As these influences interact, an integrated conceptual framework is useful for identifying which aspect need to be monitored to guide effective support for land managers in specific contexts.

The rural livelihoods framework recognizes that rural livelihoods are generated and sustained in a complex operating environment in which multiple trends and shocks interact and coalesce (Figure 3). The framework also recognizes that the ability of households to access alternative forms of capital to generate livelihoods is influenced by social and institutional factors that can be uncertain and largely beyond individual control. The position of individuals within society determined by class, gender, ethnicity, age and religion can significantly influence access to resources, as can both formal and informal institutions such as laws and local systems of resource governance (Ostrom 1999).

The rural livelihood framework includes the concept of social capital, both as reciprocal claims on, and support from others in the local community that 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 intervening and adopting innovations.

Figure 3: A framework for the analysis of rural livelihoods.



5.6.2 Methodological Approach

In implementing the socio-economic research, a mixed approach, combining quantitative and qualitative research tools has been followed. Following the quantitative sampling framework, a household survey was administrated using a structured questionnaire.

A stratified sampling was followed. The first strata involved the selection of the southern coastal regions of Bhola and Noakhali, determined as having the most potential to grow new varieties of wheat on land underutilized during the Rabi season. The second strata involved the selection of areas within these districts with underutilized land and the potential to grow new varieties of wheat.

Selection of village

A pair of villages (with/without a trial/demonstration plot) was selected in each of the Bhola and Noakhali regions during the 2007-08 Rabi season. A list of the sites where Seed Multiplication Trials (SMT) were being conducted was used to randomly select a village which was currently involved in the on-farm research. A second village, with no current involvement in the project was then selected using the Excel based program “Random village selector.xls” which randomly selects a point on the map which is located by researchers using GPS. The nearest village to that point and >4 km from the trial village, with attributes that made it amenable to crop intensification strategies, but was outside the “sphere of influence” of project agronomic activities, was then selected for interview (subject to the agreement of the local farmers). The characteristics used in making the final decision on village selection included the availability of areas with limited fresh surface or ground water storage in the Rabi season for irrigating rice, and/or significant fallow areas or areas under low intensity cropping and related land uses such as the production of grass pea (*Lathyrus sativus*) and extensive grazing.

Sampling households within villages

Within each village, exploratory field work was conducted to identify groups which would likely have significantly different perspectives on the adoption and livelihood impacts of Rabi season crop intensification. These included:

- Wealthy farming households that own significantly more land than that required to meet basic livelihood needs, and therefore rent significant (net) areas of land to others.
- Farm households of moderate wealth that own some of the land being farmed, but also rent land from others to supplement basic livelihood needs.
- Households that perhaps own the land on which they live, but rent land from others to meet almost all livelihood needs, often strongly focused on subsistence.
- Landless labourers whose primary connection to Rabi season cropping involve working for a daily cash wage or in-kind wage (or combination of these, sometimes involving advances).
- Women in each of these groups can have a significantly different perspective compared to that of men, and require specific strategies to reach because of cultural issues.
- Households for which wheat was an integral part of current farming systems (even if not grown in a particular season) versus households which did not usually consider wheat as a cropping options in the Rabi season.

Village transect and mapping

The above steps characterize the household selection process, and were repeated for the 2 villages in each region during a week of field work, before returning to undertake household interviews. The general process included:

- Making initial contact by walking through the village to observe and informally meet people.
- Important physical, social and economic characteristics of the village were observed which it was thought may be useful during interview.
- A social and infrastructure map of the village population was developed in consultation with village elders which included the location of houses and important amenities such as markets, roads and businesses that affect livelihood opportunities.
- The types of households across the village were broadly mapped to get a sense of whether different types of households were evenly distributed, or clustered around certain features or on particular types of land.

- Land use mapping was undertaken with leading farmers and landholders. Land suitable for different types of Rabi season crop were mapped and matched to current land use (especially Rabi season crops) and the criteria used to make these decisions discussed.
- A history of wheat growing in the village was captured, especially for the last 10 years.
- Important water resources across the village and places where lack of water constrains Boro rice production were mapped. The reasons for this were noted.
- Information on recent NGO activities in the area (last 5 years) was collected, especially any that may have had an impact on Rabi season cropping (e.g. credit for seed purchase, seed supply, etc).

Household sampling

Households were selected within those areas of the village where there was potential to grow wheat and Rabi season crops other than Boro rice. Fieldwork confirmed expert opinion that areas with sufficient fresh water supplies and irrigation infrastructure are likely to be used to grow Boro rice rather than other Rabi season crops. The GPS and "Random village selector" were used to select and locate 5 points within each village. These points were then used by the interview team as focal points for social mapping including identification of the closest example of each type of household. In non-wheat growing regions researchers chose the closest household to each point, rather than taking the "most available", Owner (O), Owner/Tenant (O/T), Tenant (T), Landless (L) and Wheat Grower (W)]. In wheat growing regions, it was repeated for wheat and non-wheat growing households. In non-wheat growing regions, there was only a very small number of wheat growing households in each village. By following this process 10 owners, 10 owner-tenants, 10 tenants and 5 landless households were interviewed in each village.

Participatory Assessment

The methodological approach was designed to gather the farmers' views on the adoption of a new crop. The three Participatory Research Assessment (PRA) methods used are described below:

Focus group discussion: Before obtaining data from the individual farmer a focus group discussion was held to identify their point of view on the adoption of new crops and their livelihoods capital status in terms of their ability to adopt a new crop. Focus group discussions helped to identify issues for self assessment and in-depth interview. They provided a useful starting point in revealing the range of the informant's thoughts, experiences and perceptions on the cultivation of wheat in the Rabi season and mung bean in Kharif-1. Group discussion also informed on the effectiveness of existing extension support and necessary extension strategies for adoption of a new crop rotation.

Self assessment: This approach explicitly assesses the adaptive capacity of rural households to adopt a new crop. The respondents were asked to work together as a group to derive an adaptive capacity index for the type of stakeholder type and/or community/area/village that they represented. They were asked to discuss and provide a rationale for the indicators chosen to represent each asset capital type around the following three questions:

- What was the rationale for choosing this indicator?
- Why was this indicator different (low or high) for new crops compared to the traditional crop?
- Were the existing extension support networks adequate to adopt a new crop? What are the highest priority actions for improving this?

Case studies: During focus group and self assessment activities centred on new crop livelihood capital status, a number of issues were identified requiring further investigation in order to understand how such issues influence the livelihood outcomes of the poor (e.g. patron-client relationships, institutional issues, gender issues, etc). The purpose of the in-depth case study exercise was to gain a better understanding of the asset pentagon and the transformability of the farmer asset base according to livelihoods capacity. It was a way of better understanding farmer diversification and intensification strategies. For example, how do the rural households (or other stakeholders) use and transform their assets/stocks and make decisions to adopt a new crop?

5.6.3 Economics of increased Rabi season cropping

Rural livelihoods analysis and economic assessment of current and possible farming systems options were both undertaken in the same villages in Bhola and Noakhali (see 5.6.2 for description of selection process). Stratified random sampling techniques were followed for selecting sample farmers within each village. Respondents were stratified into 6 groups - owner wheat grower, owner non-wheat grower, owner tenant wheat grower, owner tenant non-wheat grower, tenant wheat grower and tenant non-wheat grower. A total of 120 farmers were selected for this study, sixty from each region with thirty from each village. In each village five farmers were randomly selected from each stratum using the GPS to locate the nearest farmer to a set of randomly generated co-ordinates.

Data collection and analysis

Interviews were conducted in the farmer's house using an interview sheet designed to ensure that consistent data was collected from all interviewees. Interviews generally took 1 to 1.5 hours and were undertaken by the project economist.

An enterprise budgeting methodology was used to determine the viability of the current farmer enterprise with one which included wheat as a component of the rotation.

The total variable production costs for each crop included the costs of human labour, ploughing, seed, fertilizer, irrigation and insecticide etc. For purchased inputs actual cost was recorded whilst for farmer supplied inputs including family labour, seed etc, cost was calculated by applying the principle of opportunity cost. Whilst in practice there are differences in the wage rate for male and female labour, in this study all labour was costed at the male rate. Per hectare gross return was determined by multiplying the farmer's received output for each crop by the received market price. A limitation of the methodology in these farming systems is that it does not account for crop by-products such as rice and wheat straw.

Measurement of the farmers gross margin, gross return and total variable costs

Most farmers aim to achieve the maximum gross margin possible for their crop, or in some instances to incur the minimum cost possible at each level of output. To achieve either of these aims, farmers have to work within technical and economic constraints. The economics of the situation also have to be considered within the livelihoods framework of the individual farmer where issues such as meeting household consumption needs, ensuring food security and protecting against risk may be more important than pure economic return. In this study conditions for maximum gross margin were given emphasis as it was considered that this was a plausible goal for many farmers, particularly those 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 service produced by a farm and cost of resources used in production. 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 (Dillon and Hardaker, 1980). 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.

Sensitivity analysis

Sensitivity analysis of wheat profitability was done by altering wheat price, production cost and yield (in a poor, average and good season) for trial and non trial villages on Bhola. This was undertaken using a spread sheet model in conjunction with APSIM simulation. APSIM was used to determine the long term seasonal variability in yield (over 30 years using Bangladesh long term climate files and soil data from Bhola), to confirm farmer perceptions of season type ie poor, average, good, and the yields that they remembered achieving.

The spread sheet model was developed using a nominal farm size of 250 decimals (1 ha) which was then utilised for one of a suite of 8 potential cropping scenarios. These were:

Wheat/Transplanted Aus rice/Transplanted Aman Rice; Grass pea/T Aus/ T Aman; Cowpea/ T Aus/ Taman; Boro Rice/ T Aman; Mungbean/ T Aus/ T Aman; Wheat/ T Aus/ T Aman; Wheat/ Mungbean / T Aman and Fallow/ T Aus/ T Aman

Gross margins and farm household incomes were calculated for the 8 systems scenarios by the 3 seasonal types with farmer's yield and cost of production from data collected in February 2008. Simulated yields were discounted to take into consideration the impact of pests and diseases and sub-optimal farmer practices (lower than optimal fertiliser and irrigation rates for example).

6 Achievements against activities and outputs/milestones

Objective 1: To delineate and characterise the areas where Rabi–season cropping is feasible on currently fallow lands with or without supplementary irrigation

no.	activity	outputs/ milestones	Achievements against activities
1.1 PC, A	Quantitatively describe the environmental and socio-economic resources for prospective Rabi-cropping regions in southern Bangladesh	Soil characterisation data (water, N, EC) measured for the principal cropping soils at each site	• The monitoring of soil water and nitrate N was undertaken at the detailed SMT (Table 1) and research sites (Table 2). PAWC characteristics were developed from these data with a suite of 29 profiles now available in the APSoil database (Table 8). Soil water data measured at sowing and maturity, in conjunction with the water holding characteristics provides the basis for systems analysis using simulation. 41 piezometers installed at detailed SMT sites and some research sites in 2007/08 and 2008/09 were used in the simulation of water table contribution to crop production and in the development of appropriate water characteristics for soils where water tables are present. • EC and chloride were measured at Salinity Observation trial sites during the 2007/08 season (Noakhali). Concentrations of salinity in ground water were measured using the piezometers in 2009/10 calibrated to related soil data.
PC, A		Irrigation water quality / availability described for each region	Several useful datasets were provided by the relevant agencies (WARPO, BWDB and BARC) • Water tables - ArcView shape files were sourced from 1998 to 2002 containing monthly groundwater depths for all locations in southern Bangladesh. Updates for key focus areas (Pre 1998 and 2003-07) were sourced and long-term ground water data files created for use in the simulation analysis. • Surface water - determined by two methods (1) analysis of satellite photos and (2) surveys by local project staff. Data from both approaches were used in analysis of irrigation water availability.
PC		Long-term climate data accessed for key sites	• Long-term climate data was sourced for 31 sites (from 1948 to June 2009) from the Bangladesh Met Dept. 12 files were converted to APSIM format for simulation analysis of regions of interest in the south. Data includes max/min air temp., radiation, sunshine hour, wind speed (max. & min) and evapotranspiration. • Weather stations were installed in Bhola, Barisal and Noakhali and data collected and checked and processed into APSIM format files. These data have been used in the validation of the APSIM model for local conditions.

PC, A		Benchmark evaluation undertaken, including data on past system performance, crop cultivars & agronomic management, socio-economic status of local farmers	• An exploratory PRA was undertaken in Noakhali in Mar 07 to gain an understanding from farmers and extension agents of the status of Rabi-season cropping including its economics, the constraints to production and the livelihood impacts of increased Rabi-season cropping activity. This study was used to determine appropriate social research process and areas for investigation in future research activity. • A broader PRA using 3 methodologies was undertaken in Barisal and Noakhali districts in mid-2008. Two villages were selected for evaluation in each district with focus groups, self assessment and case studies undertaken to understand farmer perspectives on adoption of wheat and mungbean cropping and the impact on livelihoods. The insight that women are key decision makers in crop selection and undertake most of the post harvest threshing and cleaning led to changes in the pre-season training program. Meetings were held at the village level to allow the inclusion of spouses. • A broader more detailed livelihoods analysis was undertaken in early 2009 and reported in 2011 as part of the ACIAR Technical Report.
1.2 PC, A	To spatially represent suitable Rabi-season cropping areas using four defined land categories	Maps showing the spatial distribution of land types with: a) current shallow tube well irrigation infrastructure b) no salinity and surface storages of monsoon rainwater suitable for supplementary irrigation c) near-surface water tables or high soil water holding capacity sufficient for dryland cropping d) poor quality ground water but high quality surface water sufficient for irrigations	• Data for 20 Upazila locations in southern Bangladesh containing areas (ha) under cultivation and fallow along with land inundation type (land class) for the 2005/06 season were sourced and data used for benchmarking the satellite imagery analysis. • Analysis of satellite imagery during the 2007 and 2008 seasons for the Noakhali district produced a classification system covering water bodies; tree cover; bare fallow land and crop/grazing lands. These results are encouraging due to the small field areas targeted in the analysis. Further ground-truthing was carried out in Mar 09 to attempt delineation of cropping areas from that of grazed fallow. Further work in use of satellite imaging to help identification of land use in smaller holder farming landscapes is required if these techniques are to become a useful tool in the future. • Spatial representation of Rabi cropping areas is described using 20 key districts (Upazila) that cover the majority of 2.7 million ha of available land in southern Bangladesh. These districts have been described in terms of area for land inundation type (Section 7 Figure 4), cropping intensity and potential fallow area.
1.3 PC	Regional screening of wheat germplasm	Wheat cultivars identified and recommended for planting in each of the land categories	• Five new varieties released by WRC were trialled in southern Bangladesh. Yields and phenology of all are very similar and are able to be used in all land categories although it is unlikely that wheat will be sown on the low land as it remains wetter for longer at the start of the Rabi-season and is more suited to Boro rice production. • A limited release of the short season mungbean variety BARI Mung-6 occurred prior to the 2008/09 season. This variety is ideal for use in rotation with wheat whilst still allowing T. Aus and Aman rice to be grown during the Kharif season. Project activity has contributed to the expansion of Bari Mung-6 within areas of project activity.

			• Two new wheat varieties (BARI Gom 25 and 26), which were evaluated pre-release in southern Bangladesh have now been released by WRC.
PC		Locally produced wheat seed available for purchase by farmers in subsequent years	• The 285 SMT wheat sites (each~1000 m^2) in 6 southern regions (over the 07/08, 08/09, 09/10 and 10/11 seasons) were established to demonstrate the potential for wheat in the south and to provide a source of local seed. Farmer interviews suggest that this has been successful at the local, collaborator village level with reports of farmers keeping sufficient for their own use (and often expanding the crop area) with significant sales to neighbours and in a small number of cases to farmers further afield at prices of T35-40/kg (2007/08 prices). It was also reported that the farmer collaborator was often seen as the wheat 'expert' and sought out by neighbours for advice on wheat agronomy. • 153 SMT fields were rotated into mungbean in the 2008, 09 and 10 seasons with 42 (29%) achieving yield. In 2008 the mean yield from the 22 fields harvested was 644 kg/ha. Seed was sold to neighbours with prices of ~T35/kg in 2009.
PC, A		Identification of wheat germplasm with potential salinity or heat tolerance	• Preliminary screening of wheat lines for salinity tolerance was undertaken in 8 trials conducted over the 5 seasons of research. Approx. 60 lines were screened each year including material from Bangladesh, India, Pakistan and Australia. Local varieties, Shatabdi and Prodip were used as check lines. Trials were located in moderately saline areas in the district of Noakhali during the first 3 seasons (06/07, 07/08 and 08/09) and expanded to include Jhalakathi and Amtoli in 09/10 and 10/11. Shortlisted lines (12/season) showing improved tolerance were moved on to more detailed evaluation as part of the Salinity Observation Nursery trial program in the subsequent season. • Salinity Observation Nurseries were conducted in Noakhali in 2006/07, 07/08, and 08/09 and expanded to Jhalakathi and Amtoli in 09/10. These were more detailed trials in which the small number of lines identified through the screening process were grown under increased replication and larger plot size and compared against the newly released local varieties Shatabdi and Prodip. • Overall results for the salinity tolerance work (2006/07 to 2009/10) showed that V01078 is clearly a good candidate for use in southern saline regions where it is able to produce good yields across the potential planting window (late November to late December). BAW 680, V01078, BAW1059, BAW 1064 and GARUDA/BB/TOB….. ICTAL123 have all maintained their superiority over the check varieties. These lines, as well as BAW1103, BAW1104 and BAW1114 have filled grain well, far better than Shatabdi and Prodip.

PC = partner country, A = Australia

Objective 2: To finetune agronomic practices specific to each potential region, land category and socio-economic grouping, especially in the efficient utilisation of limited water resources and fertilisers.

no.	activity	outputs/ milestones	Achievements against activities
2.1 PC	Collect field crop-soil-climate datasets from on-farm trials testing agronomic practices in southern Bangladesh and Australia	On-farm trials involving at least 80 farmer participants used as the focus for end-of-season field days	• The 285 SMT sites (each ~1000 m^2) in 6 southern regions (over the 07/08, 08/09, 09/10 and 10/11 seasons) (Table 1) were established to demonstrate the potential for wheat and mungbean in the south and to provide a source of local seed. • Annual field days were conducted in all 6 regions. These events attracted local dignitaries and approx. 80-100 local farmers. • Pre-season training was conducted at the Upazila, and later, village level with 1195 farmers, extension agents and researchers participating. This included the participation of 115 farming couples in 2009/10 and 145 female farmers in 2010/11.
PC		Comprehensive datasets collected from trials conducted in Bangladesh & Australia	Trials were conducted in Bangladesh between 2006/07 and 2010/11 (Table 2) which reflect the requirement to identify and understand the crops being targeted for southern expansion including their agronomy and the farming system and environment in which they will be grown. A number of experiments continued throughout the project whilst others were in response to project learnings or observations that suggested alternate approaches. Collected data sets have been used in broader farming systems analysis (using APSIM), in developing cropping recommendations for wheat and mungbean production and in the development of extension and communications materials. Main data sets include: • SMT (07/08, 08/09, 09/10, 10/11)-crop data for wheat, mungbean and rice production from 285 on-farm sites with wide geographic, seasonal and management variability. Data includes yield and biomass, water management, soil water use and potential ground water contribution, crop phenology and impacts of time of sowing. • Nitrogen rate by irrigation timing (07/08, 08/09)-2 trials at Hazirhat, Noakhali provided data on the impact of N rate and timing of irrigation on yield. These trials were pivotal in understanding the differences in the irrigation requirements of the south compared to the north and resulted in the extension recommendation that a single irrigation, 20 days after sowing, in conjunction with the WRC recommended fertiliser regime was sufficient to produce maximum wheat yields. • Salinity Screening and Observation (06/07, 07/08, 08/09, 09/10, 10/11)-9 trials conducted over 5 seasons in the salinity affected districts of Noakhali, Jhalakathi (2 yrs) and Amtoli (2 yrs) identified breeding lines with enhanced salinity and heat tolerance compared to current varieties. These data have informed the national WRC wheat breeding program with some

			lines selected for on-going evaluation. • Variety (06/07, 07/08)-Data from 9 sites in 3 districts confirmed the yield potential of the improved WRC varieties when grown in the more extreme environments of the south (salinity and high temperatures) using WRC and 50%WRC recommendations for fertiliser and irrigation. • Time of wheat sowing (TOS) (06/07, 07/08, 08/09)-Data from the national TOS program which included a southern site have been used in the calibration of the APSIM model to predict phenology of local wheat varieties across the range of environments from Dinajpur in the north to Barisal in the south. This has enabled the use of APSIM to predict yield potential for wheat as a component of the broader farming system. These data have also provided the evidence to show that the southern planting window for wheat is much longer than the north, a critical finding for future southern expansion. • Time of sowing x fertiliser rate (09/10, 10/11)-With the high cost of fertiliser, the potential to reduce rates in response to time of sowing was seen as important given the longer planting window in the south. Research was undertaken at 6 locations (5 in south) over 2 seasons. Results indicated that 100%WRC fertiliser rate was advisable for optimal yield for sowings from mid November to mid December but rates could be reduced to 66%WRC for later sowings. • Formed bed vs broadcast (08/09, 09/10)-Comparison of formed bed planting with broadcasting of wheat at over 20 regional sites in 2 seasons showed no significant difference in grain yields although improved weeding and irrigation efficiency may be reasons for farmers to adopt bed improved planting technologies.
PC, A		Management packages adapted to local resources and socio-economic groups	• The release of the manual "*How to grow wheat in southern Bangladesh and fit it into a timely annual sequence with other crops*" in 2010 provides farmers, extensions agents and researchers with information targeted at a range of levels of detail to suit individual requirements. The manual covers the southern production of wheat and mungbeans in a rice based farming system with information on the agronomy of the crops including varieties, nutrition and irrigation management. The document was designed to complement currently available WRC and CIMMYT/FAO materials. • The overall research program is described in detail in the ACIAR Technical Report "*Sustainable intensification of Rabi cropping southern Bangladesh using wheat and mungbean*" (ACIAR expect to publish mid-2011). This document provides a high level of detail on the research and the integration of the crops into the rice based system and will be of value to researchers and extension agents in Bangladesh and other countries with similar farming systems.
2.2	Adapt APSIM to better simulate high temperature, water & salinity	New physiological relationships describing wheat response to high	• APSIM simulations of 2006/07 season were completed with new processes incorporated into APSIM-SoilWat2 to account for the supply of water to crops from high water tables.

PC, A	impacts on crop prodn in both South Asia and Australia	temperature & salt	• Investigation of radiation effects on photosynthesis under diffuse light levels resulted in new calibration data for APSIM and the adjustment of radiation inputs for crop simulation. • Further assessment of the influence of Rabi season low level cloud or haze on, a) sunshine hour recorders and subsequent use of sunshine hour data as a model input and b) sterility of wheat at flowering
PC, A		Upgraded APSIM model for new process understanding	• APSIM-Swim was parameterised and run using a Bangladesh soil type to inform analysis on the contribution of capillary rise to crop water use. • Further evaluation and field assessment is required in quantifying salt and soil water movement above observed shallow ground water tables
PC, A		APSIM validation against datasets in Bangladesh and Australia	• Simulation of the 2007/08 time of sowing experiment at Joydebpur correlated well with the experimental data, with APSIM able to predict grain yield (var. Shatabdi) for all except a very late sowing. Simulated flowering periods corresponded well to observed anthesis dates. However, simulation of the irrigation by nitrogen trial failed to correspond with the 4.5 t/ha grain yield achieved with one irrigation. APSIM was able to simulate the yield potential but failed to capture the water and nitrogen interaction observed locally. • Further evaluation and detailed monitoring of soil water and nitrogen dynamics during early wheat development up to first irrigation at 20 days is required for model development and simulation of interactive processes, the results of which are observed in the field.
2.3 PC,	Test the feasibility of alternative agronomic practices in sth Bangladesh & Australia through long-term simulations using APSIM	Long-term simulations of regional production potential for wheat & other crops in southern Bangladesh	• APSIM was configured to simulate a number of individual crops and a number of rotations including wheat, mungbean, T. Aus and T. Aman rice. These have been tested over a 5 year period (2000-2005). • APSIM input files were then set up for 23 locations in southern Bangladesh. Model runs for each site and long-term simulations (1981-2007) run for a number of the main crop rotation scenarios. • Rabi crop sequence options for wheat and mung bean following T. Aman rice have been evaluated in terms of production tradeoffs
PC, A		WRC staff exposed to the application of APSIM	• Training in the use of APSIM has been undertaken with WRC staff in both Bangladesh (07, 08) and Australia (09). Simulation outputs have been used extensively in communication with staff and other researchers as well as at the policy level during meetings with the Bangladesh Minister for Agriculture, heads of department and international funding agencies.

PC = partner country, A = Australia

Objective 3: To encourage farmer uptake of emergent cropping practices through training and support of the regional change agents who have on-going commitment to supporting smallholder farmers

no.	activity	outputs/ milestones	Achievements against activities
3.1 PC	Develop training programs on crop agronomy for delivery to research and extension staff	Formal training programs and relevant learning resources developed and produced by WRC	• Collaborator training-Annual training at the district level was undertaken. 1195 participating farmers (830), regional extension personnel (DAE, PROSHIKA, FoRAM etc) (305) and researchers (60) were trained in wheat agronomy and management by WRC and project scientists. The one day sessions used resources developed by the WRC and supported by research results from the previous FAO and ACIAR research programs. Training included 115 farming couples in 2009 and 145 women in 2010. • Staff training-Formal training of project scientific and technical staff was undertaken prior to the commencement of each season (06/07, 07/08, 08/09, 09/10, 10/11) by Bangladeshi and Australian researchers. Approx. 6 regionally based scientific staff and 10 technical officers were trained or had a refresher each year. Training provided an overview of the planned research, staff responsibilities, data management and the hands on use of tools and technologies including GPS and soil sampling. Training in soil monitoring was supported by the use of a video produced locally for this purpose. • Staff resource development-Annual operational plans, pre-schedules and field data books were produced by project scientists for the use of technical and scientific staff. These contained the necessary information to manage and collect data for the trials undertaken in each of the 5 seasons. • A one day APSIM familiarisation course was conducted by CSIRO for BARI scientists in June 2007. • International training-3 Bangladeshi wheat scientists visited Australia in 2008 to meet with collaborators, wheat researchers and farmers to gain an understanding of wheat and pulse production in Australia. • Extension officer training-pulses: Chris Johansen, AM Musa and Sirajul Islam (ACIAR Project LWR/2005/001) conducted pulse production training with Proshika (15), DAE (12) and BARI (1) staff at Barisal prior to the commencement of the 2008 pulse season. • Crawford Foundation funded a 3 week training visit to Australia for 2 scientific officers (2009) to learn more on crop and soil monitoring techniques and for exposure to simulation modelling. • The project economist visited Australia for detailed APSIM model training as a prelude to 2 weeks working with collaborators on the simulation of potential southern Bangladesh farming systems and their economics.

			• The release of the manual "*How to grow wheat in southern Bangladesh and fit it into a timely annual sequence with other crops*" in 2010 provides farmers, extensions agents and researchers with information targeted at a range of levels of detail to suit individual requirements. • The overall research program is described in detail in the ACIAR Technical Report "*Sustainable intensification of Rabi cropping southern Bangladesh using wheat and mungbean*" (planned release in mid-2011). This document will be of value to researchers and extension agents in Bangladesh and other countries with similar farming systems. • Post graduate training-Ms Nasrin Sultana was a recipient of a John Alwright Fellowship and is currently finalising her PhD on the role of women in Bangladesh Agriculture at the University of Queensland.
PC		Over 30 extension staff trained in crop cultivation	• 305 regional extension staff from the DAE and NGOs were trained in wheat agronomy through the district training program (see 'collaborator training' above). This included specific training for DAE extension staff conducted in 4 districts prior to the 2008/09 season.
3.2 PC	Support WRC, DAE and PROSHIKA in on-ground extension activities targeted at farmer uptake of Rabi-season cropping practices	Project-supported demonstrations and field days within the three districts of Barisal, Noakhali and Bhola	• 2007-a post season field day was conducted at Khanjapur, Barisal to demonstrate the potential for wheat integration into the local jute based system in which land often lies fallow during the Rabi season. • 2008-Post season field days which supported the SMT program were conducted in each of the three districts of Barisal, Bhola and Noakhali • 2009-Field days were conducted in Barisal, Bhola, Noakhali, Pirojpur and Patuakhali prior to wheat harvest. The meetings were used to promote and distribute Bari Mung-6 seed to interested farmers. This resulted in 61 SMTs being sown to mungbean. Field days were similarly conducted in 2010 and 2011 • Communication of project outputs at the policy level in 2009 and 2010 resulted in increased DAE activity on the extension of wheat in all regions. This included the establishment of 'block' demonstration trials and increased collaborative involvement with project staff in the on-farm research.
PC		Farmers outside the project supported by DAE and PROSHIKA in Rabi-cropping enterprises	• In 2009 and 2010 DAE increased the demonstration of southern wheat production as a result of the commitment by policy makers to support wheat production in southern Bangladesh. Increased on-farm demonstration and support of farmers was possible through the experience gained by DAE staff within the project over a number of years. • Noakhali-The NGO, Poverty Alleviation Committee which is involved in food security amongst the rural poor of Noakhali district commenced growing wheat and mungbean with farmers in 3 Unions in 2008/09 using the SMT model of demonstration. • Bhola-in 2007/08 2 SMT sites were established in each of the Unions of North Joynags and

			South Balia promoting the potential for new wheat and mungbean varieties to impact on crop yields and system sustainability. Through demonstration, strong support from the DAE block supervisor and the provision of seed by the Bangladesh Agricultural Development Corporation (BADC) the area of wheat production in North Joynags increased from 105 to 150 ha in one season.
3.3 PC	Evaluate the current and evolving perception of farmers and other stakeholders to Rabi-season cropping and track its on-ground adoption	Perceptions and practices of project stakeholders documented on project performance and outcomes	• Formal evaluation by the social science team, undertaken as part of PRA and Livelihoods analysis in 2009 and reported in the ACIAR Technical report (due for release in mid 2011) indicate that despite farmers seeing the financial benefits of growing wheat and mungbean as Rabi-season crops they are unlikely to adopt the technology unless imbalances in other components of their livelihoods, including the human, social, natural and physical aspects are addressed. The farmers are likely to adopt new crops only when the livelihood capital support for the new crops equal that already present in existing crops. In short this means that farmers have to be sure in their own mind that the risks associated with growing the new crop (financial, human, social, natural and physical) are no greater than with existing crops. This confidence does not currently exist in non-collaborating villages. • Through informal interview participating farmers have been keen to inform staff of their successful crop production and sale of product although sustainability of production, as with any crop, will depend on markets and the availability of resources including irrigation water, fertiliser and threshing equipment.
PC		Quantitative evaluation of on-ground adoption of Rabi-season cropping practices	Whilst no formal quantitative assessment of crop adoption has been undertaken there is anecdotal evidence, gained through informal interview, that wheat and mungbean areas are expanding in collaborating villages. • Bhola-in Unions where the project had been active for at least 2 seasons (07/08, 08/09), and there was good technical support from the project, DAE and NGOs, crop area expanded by 30% in the second year of wheat/ mungbean production. This was a result of the introduction of new varieties, technical support and the realisation by farmers of the potential economic returns from these crops. This increase was to the detriment of Boro rice production even though water supplies were available for its production. • Barisal (Khanjapur)-farmers commenced growing wheat in 2005/06 (ACIAR scoping study) and have continued for the last 5 years, 3 without support from the project. In that time Rabi-season fallows have been replaced by wheat which has become an integral component of the jute based farming system. Production area has doubled with the original farmer collaborators now acting as technical advisors to their neighbours. • Barisal (Babugonj)-in 2007/08 Nasima Begum grew 1040 m^2 of Sourav wheat which yielded 3.6 t/ha. She then rotated mungbean (Bari Mung-6) into the area which yielded 628 kg/ha. In late 2008, immediately after the harvest of Kharif rice she planted 2400 m^2 to mungbean using seed she had stored from the previous season. She had also sold excess seed to 5 neighbours. In 2008/09, the farmer was asked to grow the wheat variety, Prodip,

			consequently she sold all of her remaining Sourav seed to 8 neighbours at a profit and planted 1080 m^2 of Prodip which yielded 3.2 t/ha. The area was then rotated into mungbean (yield unknown). Nasima is now sought out by her neighbours for advice on wheat production. • Noakhali (Senbagh)-A number of farmers in Senbagh village indicated that Boro rice was dying due to the need to irrigate with whatever water was available, in this case brackish ground water. After seeing SMT sites in the village and the resultant wheat yields farmers increased wheat production in the 2009/10 season. • Noakhali (Hazirhat)-Abdul Motin is a leading local farmer who hosted the 2007/08 and 2008/09 NxI wheat experiments. In 2008/09 he grew an SMT which yielded 2 t/ha of wheat. Whilst the yield is lower than in other districts this is not unexpected due to the high soil salinity levels. In 2008/09 he grew commercial areas of wheat and mungbean using seed retained from the previous season.

7 Key results and discussion

Whilst increasing national food security is an important component of Bangladesh government policy the potential for the south to contribute to increased Rabi-season production of wheat and other crops has been largely ignored due to the idea that the environment is too hostile. In the past this view could be justified, however with the release of new, locally bred wheat varieties that have increased salt and temperature tolerance, and a short season mungbean variety, things have changed. Building on the past work of FAO and ACIAR this project has shown through detailed agronomic and social research, on-farm demonstration and extension, and spatial analysis of land and water resources that not only is it technically feasible to grow wheat but that the natural resources are available to do so.

7.1 Spatial analysis of natural resources

7.1.1 Land availability

Not all land considered as available for Rabi season cropping is suitable for 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 highland (class 1) to very-low land (class 5). Very-low and lowlands are not normally considered for growing wheat as they drain slowly at the end of the monsoon and can remain water-logged 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 81% of the southern region. Land inundation type as a percentage of cultivatable land is shown in Figure 4 and is applied to estimating available and suitable fallow land.

Two approaches were tested in an attempt to determine the area of fallow available for increased Rabi season cropping. In broad terms these focussed on the use of published statistics on land use and spatial analysis of satellite imagery. The methods are described in detail in Chapter 2.3 of the ACIAR Technical Report.

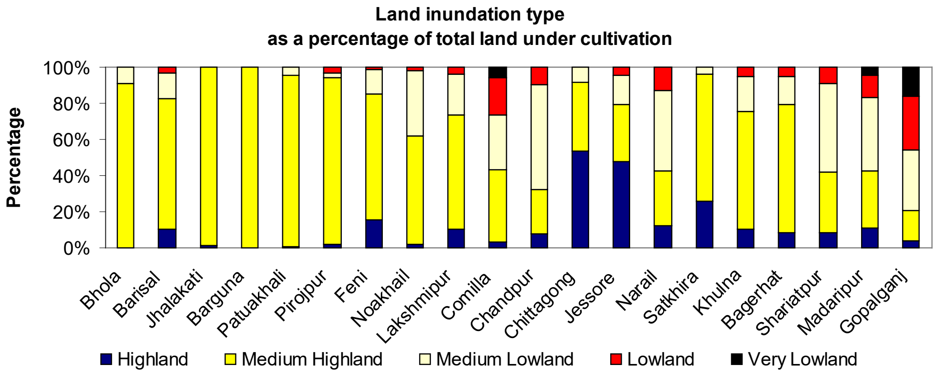


Figure 4: Estimated percentage of land in each of the recognised land classification classes for each of the 20 Upazila that formed part of the analysis.

Using statistics to estimate land availability

Initial evaluation of the Bangladesh Bureau of Statistical data on land utilisation and cropping intensity for the years 2001 to 2007 found that the area reported as remaining fallow within 20 districts of the south (Figure 5a) varied from almost no available fallow to >12% of cultivatable land for individual districts. If fallow and wasteland (land considered as arable but currently not cultivated) estimates are combined this analysis suggests that 191,773 ha of the 2.7 million hectares of available agricultural land in the southern region is underutilised during the Rabi season (Figure 5b). These data are based on reported land deemed as uncultivated fallow during the year and do not consider underutilised land used for stubble grazing or forage crops such as grass pea (Lathyrus sativus). Data from the 2005-06 agricultural census indicate a mean cropping intensity of 176 % (Figure 6) of 3 potential cropping seasons (*Kharif1, Kharif2* and *Rabi*). This indicates some potential for additional crops to be included into the current cropping sequences. Use of cropping intensity data provides an additional method for calculating land remaining fallow. The 2003-04 BBS district-wise cropping intensity statistics (single, double and triple cropped area) estimate potential fallow area at between 0.7-1.09 million ha. These estimates consider periods between dominant rice crops where an opportunity exists for sowing high value Rabi crops on underutilised land. A third approach to estimating potential fallow land is the use of boro rice planting statistics. BBS data from 2006-08 for 20 southern districts estimates land planted to boro rice as 35-38% of cultivatable area and other Rabi crops as 38-41% of cultivatable area. By subtraction, 38-41% of cultivatable area or ~1.0 million ha was potentially fallow during the 2006-08 Rabi season.

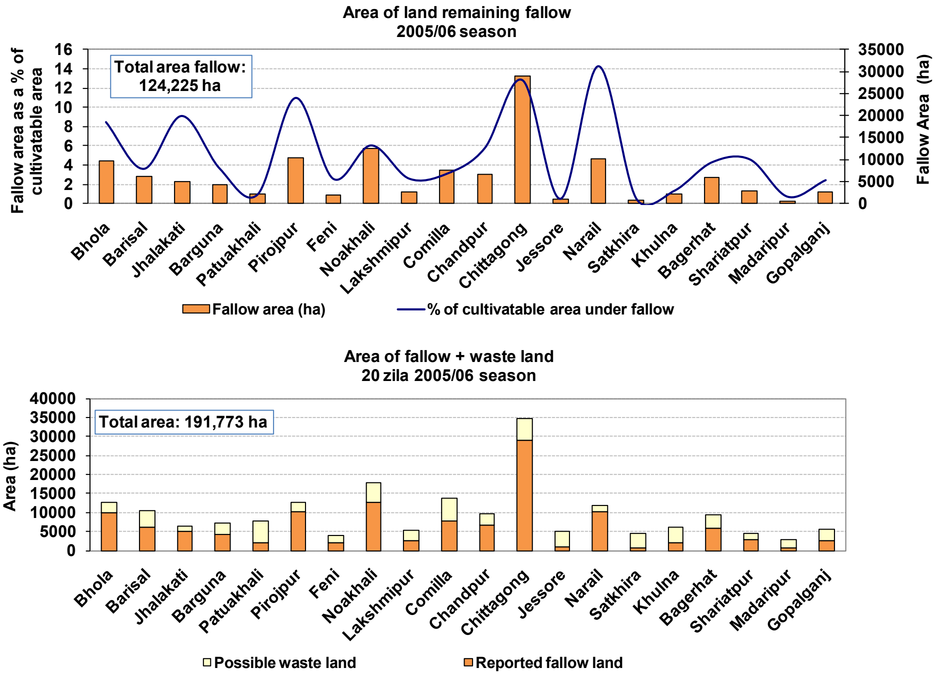


Figure 5: (a) Area remaining under fallow (ha) during the 2005-06 season). Calculated values for fallow land are expressed as a percentage of the total area under cultivation for each Upazila. (b) Reported estimates of fallow and waste land for each district (bottom). All data sourced from the 2005 Agricultural census.

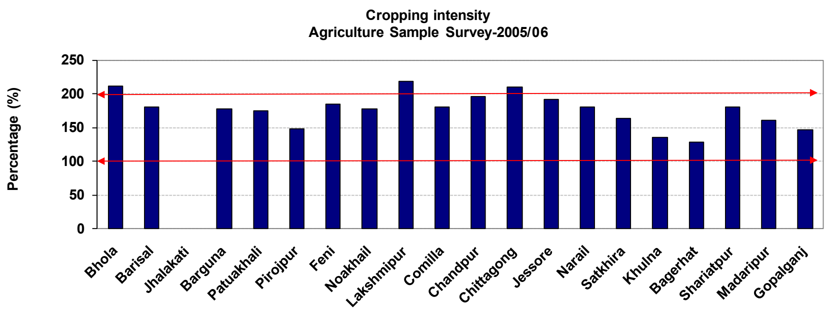


Figure 6: Cropping intensity for 19 of the 20 locations in southern Bangladesh with a mean intensity of cropping of 176%. The red lines indicate 1 and 2 (200%) crops per year. All data sourced from the 2005/06 Agricultural Census.

Using satellite imagery to estimate land availability

Detailed land use data collected at a regional scale by DAE and reported by the BBS is the main source of land use information in Bangladesh. 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).

Testing of the potential to use satellite imagery in small holder systems was trialled at Noakhali in a region of interest (ROI) of 1592 ha. Land use patterns were generated from satellite images as described by Poulton and Dalgliesh (2008). Estimated land use for the study region correlated well with observed land use from ground assessment and Google earth ® images. The use of small and highly variable fields in smallholder agricultural practice presents a challenge in using satellite imagery even at resolutions of 10m. The use of land for water sources and ponds, tree and forest reserves, and bare or fallow land can be easily classified (Figure 7b), however individual crops or weedy fallow lands are not as easily identified and are aggregated as cropped land (Figure 7a). Results indicate that 10.8% to 13.7% of the 1500 ha study area in Noakhali remained crop free during the 2006-07 Rabi season. This estimate differs from the DAE reported fallow area for 2005-06 of ~6% and is suggested to be a result of bias due the small area used in this analysis. Applying results from the work in Noakhali to the entire southern region a conservative estimate of between 0.23 - 0.37 million ha of potentially fallow land was available during the 2006-07 Rabi season.

In an attempt to delineate between field crops and grazed fallow land currently aggregated as cropped lands during image classification, a field survey of 2 regions in Barisal and Noakhali was undertaken in March 2009, 58 fields were identified as growing wheat and other vegetation. Farmer interviews clarified that many of these fields, which appeared to be weedy fallows, were in fact sown to grass pea (*Lathyrus sativus*) an important component of the farming system.

Summarising resource availability for increased Rabi-season cropping

Whilst this methodology of rapid land use assessment using satellite imagery has demonstrated some potential it requires further development and ground truthing of techniques if it is to be a suitable tool for land use appraisal in landscapes dominated by small holder farming systems. Whilst this has been one technique evaluated by the project estimates of fallow availability in this study have been done based on the statistical data sets available from the Bangladesh Government. Of these statistical and spatial techniques, the use of detailed district wise land utilisation data has been demonstrated to provide the most consistent estimates of fallow across datasets spanning a period of up to 7 year. Using this techniques suggests that approximately 0.86 million ha of land of medium high and medium low inundation type remain fallow in the 20 major districts of southern Bangladesh (Figure 8b) though 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. The seven regions in which agronomic and social research was undertaken (Figure 8a) cover some 56% (0.48 million ha) of the potentially fallow land (0.86 million ha) in the entire southern region of Bangladesh.

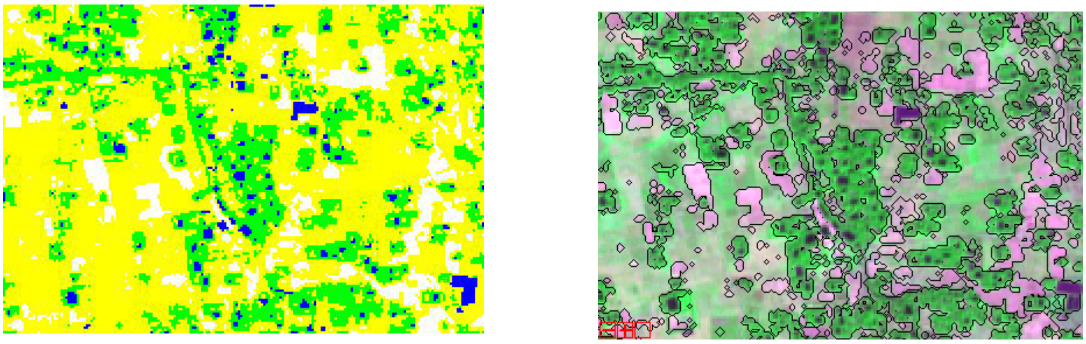


Figure 7: (a) Image resulting from supervised classification using four selected elements (fallow, trees, ponds and cropping). White regions represent land interpreted as remaining under fallow as of March 3rd, 2007. Blue, green and yellow regions represent ponds, trees and cropping respectively; (b) Image showing a contour overlay based on classified zones. White to light purple regions represent land remaining fallow as of March 3rd, 2007.

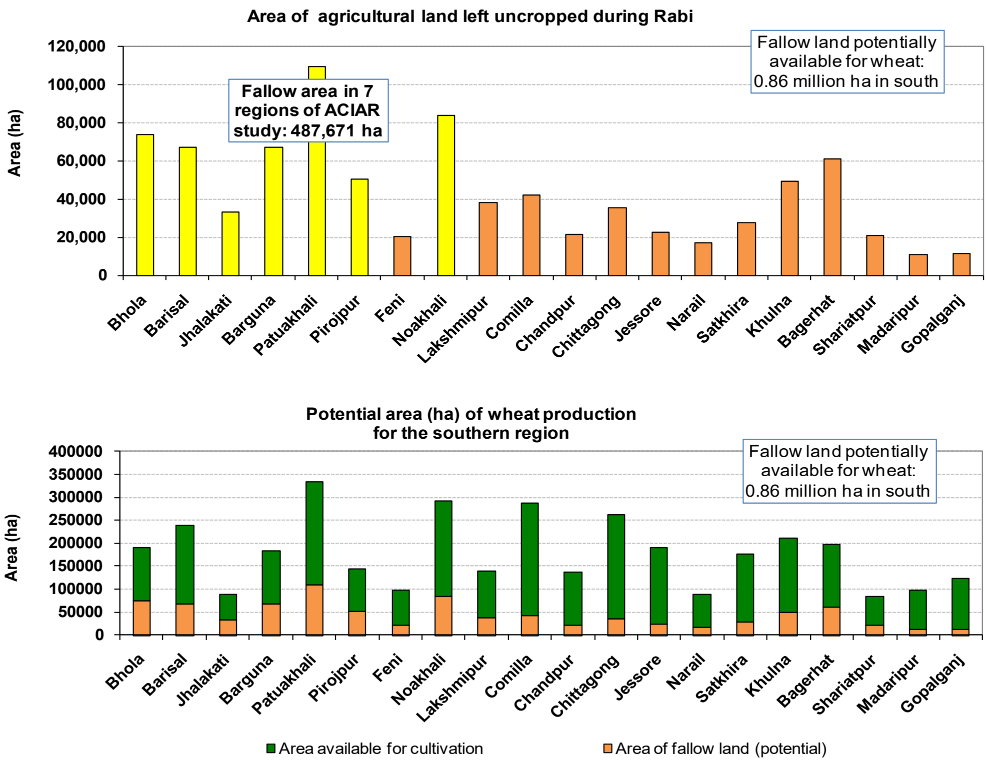


Figure 8: (a) Area suitable for wheat in each of the seven areas evaluated during the current ACIAR project (yellow) and Rabi fallow area in the remainder of the 20 southern subdistricts (brown), (b) Estimated fallow area of land considered as medium-high and medium-lowland class shown in association with current area of cultivatable land available in each of the 20 sub-districts.

7.1.2 Water supply for Rabi season crop production

The majority of southern Bangladesh lies on a flood plain which is subject to monsoonal influences including annual flooding and fluctuation in water table depth. This annual flooding both fills surface irrigation storages and recharges the soil profile, the extent of which depends on the rainfall, soil type, geographic location and the level of previous irrigation exploitation. As 70% of southern irrigation water is sourced from surface storages (canals and ponds) and infrastructure to access ground water limited, a key question to realising wheat production is identifying sources of water to meet the demands of potential production. The ACIAR scoping study (Carberry et al 2008) presented data suggesting a significant amount of stored soil water, surface water or shallow ground water of high quality could be available at the start of the Rabi season

Surface water contribution to crop production

Evaluation of surface water as a potential source for irrigation was determined using a number of methods including; classified satellite imagery, visual assessment of Google images and surveys by local project staff. Early estimates of a 300 ha study area in Noakhali identified an area of approximately 9.7 ha of water bodies containing 194 ML (assuming 2m depth) at the end of the monsoon in November with the potential to irrigate around 100 ha of wheat using 3 applications of ~60 mm.

The contribution of ground water to crop production

An analysis of ground water availability at the start of the Rabi season for key districts in the south was undertaken, and contribution of shallow ground water to crop water use evaluated using modelling tools. In the north (Dinajpur), which receives less rainfall than the south, and where the use of tube wells is more prevalent, variation in depth to water table varies annually between approximately 1 and 6 m (Figure 9a), whereas in the south (Patuakhali), where rainfall is higher and water extraction for irrigation less, depth to water table varies between approximately 0.5 and 3 m (Figure 9b). As a consequence of the relatively shallow water tables in the south, there is potential for ground water to contribute to production through the process of capillary rise (Poulton and Saifuzzaman 2010) during the Rabi season.

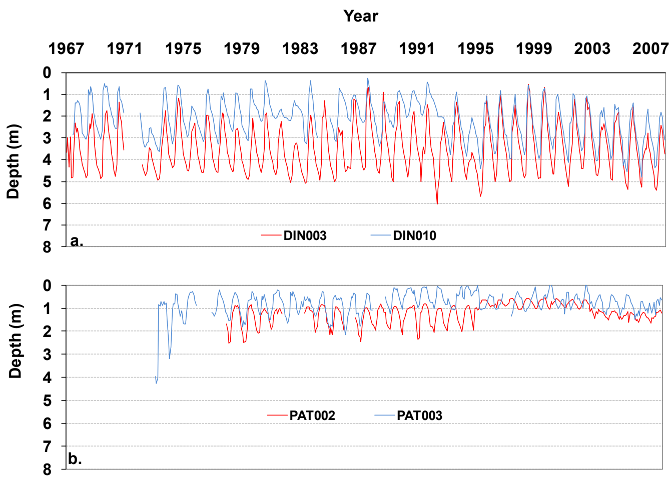


Figure 9: Fluctuation in depth to water table from 1967 to 2007 at the northern site Dinajpur (bore holes DIN003 and DIN010), and southern site Patuakhali (PAT002 and PAT003). Data supplied by BWDB.

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 water tables were commonly at a depth of approximately 1 m at sowing in December and at 1.5 to 3 m by crop maturity.

Given the soil and water conditions under which capillary rise is a significant contributor to crop water supply, water tables in the north during the Rabi season are too deep to impact on crop production (Figure 9a). This is reflected in the WRC recommendations for wheat production which suggest that 3 irrigation applications, each of 100 mm are required. In the south however, where Rabi season water tables are regularly at depths of 1 to 2 m, capillary rise is a much more significant contributor to crop production. Using the water balance model, SWIM (Verburg 1996), to simulate the contribution of capillary rise to crop water supply at Bhola, during the period 1971 to 2007, shows that capillary rise contributed between 60 and 105 mm of water to crop production resulting in additional yield increases (in the majority of years) of between 0.6 and 1.8 t/ha above that of crops without access to shallow groundwater (Figure 10) (Poulton and Saifuzzaman 2010).

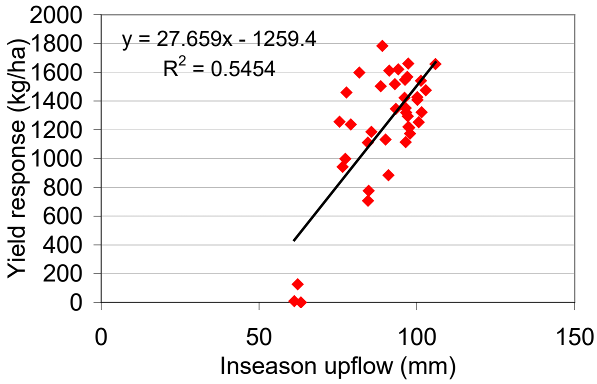


Figure 10: Simulated additional yield response in wheat at Bhola (1971-2007) from upflow of soil water as a result of capillary rise during the Rabi season using the SWIM model.

7.2 Rabi-season cropping demonstration

Seed Multiplication Trials (SMT) formed the main form of demonstration and extension for the project. As indicated in Section 5.2 these were conducted over four seasons with increased numbers and geographic spread increasing with time. In 2008/09 there were 87 SMTs located in 5 districts representing the range of environments and regions, this declined to 67 in the following year but again increased to 90 in 2010/11 season (Table 1; Figure 11).

Figure 11: Locations of cooperating farmers' seed multiplication trials (SMT) on the island of Bhola (centre), Noakhali (top right), Barisal (top left), Patuakhali-Barguna (centre-bottom left), Jhalakathi-Pirojpur (centre). Blue symbols 2007–08 (Noakhali sites not shown), magenta pins sites added 2008–09, red circles sites added 2009–10, orange F-flags two Food and Agriculture Organization wheat sites from 2003-5

7.2.1 Aim of the Seed Multiplication Trial program

Each SMT farmer was provided with fertiliser and sufficient seed of one of the elite wheat varieties, Shatabdi, Bijoy, Prodip, Sourav and Sufi to plant 1000 m^2. Newer elite varieties such as BAW 1059 and BAW 1064, later named BARI gom 25 and BARI gom 26 when they were proved suitable for the south, were distributed as they became available. Under the agreement farmers followed management practices recommended by the project to grow the crop, with some latitude on planting time, planting method and number of irrigations. They were then asked to sell the harvested seed to neighbours for their following year cropping. Farmers were then provided with seed of the short season mungbean variety BARI mung 6 to grow as a rotation crop after the wheat. The aim was to spread the elite seed and extend the technology through the region by using the farmer networks. Additional to extension, the SMTs were used for on-farm experimentation to test ideas aimed at improving resource and crop management specific to the locale. For example, studies on salinity are not required in much of Barisal but are critical in some parts of Noakhali.

7.2.2 SMT impact on wheat expansion

As indicated above the primary aim of the SMT has been to increase Rabi-season cropping through demonstration of the potential for new varieties of wheat and mungbean to contribute to farming systems in southern Bangladesh. In terms of geographic spread this was highly successful with 285 sites established during 4 seasons of activity in 5 districts and around 50 Upazila. The training and workshop program has exposed around 830 farmers, 305 regional extension personnel (DAE, PROSHIKA, FoRAM etc) and 60 researchers to wheat and mungbean agronomy. With the support of project staff wheat yields of over 3 t/ha were common amongst farmers who managed their crops well and applied recommended fertiliser rates (2-2.5 t/ha in salinity affected Noakhali). This compared to the average yield for Bangladesh of 2.8 t/ha (Md. Saifuzzaman, *pers com* 2009/10 data). What was particularly exciting was that yields were able to be achieved with the application of only 1 irrigation applied at 20 days after sowing compared to the north where crops require 3 irrigations to reach potential. The research has also shown that the yields from non-irrigated crops are often only 0.5 to 1 t/ha less than irrigated, which opens up the opportunity for farmers without access to tube wells or the infrastructure to store and move collected surface water to grow viable crops. Improved use of irrigation water means that there is potential for larger areas of wheat to be grown on the same available resource or the water can be used for other crops including chillies and water melon. The lower water requirement of wheat has not been lost on farmers in areas of the Noakhali district where ground water, generally used for Boro rice production, is in short supply and becoming increasingly saline. Anecdotal evidence suggests that many will move to the production of alternate crops such as wheat to better utilise the resource.

The impact that the SMTs have had on wheat expansion in areas surrounding collaborating farmers has been substantial. Informal farmer interviews and field observation shows that the areas of production are expanding using seed sold to neighbours by collaborators. The village of Khanjapur in Barisal district is an example of where farmers were shown how to grow wheat as part of the ACIAR scoping study in 2005/06 and have since, without further project intervention for 3 years, made wheat a permanent component of their jute production system. They are currently in their sixth year of production, use the fertiliser and irrigation management protocols provided during initial training and routinely achieve yields of 3.5 t/ha.

Whilst there is ample evidence in all districts of localised expansion around collaborating villages there has not been a wholesale move to wheat and mungbean production in the south. This should not be surprising given the relatively short term nature of the project, however it is important that the project, and those involved in future expansion of Rabi-cropping take note of the salient points emerging from project socio-economic studies.

Whilst farmers appreciate that the financial rewards from alternate Rabi-cropping options are high, they indicate during formal interview, that widespread adoption will not occur unless imbalances in other components of their livelihoods, including the human, social, natural and physical aspects are addressed. The farmers will only adopt new crops when the livelihood capital support for the new crops equals that already present for existing crops. In short this means that farmers have to be sure in their own mind that the risk associated with growing the new crop (financial, human, social, natural and physical) is no greater than with existing crops.

Recognising the validity of these arguments the project moved to address at least some of them through dialogue with national policy makers. The aim was to ensure that the potential contribution of the south to Bangladesh food security was known and acted on through changes in national policy relating to regional technical support, distribution of seed and infrastructure development.

7.3 On-farm research conducted as part of the SMT program

7.3.1 Wheat variety evaluation

In general 5 elite varieties were provided to three farms in each region and additionally three farms were asked to grow the variety Shatabdi without irrigation. Previous studies have shown that high yields can be achieved in some areas without irrigation, the implication being that a proportion of the required crop water is being accessed from shallow ground water. Because of the variability in time of planting, quality of seedbed and weed management inherent in this type of on-farm research, regional average yields should only be taken as an indicator of the potential of the variety and recommended management methodology.

In 2007/08 (Table 13) there was a wide range of planting dates from the 9th to 30th December in Noakhali, the 3rd to 22nd December for Bhola and the 1st to the 13th December for Barisal. Whilst seed was generally broadcast after a number of passes by power tiller there were three sites sown in rows using the Power Tiller Operated Seeder (PTOS) that allowed comparison with broadcasting. This indicated no advantage for either method in terms of yield. The four varieties chosen for seed multiplication were tested on three farms in each region with some spread amongst villages. This approach worked well as it allowed fair comparisons amongst varieties and regions and planting dates assuming farmers and farms would provide additional normal background variation.

SMT average yields were good on both Bhola (3.65 t/ha) and in Barisal (3.93 t/ha) contrasting with the lower average for Noakhali SMTs of 2.26 t/ha. All four varieties grown under irrigation at Barisal and Bhola yielded >3 t/ha with 2 in Barisal yielding >4 t/ha (Bijoy and Sourav). The lower and more variable yields achieved in Noakhali reflect the effect of soil salinity and poorer agronomic practice of the farmers. Table 13 summarises yields (g/m^2) for the SMTs for the three regions with each cell being the average of three farms.

Table 13: SMT wheat yield (g/m²) by region and variety for 2007/08

YIELD (g/m²) 2007/08	Noakhali	Bhola	Barisal	Mean
Shatabdi rainfed	170 (56% of irrig)	382 (99% of irrig)	336 (85% of irrig)	296
Shatabdi irrig	301	387	395	361
Bijoy	211	375	443	343
Prodip	161	304	309	258
Sourav	230	392	426	349
Mean all irrig farms	226	365	393	328

In 2008/09 Prodip was the best-yielding variety, although other varieties apart from Sourav were generally within 10% of Prodip (Table 14). Prodip also produced the boldest grain with Bijoy a close second and Sufi last (Table 15). Average 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 13).

Table 14: SMT wheat yield (g/m²) by region and variety for 2008/09

YIELD (g/m²) 2008/9	Noakhali	Bhola	Barisal	Jhalakathi	Patuakhali	mean	se
Shatabdi rainfed	250	240	301	249	299	268	±13
Shatabdi irrig	207	367	236	291	243	269	±28
Bijoy	250	348	296	234	269	279	±20
Prodip	280	363	319	198	271	286	±27
Sourav	230	291	265	164	248	239	±21
Sufi	232	313	279	199	298	264	±21
all irrig farms	240	336	280	216	263	267	±20
se	±12	±15	±14	±22	±10		

Table 15: SMT wheat grain weight (mg) by region and variety for 2008/09

wt/grain (mg) 2008-9	Noakhali	Bhola	Barisal	Jhalakathi	Patuakhali	mean	se
Shatabdi rainfed	36	37	38	36	42	38	±1.0
Shatabdi irrig	35	41	38	33	38	37	±1.3
Bijoy	38	42	41	35	41	39	±1.2
Prodip	40	46	40	33	40	40	±2.0
Sourav	32	35	35	29	36	33	±1.2
Sufi	26	31	36	25	30	29	±1.9
all irrig farms	34	39	38	31	37	36	±1.5
Se	±2.4	±2.7	±1.2	±1.9	±2.0		

7.3.2 Effects of time of sowing on wheat yield

2007/08

In the 2006/07 and 2007/08 seasons the south was found to be far less sensitive to sowing date than the traditional northern growing regions for wheat. The project has generally found that wheat in the south can be sown up to mid December without significant loss in yield. The implication for this is that wheat is able to follow and fit with the harvesting pattern of current varieties of T. Aman rice and there is no need to consider introducing short duration varieties of Aman into the sequence. The effects of planting time on yield in 2007-8 are shown in Figure 12.

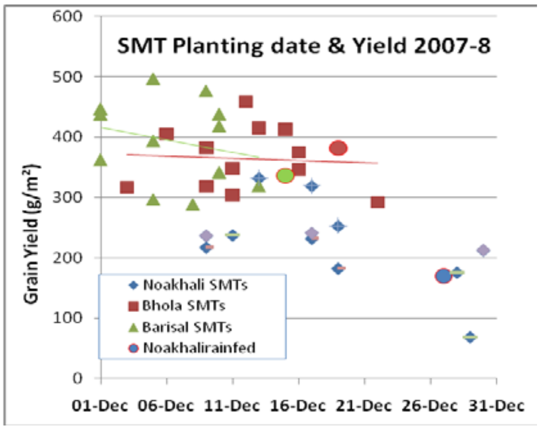


Figure 12: Effect of planting date on yield for wheat at Noakhali, Barisal and Bhola sites during the 2007/08 season

2008/09

The 2008-9 season had many more SMT sites than the previous season but produced very similar findings despite having no rain and a hot finish. There was evidence for an effect of planting date on yield at the most southern regions of Patuakhali-Bharguna and Jhalakhati-Pirojpur where yields from sowings after 12 December were much lower than from earlier plantings. This trend was absent in other regions. It was hypothesised that the yield decline in these most southern regions could be explained by ground water there being depleted rapidly with season advance. However, piezometer readings showed rates of decline in ground water at Patuakhali/ Barguna and Jhalakathi/ Pirojpur averaged 7-10 mm/day, similar to the rate for Barisal. This was much less than the decline on Bhola of 14 mm/day and in Noakhali of 25 mm/day where dates of planting effects on yield were absent. In addition water table depth by harvest in March was least in these most southerly areas, remaining at 1.5 m compared to 2-3 m on Bhola and deeper than 3 m in Noakhali. Ground water levels and extraction rates alone did not explain the apparent regional planting date effects on yield.

The 2009–10 season

Further SMT farms were added in 2009 while many from the previous season were retained for continuity of data. Google maps shows locations of all SMT farms by year at http://maps.google.com/maps/ms?ie=UTF8&msa=33&msid=106289035230357558981.0004865c70c964ee24e9f&abauth=4beb5cd0xLcgigdlvtZoXMczumNapkC9ffE

For this season the main conclusions were confirmed that yield is not modified by planting date as long as it is prior to mid-December (Figure 13) and that the main within-season yield variation is due to differences between locations and individual farmers in a locality. 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 in that figure. There, early and late December plantings were not greatly different in yield. Similarly, in Patuakhali Sadar, early December and 20 December sowings showed no yield reduction. The mean yields for each of the 5 districts was >2.5 t/ha with Barisal recording the highest and then Barisal and Barguna, followed by Noakhali, Jhalokathi and Patuakhali.

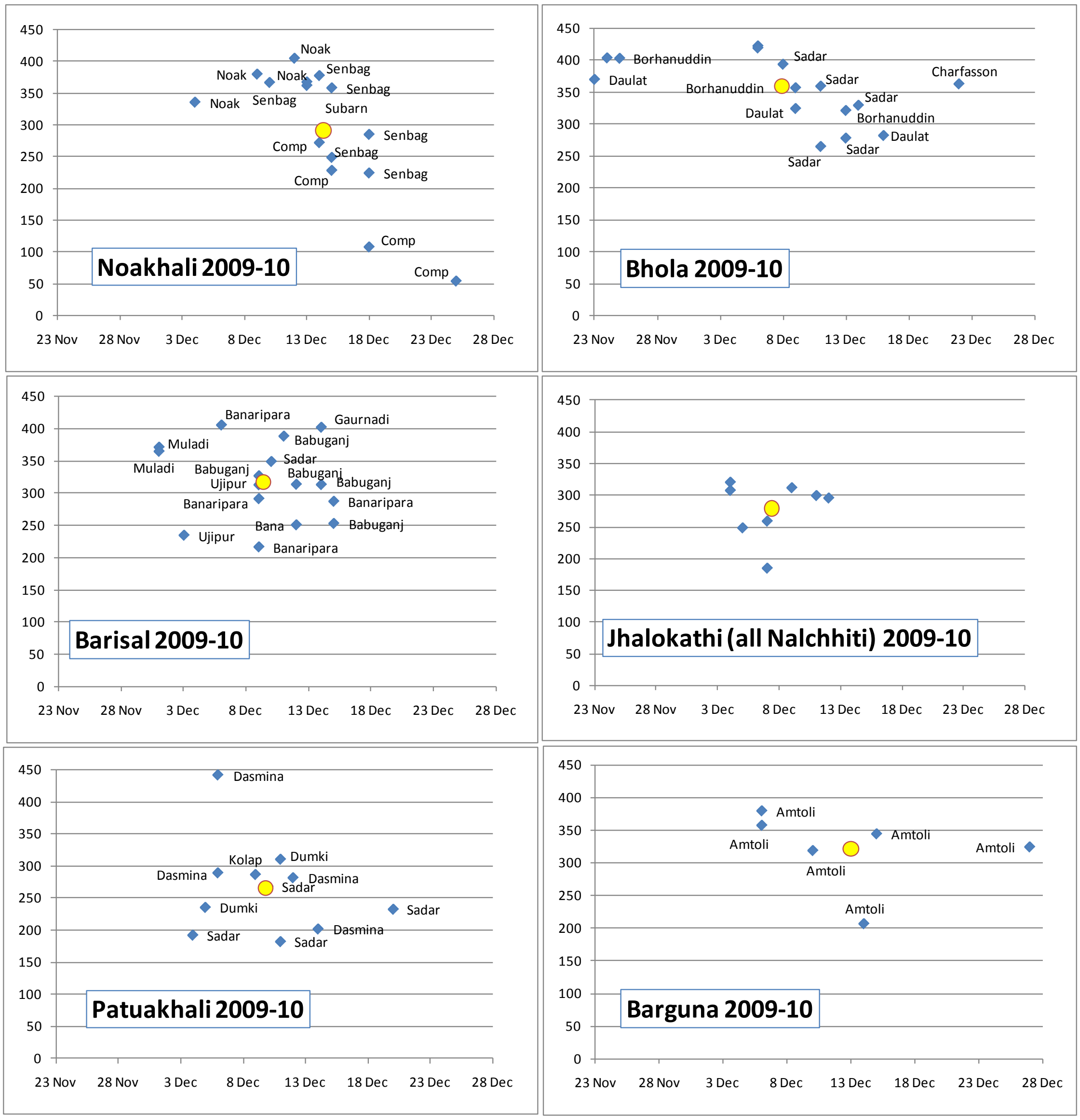


Figure 13: Yield (g/m^2) expressed against sowing date (2009–10) for seed multiplication trial farmers in Noakhali, Bhola, Barisal, Jhalokhati, Patuakhali, Barguna. Varieties are not identified as by this stage it was established that variety yield differences were insignificant. The yellow circle shows mean yield at mean planting date for each figure. Note that despite wheat generally following rice, planting dates always averaged before mid December

Comparison of seasons

Table 16 shows average yields achieved by farmers for the regions studied. This is indicative of trends rather than being a statistical data set 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 to 3 t/ha mean yields were assured for Barisal and in excess of 3 t/ha assured for Bhola. Noakhali yields of 2 to 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 of the ACIAR Technical Report) and in the warmest regions of Jhalakathi 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 on Bhola. This is the only season for which reliable comparative phenology data were collected on all SMT crops.

Table 16: Yield (g/m^2) for southern regions over three seasons. There are different numbers of farms in each grouping so comparisons can only be indicative (300 g/m^2 is the same as 3t/ha).

Season	Noakhali	Bhola	Barisal	Jhalokhati	Patuakhali	Barguna	Only Noakhali Bhola, Barisal	All mean
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
mean	252	353	330	248	264	322	312	300

Some overall conclusions about SMT farms

The outstanding finding from this study was that 2.5 t/ha crops of wheat could be produced almost anywhere that farmers were interested in growing them. The locations were extremely diverse from the Charlands in the far north of Barisal, to the vicinity of the mangrove swamps of Kuakata in the far south of Bangladesh, to Dasmina 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.

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 recommended. It was hypothesised that this was necessary to leach the surface-broadcast fertilisers into the root zone (Chapter 3.4 ACIAR Technical Report). This finding of an apparent low water requirement for wheat was contrary to expectations and observations from crops grown in the north of Bangladesh (see Chapter 3.1 ACIAR Technical Report). The difference in the south is that water tables are close to the surface and water is accessible by the plant (Figures 9, 10).

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 ACIAR Technical Report), there is an opportunity to produce a large amount of wheat in the region.

7.3.3 Other crops within the proposed rotation

SMTs were an ideal avenue to test the viability of mungbean as a component of a rice/wheat based farming system. Whilst no detailed agronomic research was undertaken the availability of SMTs to test environmental adaptation and to explore management issues was invaluable. Additionally, to enable the simulation of the rice based farming system, knowledge of the agronomy and productive capacity of the Kharif 2, T. Aman rice crop was developed through two seasons of SMT monitoring.

Mungbean production

In 2008, 42 SMTs in 3 districts were rotated into mungbean on the harvest of the wheat crop in March. This increased to 76 in 2009 (5 districts), with 35 planted in 2010 (5 districts). Of the 153 fields planted to mungbean over the three seasons only 29% (42 fields) achieved yields of significance (Figure 14).

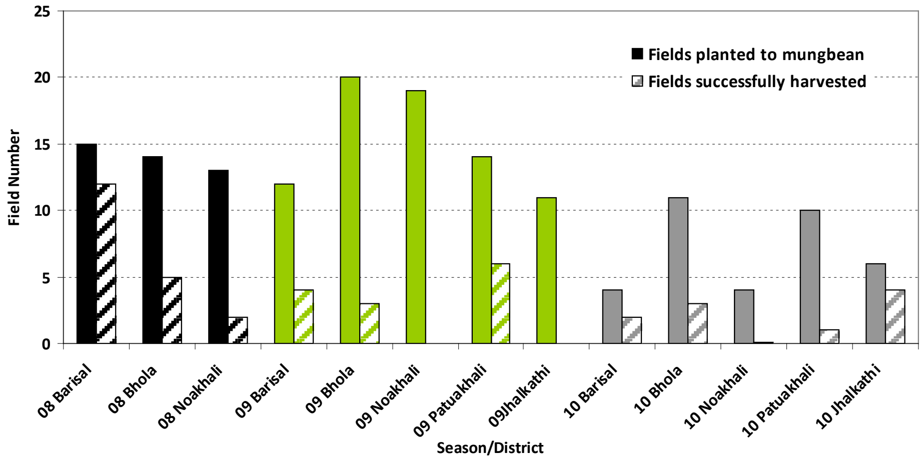


Figure 14: Number of farmer fields planted to mungbeans during the 2008, 09 and 10 seasons and the number which were able to be successfully harvested and from which economically significant yields were achieved.

The high attrition rate was a result of late sowing, poor management practice and environmental issues including dry sowing conditions, high rainfall and flooding. In 2008, the most successful year for mungbean production, an average weeded grain yield of 921 kg/ha was achieved in Barisal (12 fields harvested), 646 kg/ha in Bhola (8 field) and 364 kg/ha in Noakhali (2 fields) (Fig 15). Yields in the 2 subsequent years were lower due to the impact of cyclones and tidal surge.

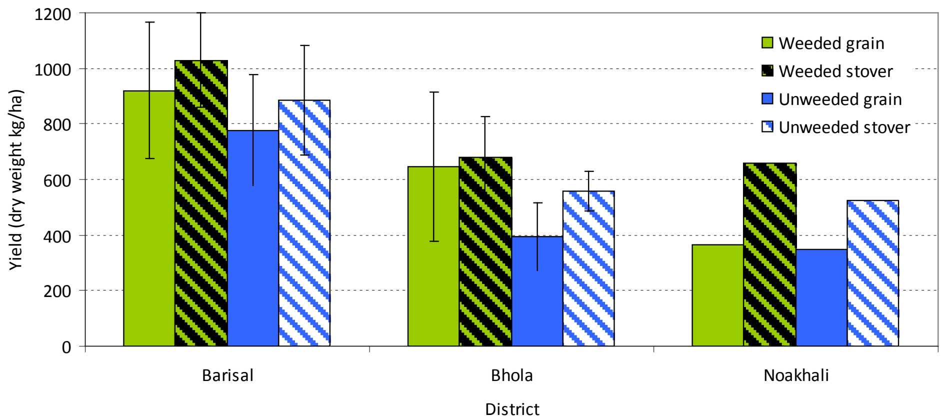


Figure 15: 2008 mungbean grain yields achieved in the districts of Barisal, Bhola and Noakhali from a total of 22 fields (of 42 planted) where the crop was successfully established and grown through to maturity. Also shown is the impact of weeds on both grain and crop stover (non-grain dry matter) yields for the three districts.

Pests and diseases

It became abundantly clear that farmers had little experience in growing mungbean; consequently weeds went uncontrolled, resulting in yield losses (compared to weeded areas) in the 2008 and 2009 seasons of between 5 and 62%. The importance of insect control was not fully appreciated by either farmers or extension personnel resulting in high losses to pod sucking insects. This was a particular issue in the wake of Cyclone Sidr

(November 2007) when farmers were provided with mungbean seed as reconstruction aid. The seed was sown as soon as conditions allowed at the start of the Rabi-season and a number of weeks prior to the sowing of the SMT program. Asynchronous sowing of the 2 crops, and the subsequent prolonged periods of flowering and seed set, resulted in the development and carryover of high populations of insects which severely damaged the later sown crops.

Systems implications

For mungbean to be seen by farmers as a reliable, viable option in rice/wheat systems a number of issues require addressing, the most important being the timing of crop planting. As discussed above there is a significant risk of crop spoilage as a result of late season climatic conditions, as well as problems associated with successful crop establishment resulting from the dry sowing conditions. Analysis of the timing of crop sowing, which included all 118 SMT sites (in 5 regions) planted to mungbean during 2008 and 2009, provides evidence of the importance of establishing the crop as early as possible (Figure 16). A probability analysis, comparing March (52 fields) and April (66 fields) plantings, shows that the potential for significant yield drops dramatically for crops planted after the end of March with successful grain production occurring in only 6% of years. Even in March there is still a 48% chance of total failure. However, in the other 52% of years the analysis shows a yield potential of >380 kg/ha with 20% of years being >800 kg/ha (Figure 16).

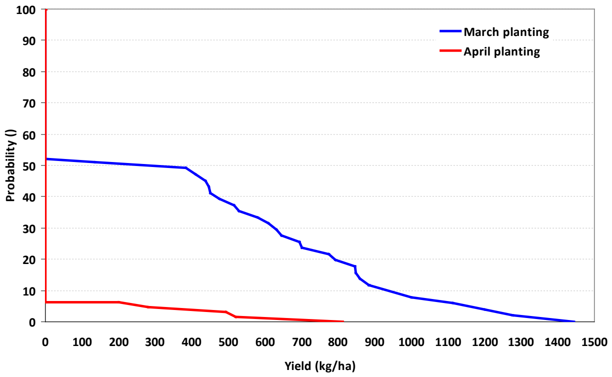


Figure 16: Probability distribution of mungbean yield (kg/ha) by month of sowing (March; April) for 118 crops grown across 5 regions of southern Bangladesh during the 2008 and 2009 seasons.

Whilst poor farmer management practice contributes to the results, analysis of the Barisal weather record for the months March to June (1949 to 2009-data provided by BMD) shows the impact that dry sowing conditions have on March plantings. The record shows that in 25% of years (15 of the 60 year record) no rain was received during March, although >30 mm was received in 50% of years and >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 dryland mungbean establishment difficult.

Analysis of mungbean production using the APSIM model supports this view. Based on the 40 year meteorological record (1967-2007) for Barisal the analysis shows that in 60% of years a crop being established on rainfall between the 20th and the 31st March would have been a total failure due to a lack of planting opportunities. In 35% of years however, it was still possible to plant and achieve yields of at least 1000 kg/ha, with a maximum simulated yield over the 40 year period of 1392 kg/ha. What this analysis indicates is that if a planting opportunity arises prior to the end of March, there is a good chance of significant yield, as long as good agronomic management is practised.

Whilst the logical farmer response to dry March soil conditions would be to postpone planting until sufficient sowing moisture was available (there is a 70% chance of >38 mm rainfall in April), the issue of later crop maturity and the potential for spoilage through early monsoonal rainfall or cyclonic activity needs to be seriously considered. Again, using the Barisal weather record, analysis shows a 98% probability of rainfall in May with >180 mm falling in 50% of years and >280 mm in 20%. 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 >160 mm, and a 50% chance of >386 mm during the month (Figure 17). This analysis indicates that the majority of failures that occur in April planted crops are due to late sowing and the increased probability of severe climatic conditions occurring as crops mature (Figure 16).

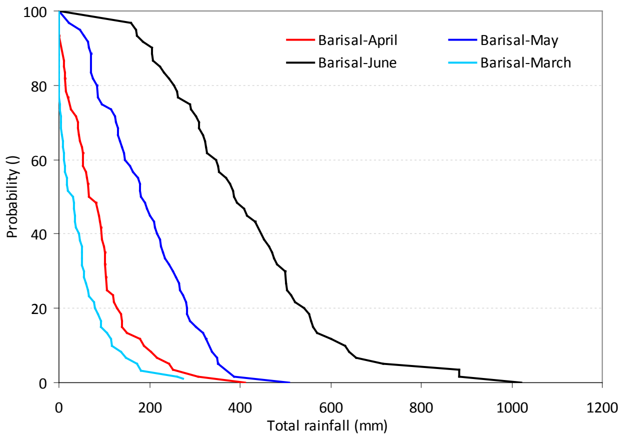


Figure 17: Rainfall probability distribution for March, April, May and June for 1949 to 2009 for Barisal, southern Bangladesh.

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 their 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, prior to the end of March are not conducive to establishment, then an alternative crop such as Aus (Kharif 1) rice should be considered. Mungbeans should not be considered for planting after the end of March, due to the potential risk from late season catastrophic weather events. If a farmer has a preference to grow mungbeans compared to wheat, then they would be best advised to replace wheat with mungbean as a Rabi-seson crop planted in January.

Underlying all of the assumptions about the ‘fit’ of mungbeans in the farming system, and the yields which are achievable, is the premise that farmers have the expertise to grow the crop successfully. This is currently not the case. If the potential for mungbean to contribute to farmer livelihood and national food security is to be fully 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.

Kharif Rice production

T. Aman rice production was monitored for yield and agronomic management on 89 SMTs located in 4 regions during the 2008 and 2009 seasons. These data were recorded by the regionally based field staff and formed part of the data set for simulation of the farming system, examples of which are provided in section 7.5. Yields ranged between 1.5 and 5 t/ha with an average yield of around 3.4 t/ha dry weight (rough rice).

7.4 Fine tuning agronomic practice

7.4.1 Nitrogen by Irrigation

The N x Irrigation study in 2007-8 (Figure 18 and 19) undertaken in Hazirhat, Noakhali produced very clear findings that irrigation at 20 days after sowing (DAS), when the wheat crop was at the 3-4 leaf stage, was essential for a high-yielding crop, particularly as it resulted in a response to nitrogen application right through to the high levels recommended by WRC (100 kg/ha N). Other times of irrigation and no irrigation resulted in response to nitrogen but only to lower levels of application with no benefit from high application rates. These finding, if general were important both for timing (20DAS) and for amounts of N applied showing that there was no point applying high levels of N if there was no water for irrigation or if it couldn't be applied at 20 DAS. Due to concerns that there were likely to be high background levels of soil N the experiment was repeated during the 2008/09 season on a low N site on the same farm at Hazirhat and at a site at West Narayanpur, Barisal.

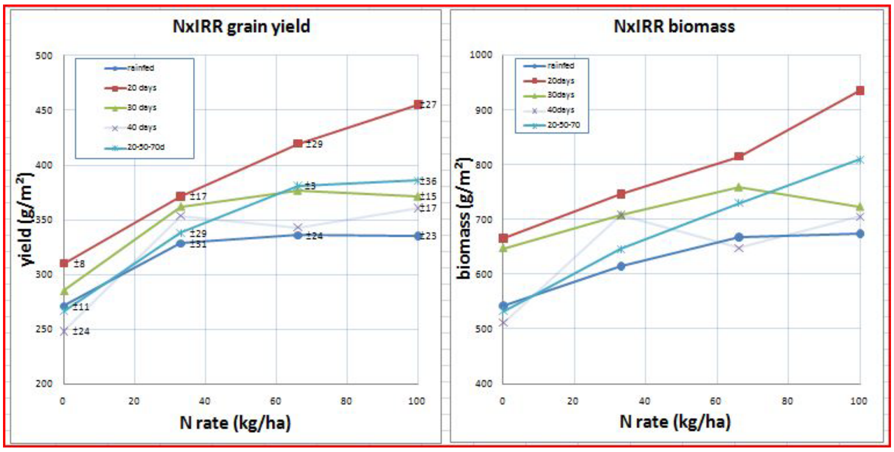


Figure 18 and 19: 2007/08-Grain yield and biomass in response to Nitrogen rate (N0, 33, 66 and 100 kg/ha N) and irrigation timing (rainfed, 20, 30, 40 and 20/50/70 DAS) at Hazirhat, Noakhali

As the low nutrition site at Hazirhat was planted very late (31st December 2008) it was constrained by length of season as well as by nutrition. This was reflected in the yields of the N0 dryland treatment which yielded 0.5 t/ha. This contrasts with 2.7 t/ha from the dryland, N0 treatment at the same farm though a different field in 2007-8. There was a progressive response to increased N, even when no water was applied. In this case however, irrigation at 20 DAS was no different to dryland, while delaying irrigation to 30 DAS was the best treatment though effects were not significant (Figure 20 and 21). The response to N was achieved primarily by setting more grains per m², in part through more culms and in part by more grains per culm. This resulted in each additional kg N being equivalent to 29 more grains /m² in the rainfed treatment, and 40 more grains in the 30-day irrigated treatment, both being added above a base of ~1400 grains /m² in the zero N treatment.

The 2007/08 crop grown at Hazirhat on a higher fertility site responded differently in terms of grain number/m^2 to increased N. All N treatments, apart from those irrigated at 20 DAS and including the 20-50-70DAS treatment, reached maximum grain number at 33 units of N. There was no increase with higher levels of N. The 20DAS irrigation produced a progressive rise in grain number to 100 units of N at the rate of 22 grains /m²/kgN. The basal N in the soil produced over 6000 grains/m². Assuming that there was 100 kg of soil N available at sowing in 2007/08, no additional N applied, and a rise in grain number of 40 per kg N applied, as in the 2008/09 Noakhali study, the grain number achieved from 100 kg N was 5500. This is not dissimilar to the 6000 grains/m² in the N0 treatment of the 2007-8 study.

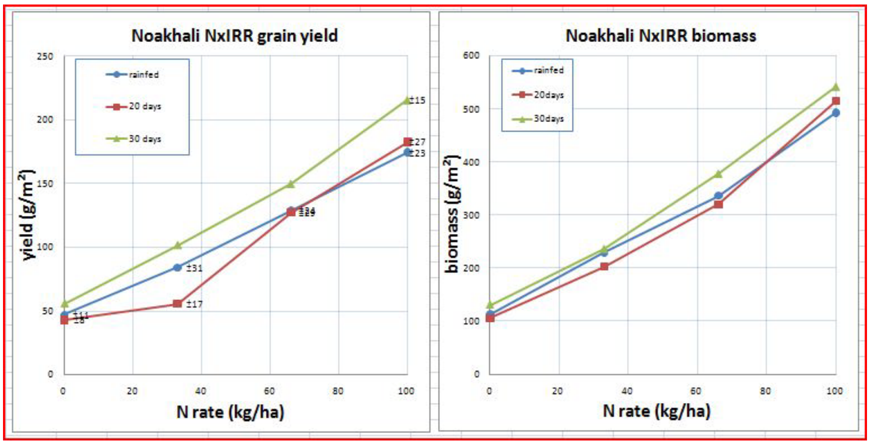


Figure 20 and 21: 2008/09-Grain yield and biomass in response to Nitrogen rate (N0, 33, 66 and 100 kg/ha N) and irrigation timing (rainfed, 20 and 30DAS) at Hazirhat, Noakhali.

Does this mean that grain number is set primarily by nitrogen, at least up to 133 units of N (including that available in the soil) and that irrigation at 20 DAS in a “normal” season assists in activating the N applied to ensure higher grain numbers? Combining the data on grain number vs N from the 2007/08 Hazirhat N x irrigation study with that from the 2008/09 N x irrigation study and using the data only from the 20 or 30-day irrigation, and assuming that the 2007-8 study had 120 kg soil N available (in addition to that applied as urea) produces the graph in Figure 22. This suggests that an irrigation at around 20 DAS is critical for getting good yields in southern Bangladesh by making available the N that is added and mineralising in the soil. At higher N levels and in longer seasons additional yield is achieved through increased kernel weight. At Hazirhat in the 2008-9 season kernel weight averaged 38mg and reduced slightly as kernel number increased. In 2007-8 it averaged 44 mg. In low N environments effective culm number per m² drops leading in part to the reduced grain number.

The implications of this work are important for future sustainable production of wheat in southern Bangladesh where water resources are often limited. One irrigation (as opposed to the 3 recommended for northern growing regions) around 20DAS and nitrogen at the WRC recommended rate of 100 kg N provides the best chance of maximising yield when the crop is planted in early to mid-December. Crops that are planted later or where irrigation is not an option are unlikely to be able to utilise such high rates of N and it is recommended that the rate be reduced to 33 kg N. Even though there is a response to N, the yield plateau in some areas can be so low that the benefit does not justify the cost. To test this hypotheses a series of trials was conducted at Noakhali and Barisal in the south and Dinajpur in the north during the 2009/10 season (Described in 5.3.4).

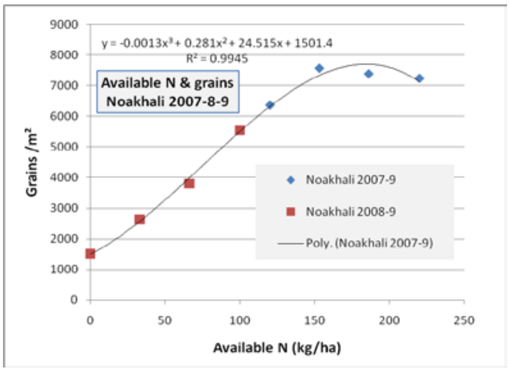


Figure 22: 2007/08 and 2008/09 Grain set in response to N application over 2 seasons at Hazirhat, Noakhali.

The mechanism by which the crop responds to irrigation at 20DAS is yet unknown. Whilst it is assumed that it is related to the increased availability of N at a critical time in the plant's development this has not been proven through work undertaken in Australia in 2007/08 or Bangladesh in 2008/09. It is also not clear why some SMT yields, in the absence of irrigation, were as high as when full irrigation was applied. Speculation is that this can happen where water tables are high.

7.4.2 Variety assessment

In 2006/07 trials were conducted at 6 locations across the three districts (Table 4). All sites were sown in mid-December using the 100%WRC fertiliser recommendation. Overall highest mean yield across all sites was the WRC line BAW1064 (3.68 t/ha) closely followed by Shatabdi (3.63 t/ha). The lowest yielding irrigated variety was Prodip (3.18 t/ha). Dryland Shatabdi yielded 630 kg less than the irrigated Shatabdi crop (and see Tables 13, 14 and 15).

In 2007/08 the variety trials were conducted at one site each in Bhola and Barisal (Table 4) with the additional comparison made between application of fertiliser at 100%WRC recommended rate and 50% of recommended. This was done to test the impact on yield and income of a strategy likely to be used by farmers in an environment where fertiliser costs are rising. Sowings were on the 15^{th} and the 18^{th} Dec for Barisal and Bhola respectively. Bhola received its irrigation 24 days after planting, close to the recommended day, while at Barisal this was delayed to 30 DAS.

Average yields for the two seasons were the same for the WRC100% fertiliser rate (3.62 vs 3.57 t/ha) considering only varieties common to the trials (Shatabdi, Bijoy, BAW1059, Prodip, Sourav) and excluding saline-prone Noakhali sites. BAW1059 was the top variety using full WRC recommendations. BAW1064 also showed good potential being the best at Barisal.

Whilst the ranking of varieties is a useful exercise it is also worth noting that all of the varieties achieved yields in non-saline conditions which far exceed the national yield average of 2.8 t/ha (Md. Saifuzzaman *pers. com*, 2009/10 data). In the 2006/07 season average yields across varieties ranged between 3.36 and 3.86 t/ha under irrigated conditions (at 4 sites in 2 districts) and in the subsequent season between 3.1 and 3.9 t/ha (at 2 sites in 2 districts). In the 2007/08 season individual yields of 5 varieties at the Bhola site exceeded 4 t/ha. Even under conditions of higher soil salinity crops at the 2 sites at Noakhali yielded between 2.82 and 3.45 t/ha. These combined data show the potential of the newly released varieties to contribute significantly to future production if they are able to express their potential through being able to access the necessary nutrition and water.

7.4.3 Do late-planted crops require less fertiliser?

In the 2009/10 season and 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 detailed in the methodology sections. Irrigation and appropriate N top-dress 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 at 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 23a). 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 vs 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 23b). 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), with 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.

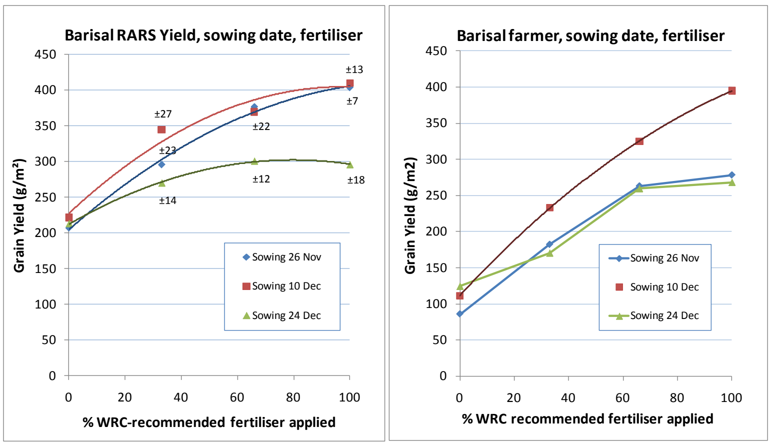


Figure 23: Yield in Barisal as related to % Wheat Research Centre-recommended fertiliser applied and sowing date at a) Regional Agricultural Research Station, and b) a local farm.

Crops at 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 24). It was linear from the earliest planting with only slight reduction in response to the late planting of 24 December.

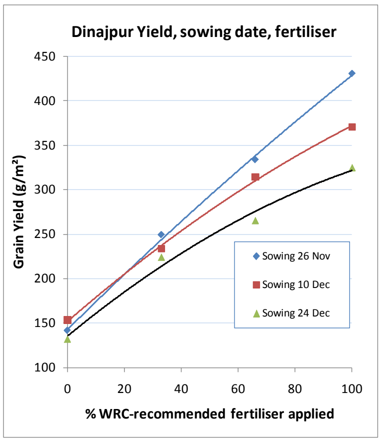


Figure 24: Yield at Wheat Research Centre (WRC) Dinajpur as related to % WRC-recommended fertiliser applied and sowing date

The conclusion from these Dinajpur data is that the fertiliser (and planting date) recommendations are correct for the area. Consequently, 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 Tk 5000 to raise fertiliser application from 66 to 100% WRC 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.

7.4.4 Assessing organic fertilisers and yield

This study was done at Barisal RARS in 2009/10 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.

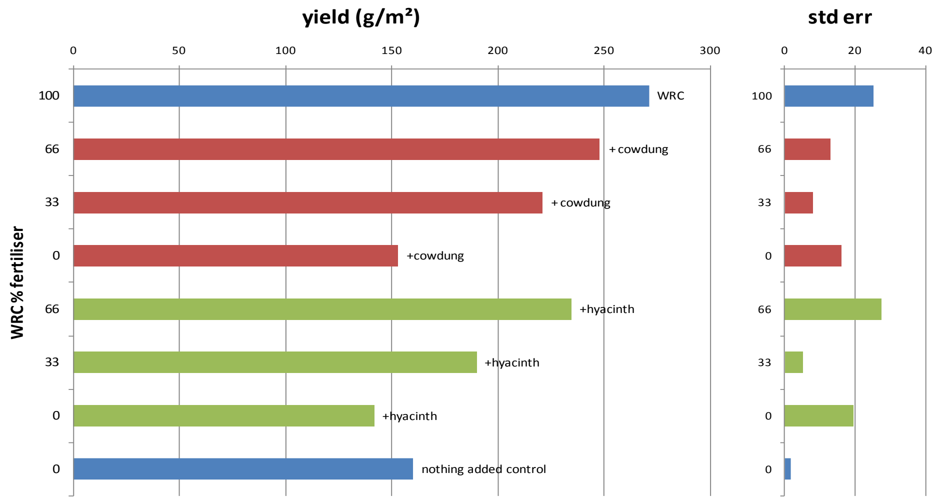


Figure 25: Effect of using 0, 33, 66 or 100% WRC-recommended fertiliser amount mixed with 5 t/ha cow dung or 5 t/ha hyacinth and the standard error mean for each treatment.

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.

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 25). 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.

7.4.5 Salinity screening and observation

Salinity at Hazirhat, Noakhali

Salinity evaluation was centred at Hazirhat due to the high levels of salt generally present during the Rabi season. Whilst levels vary spatially and temporally it is common for EC to reach levels of 8 dS/M at the soil surface by wheat harvest. During the monsoon season many areas are flooded which results in any salt present being leached away from the surface to deeper into the soil profile. Consequently in the early Rabi season surface concentrations of salt are sufficiently low to allow successful establishment of crops such as wheat. However, as the Rabi season progresses the salt rises again via capillarity into and through the crop root zone leading to reduced crop yield.

Salinity screening

The screening trials undertaken in each of the 5 seasons in the Noakhali district were used as a broad brush evaluation of salinity tolerance amongst WRC advanced breeding lines and materials from a number of other countries including several sourced in Australia from CSIRO Plant Industry. Lines were assessed against checks of the known varieties Shatabdi and Prodip. Any promising lines were moved from this coarse screen to a more detailed evaluation under the Salinity Observation programme. In 2008-9 the Bangladesh Wheat Screening Nursery was also checked for salinity tolerance. This nursery that included many lines originally from CIMMYT, was also assessed by WRC in the northern wheat production areas of Joydebpur, Jamalpur, Jessore and Dinajpur. The following discussion focuses on the results from that season.

Grain yields and kernel weight

Figure 26 shows the yield averages for the two replicates and associated standard error with the highest yielding lines at the top. Yield of the check varieties (in yellow on the graphs) was very low at 600 and 450 kg/ha reflecting the late planting and salinity level of the soil in 2008-9. The best-performing selections (60, 23, 24, 44) almost doubled the average yield of the check varieties and more than 30 selections did better than the best check, showing considerable salinity-tolerance promise in this collection of crosses. The performance of each line needs to be assessed in relation to its standard error which shows variation across replicates with a small s.e. indicating stability. For example selection 27 had almost the same yield in the two replicates while selection 29, with the same average yield, had a high se, yielding very well in one rep but poorly in the other. This is indicative of some variation in salinity across the site.

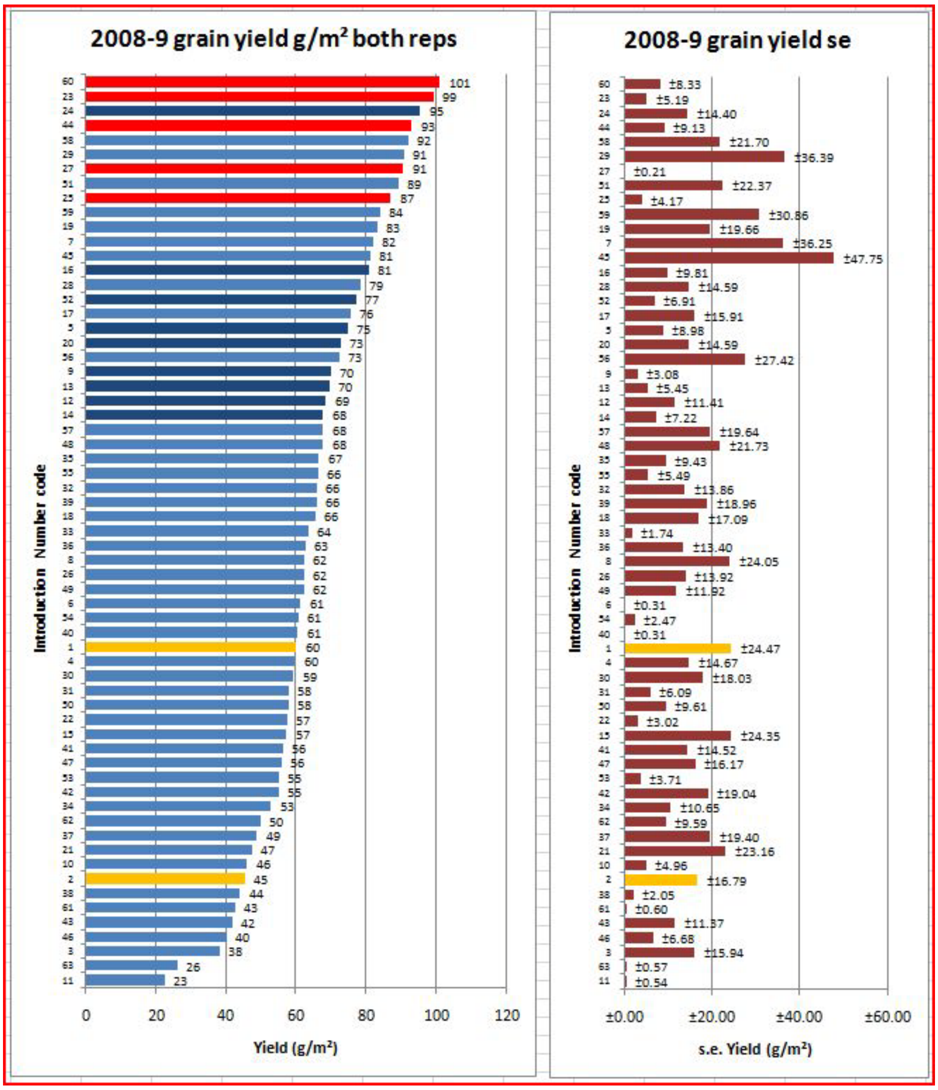


Figure 26: Salinity Screening Trial, Hazirhat, Noakhali 2008/09: Ranking of lines for grain yield (g/m^2).

Kernel weights ranked the same as for yield. Sometimes kernel weight can be low in high-yielding lines and such lines should be noted. Kernel weight across the lines varied between 27 and 42 mg, a good overall result considering the late planting and very hot finish to the season. Most had standard errors less than 1mg indicating stability. Some of the best-yielding lines had kernel weights of 37-38 mg which is a good result.

The situation in the north (at Joydebpur for example) is quite different to Hazirhat. Under optimum conditions (planting 15-30 Nov and no salinity), the check variety Shatabdi was ranked No.1 (40th in the Hazirhat trial) with none of the top 15 screening lines considered as salinity tolerant in Hazirhat producing well in the north.

Under late planting at Joydebpur (Dec 20-25 and no salinity) only two lines common with Hazirhat ranked well (E 44 and E 23); the check variety Shatabdi ranked 12th. The salinity/no salinity and normal/late planting comparisons suggest that the highest yielding varieties at Hazirhat may be doing well in part because of their improved suitability to late planting. However the fact that Shatabdi ranked 40th at Hazirhat and 12th in a non saline environment at Joydebpur suggests the top ranking lines at Hazirhat are doing so in part because of their better relative salinity tolerance.

Lines identified during the above 2008/09 screening were either moved to the salinity observation trials for 2009/10 or further evaluated in the screening trial of that and the following season. Details of these later screening trials appear in the ACIAR Technical Report.

Salinity observation

2007/08

The Salinity Observation Nurseries were designed to take promising lines from the screening nursery and subject them to more rigorous analysis in larger plots with 4 replications. Results from the 2007-8 trial at Hazirhat, Noakhali were as follows. Yields averaged 2.5 t/ha with the best varieties being BAW 1059 (2.94 t/ha) and V01078 (2.72 t/ha) followed by check varieties Shatabdi (2.68 t/ha) and Sufi (2.58 t/ha). Differences between new selections and check lines were not significant.

2008/09

The 2008/9 observation trial was also sited at the saline Hazirhat site adjacent to the screening nursery. Planting was very late, on 31st December 2008. 11 of the 18 lines had been identified through the project's salinity screening procedure. The check variety Shatabdi ranked poorly from this late planting date, exactly as in the previous Salinity Screening Nursery. The best selections doubled the yields of the checks with the 7 best lines producing over 1 t/ha. The top lines also achieved acceptable kernel weights of around 30 mg.

It was concluded from the 2007 to 2009 data that V01078 is suitable for use in southern saline regions being able to yield well across the potential planting window. Dr ABS Hossain, consultant to the project and retired WRC Plant Breeder summarised the findings "V01078, BAW 680, BAW1059, BAW 1064 and GARUDA/BB/TOB...ICTAL123 have all maintained their superiority over the checks of Shatabdi and Prodip again in 2008/09. These lines, as well as BAW1103, BAW1104 and BAW1114 have filled grain well, far better than Shatabdi and Prodip". These lines all figure in the 2009/10 trials.

Salinity yield trial (2009–10)

A more comprehensive yield trial was planted for 2009/10 in four replications at optimum and late sowing dates, at three saline sites, Satkhira, Noakhali (Hazirhat) and Patuakhali, and at the more northerly site Joydebpur (non-saline). Twelve varieties/lines were used that were selected from the 2008–09 trials. WRC recommended management practices were followed. The Patuakhali plots were not harvested due to time constraints.

Considering Satkhira is reputed to be saline, though EC was not measured in this trial, yields of between 4 and 5 t/ha from normal planting and 3 t/ha from late planting is remarkable. The effect of late planting overall was to reduce yield by 27% though in BAW 1114 this was only 5% (Figure 27). Joydebpur also produced 4 t/ha yields from optimum planting dates but reduced production to less than 3 t/ha as a result of planting late, or by 37% overall. All varieties there were reduced similarly by late planting. By contrast, the saline Hazirhat site showed the constraining effects of salt by averaging only 2 t/ha from 'optimum' planting date and 9% less from late planting due to three lines actually improving their yield. 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.

Highest yield was obtained in V01078 under both optimum and late planting dates at Satkhira followed by BAW 1111, Prodip and BAW 1104. V01078 also ranked top at Joydebpur. In Noakhali highest yield was produced by BAW 1114, followed by Garuda/ Bb… under optimum condition. 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, 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. If Satkhira is to be used in any future salinity assessment trials, it is vital that EC levels are measured in all plots. The suspicion is that the 2009-10 salinity site may not have been effectively saline.

The problems of salinity screening and a solution

Salinity within the south of Bangladesh varies on a regional scale from ‘strongly saline’ to ‘no salinity’. 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.

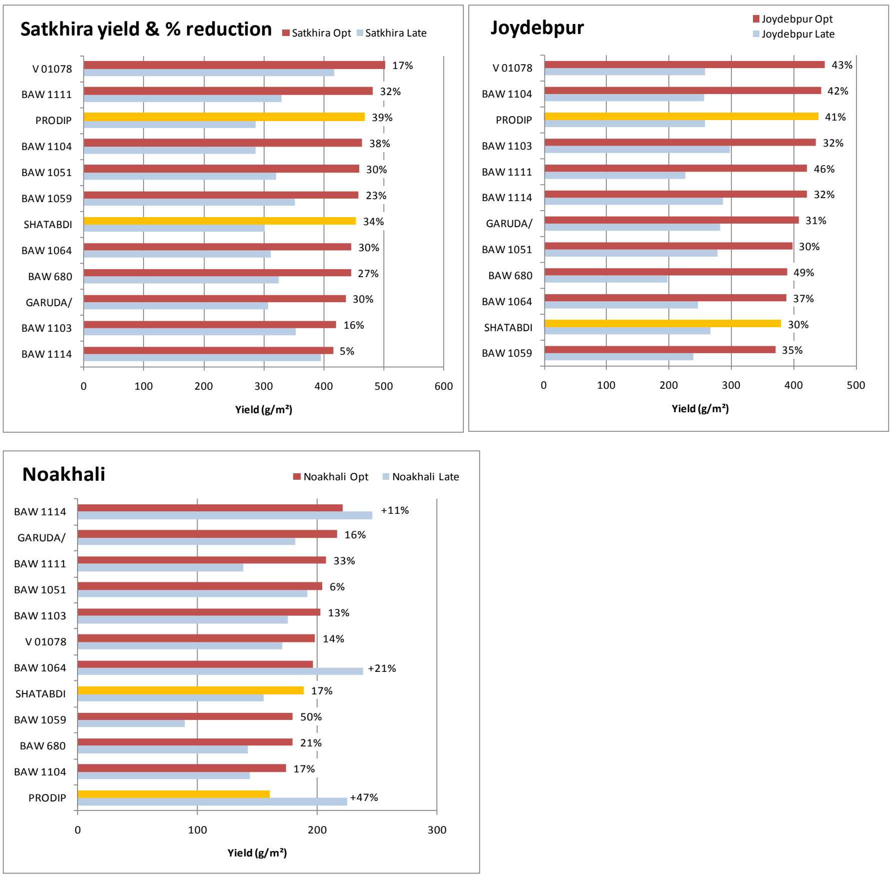


Figure 27: Salinity yield trial 2009–10 showing yield (g/m2) after planting at optimum date (brown) and late (grey) and % reduction from late planting for 12 wheat lines at Satkhira (slightly saline), Joydebpur and Noakhali (below). Check varieties are yellow. Noakhali yield scale differs from other locations.

During the dry Rabi the salt moves in solution back up the soil profile by capillarity and can crystallise on the soil surface as the water evaporates. Salt concentration is very variable temporarily and spatially, both vertically and horizontally. It can differ substantially not only at the scale of experimental replications but even at the scale of neighbouring plants. In Patuakhali 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 (Figure 27). There the average salt content in the surface soil of the four replicate blocks was 13.1 dS/m varying from an average of 9.2 in replicate 2 to 18.8 dS/m in replicate 4, but within those blocks individual plots ranged between 2 and 29 dS/m at planting to 3.3 to 35 dS/m two months later. The adjacent optimum-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 28 shows a cursory attempt at this approach. Biomass production at maturity for the 2009–10 salinity screening trials is plotted against ECe (Electrical Conductivity of a saturated extract) measured in each plot in the surface soil on one date and then on a date six weeks later. On the first date of Figure 28a 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 28a) reveals a general response of wheat to salinity with varieties providing the variation in tolerance around the fitted power curve. Logically 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 that ranked highest (Entry 21 with 113 g/m^2 yield) and lowest (Entry 5 with 20 g/m^2 yield) are plotted as yellow and red markers respectively in Figure 28a.

It can be seen on either graph of Figure 28 that the best ranked line was grown at lower 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 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, BAW698/Shadabdi as a promising salt-tolerant cross because all of its replications fall well above the average curve of Figure 28a. This ranked lower mid range in the traditional analysis so following that method would be excluded from further trials.

Does this mean that the selection methods for salinity tolerance 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). Indeed that method has worked satisfactorily to identify lines that seem more tolerant of salt. The worry has been that the chosen lines have not always ranked best in consecutive trials. The explanation for inconsistency is likely to be the unmeasured plot to plot variation in salinity. It is suggested that in all future salinity trials ECe should be measured in all plots on at least two occasions to generate graphs as in Figure 28. Then varieties should be assessed for salinity tolerance by following both the traditional method used in this project and the method of Figure 28 of above and below the common biomass vs salinity line.

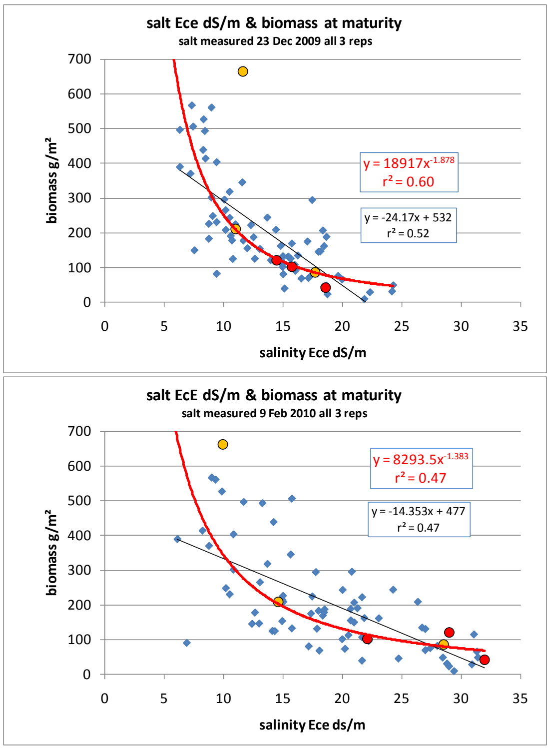


Figure 28: Biomass at maturity (g/m2) for each replicate of each wheat line as related to salinity (ECe dS/m) of the surface soil in its plot measured on a) 23 December 2009 and again on b) 9 February 2010 for the salinity screening nursery. Curves are fitted to all data; the power curve is in red. The yellow circles are from the best-yielding line E21 and the red from the worst E5.

7.4.6 Formed bed versus flat planting

2008/09

This trial was conducted during the 2008/09 season using a sub-set of 4 SMT sites in each of the Barisal and Noakhali districts. Half of each SMT was sown using the conventional system of rotary tillage and seed broadcasting and the other formed into beds with the seed sown in rows as a one pass mechanical operation (using a 2 wheel tractor). With the exception of a poor crop of the variety Sourav, yields generally exceeded 3 t/ha at Barisal with no significant difference between bed and flat planting for any of the varieties. This was also the case at the Noakhali site where yields of around 2 t/ha or less were achieved. This is common for this area, particularly from late sowings.

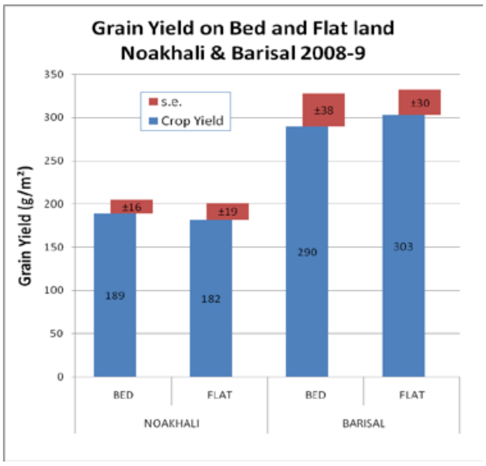


Figure 29: Average yied response to tillage system across 4 varieties x 2 tillage treatments and 2 locations in the 2008/09 seasonl.

The average yield response to bed vs flat planting (Figure 29) showed no method was better at either site. There was also no evidence that beds produced more and larger grains on fewer though stronger shoots though visual comparisons during grain filling suggested a difference. Weight per grain was 32/33±2 mg at Noakhali and 40/41±3 mg at Barisal. Harvest index was also the same between cultivation treatments being 37±1 at Noakhali and 44±3 at Barisal.

2009/10

Despite the 2008-9 conclusive evidence that beds and flat-plantings do not differ in yield, the feeling continued amongst the involved researchers that beds should be better. So the comparisons continued at more locations in 2009–10. Four farmers were involved in each of four regions Barisal (Khanjapur), Barguna Amtoli (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 BAW1059 and BAW1064 (BARI gom 25 and BARI gom 26, at that time as un-named lines). Sowing dates were earlier in an attempt to encourage longer durations and thereby to possibly advantage bed-plantings. Regions and sowing dates for the studies are shown on the headings of Figure 30 and the varieties used appear over each pair of tillage comparisons.

No region showed any consistent or significant advantage for either cultivation method or for any variety used for a cultivation method (Figure 30). One of the saline Hazirhat farms (farm 16) seemed visually to have better performance in beds. This was because the flat-plantings had areas of poor performance though 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.

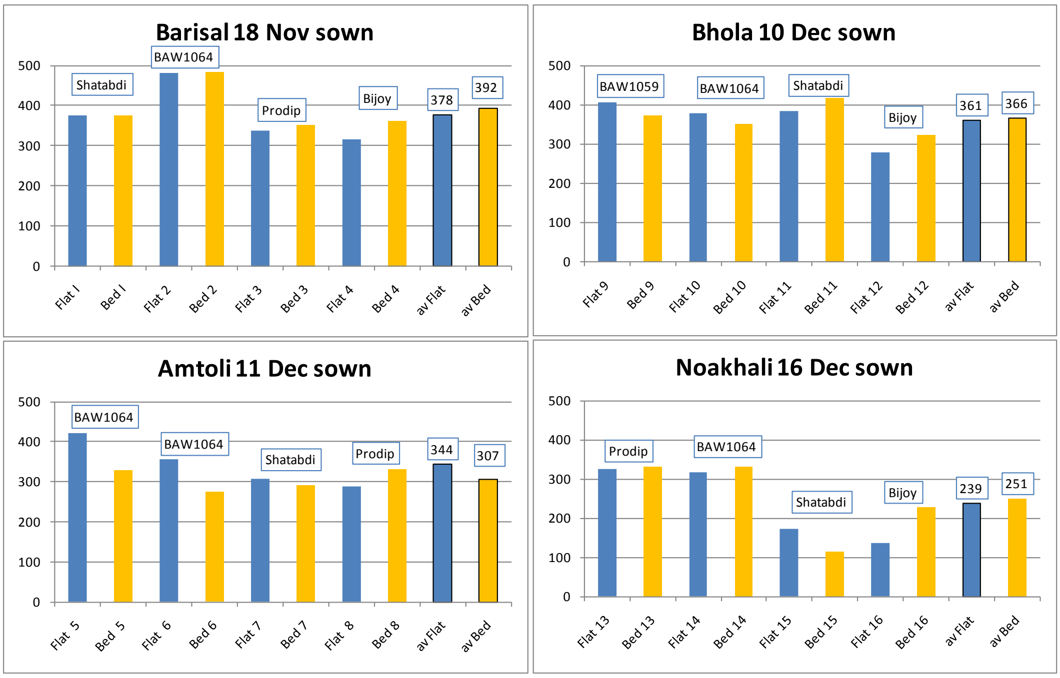


Figure 30: Yields (g/m²) of wheat crops planted on the flat (blue) or on beds (gold) on 16 numbered farms in four regions using five varieties in 2009/10. The average for the four farms in each region is shown as the last pair of histograms on each graph.

Why would any farmer want to use beds?

The experimental results indicate no yield benefit from the use of beds. This is similar to results of work undertaken by FAO/WRC between 2003 and 2005. However there are still compelling systems reasons that a farmer may consider their use. One of the most important of these is gains in irrigation water use efficiency. In the flat plant system it is common to see quite variable distribution of water after irrigation with shallow pools often present post-application. In saline lands this can lead to salt concentrating in these pooling areas which can result in poor plant growth. Using beds allows the water to move across an area more quickly and evenly, both saving water and reducing the potential for water logging, pooling and plant stress. One of the major labour inputs to crop production is in weed control. Whilst farmers tend to weed wheat once in the early stages of growth they find it too difficult, in the flat plant system where the seed is broadcast, to undertake later weeding. This however, is a relatively easy operation in the bed system where plants are in rows. Anecdotal evidence from farmers is that the use of beds also reduces the incidence of rat infestation and crop damage, a serious issue in some areas. Beds are also attractive to farmers wanting to establish crops such as vegetables which are generally grown using beds.

7.5 Farming systems analysis

Radiation data quality

Use of quality solar radiation data in (Radiation Use Efficiency (RUE) type models should not be underestimated especially in environments with high levels of atmospheric pollutants. Radiation data for APSIM was converted from daily sunshine hour records and long-term values compared to accepted monthly means for a number of locations (Figure 31b). An inherent problem during conversion is dealing with zero values for sunshine hours. A zero value is effectively an instrument failure due to a reduction in energy required to burn a trace but can be associated with conditions of a high proportion of diffuse light which also does not burn a trace though it still supports crop photosynthesis.

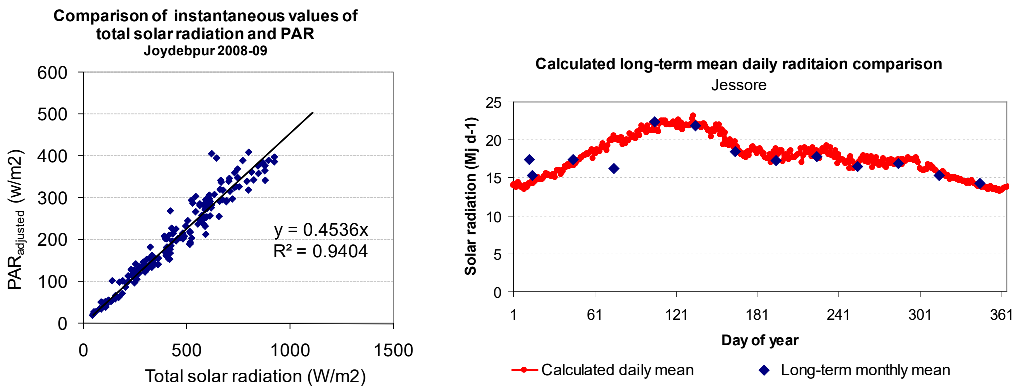


Figure 31: (a) Measured ratio of instantaneous values for total solar radiation and photosynthetically active radiation (PAR) at Joydebpur, August 2008 – February 2009. (b) Comparison of mean monthly solar radiation values with calculated radiation from daily sunshine hour data using Angstroms equation for Jessore.

Dust in the lower atmosphere is associated with a significant reduction in the blue spectra (~450 nm) but only a slight decrease in the red (~650 nm) which can have minimal impact on the process of photosynthesis, and effectively, plant growth. Setting a minimum of 3 for sunshine hours results in minimum daily solar radiation values of ~9.2 MJ d^{-1}. This is a high base. Data for instantaneous spot values for total solar radiation and photosynthetically active radiation (PAR) were measured at Joydebpur during the 2008-09 season (Figure 31a). Measurements show a reduction in radiation in the PAR spectrum (400-750 nanometres) and suggest further evaluation of the 2:1 ratio of total radiation to PAR (used in APSIM) when simulating crop development in haze effected environments.

These preliminary results have enabled better parameterisation of APSIM in simulating crop growth in response to radiation. Further measurement and evaluation is required over a number of seasons to better capture the effects of low level haze conditions on wheat development during the Rabi.

Simulation results

APSIM was parameterised and run against field measured data from the time of planting study (TOP), seed multiplication trials (SMT) and irrigation by nitrogen experiments (Irr x N) sown between 2007 and 2009. Data from wheat cultivars (cv. Prodip, Sufi and Shatabdi), Mungbean (BARI Mung 6) and rice (local upland, BR3, BR23, BRDan32 and BRDan41) were modified for use by APSIM. Demonstrated capability of APSIM to simulate both grain yield and biomass for 3 wheat cultivars at 4 regional locations, based on SMT data collected from 2008-09, is presented in Figure 32.

A number of cropping sequences were explored, (a) to benchmark the modelled cropping system with that of the observed or measured field data and (b) to evaluate water (ponding and irrigation) and soil nitrogen dynamics of those systems. Simulated results of the cropping sequence sown at SMT site 1 at Bhola from 2007 to 2009 is presented in Figure 33a. Measured biomass and grain yield along with simulated soil nitrate (NO3-N) and nitrogen available to the T. Aman rice crop (2008) are also included. Simulated soil water dynamics for the rice paddy demonstrating flooded conditions during the monsoon period (2008), irrigation events and daily rainfall for the entire period (2007-09) are presented in Figure 33b.

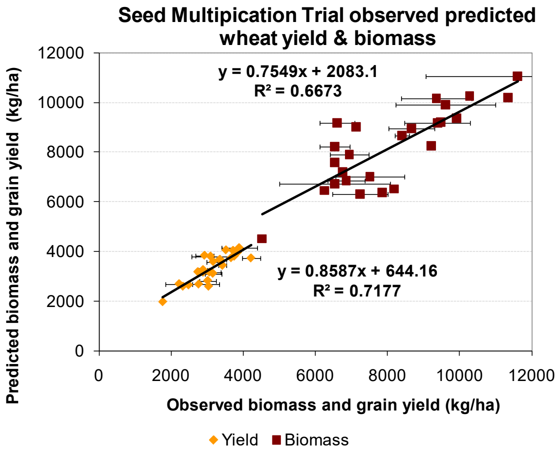


Figure 32: Measured and simulated grain yield and biomass for 25 Seed Multiplication Trial (SMT) sites at Barisal, Jhalakathi, Bhola and Noakhali for the 2008-09 Rabi season. Three cultivars are included in the simulation (cv. Prodip, Sufi, Shatabdi).

Potential wheat yields for 20 districts in southern Bangladesh were evaluated using climate records from 1980 to 2007 and presented in Figure 34. Results indicate very little spatial variability between districts with the majority of locations achieving mean grain yields of 2.5-3.0 t ha^{-1}. Simulation (not presented) of the main cropping sequences (Table 11) were undertaken for each of the 20 districts with yield results compared to those recorded during farmer interviews and evaluated as part of the economic assessment (ACIAR technical report). These simulations contributed to the scenario analysis of possible cropping sequences and options available to farmers during the Rabi season. An example is presented in Figure 35 comparing potential mungbean yields following a wheat crop sown in December with that of a sole mungbean crop sown in January. Simulations are based on Bhola soil and climate data and represent best management practice for weed and insect pest management.

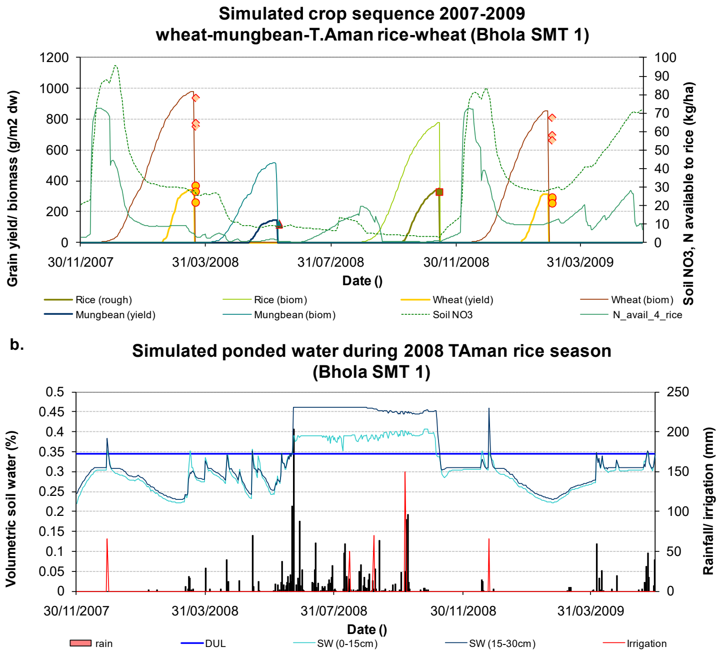


Figure 33: (a) Simulated wheat, mungbean and T. Aman rice crops at Bhola SMT 1 (2007-09). Measured biomass and grain yield are presented (symbols) along with simulated total soil nitrate (NO3) and nitrogen available for the rice crop (N_avail_4_rice); (b) Simulated pond dynamics showing ponded paddy conditions (soil water (mm/mm) above DUL layers 0-15 and 15-30 cm) during the 2008 T. Aman season. Daily rainfall (mm) and irrigation (mm) events are also included.

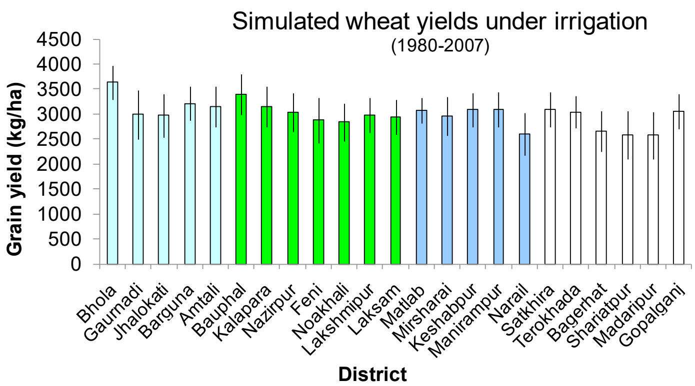


Figure 34: Simulated mean wheat yields for each of the 20 southern districts (4 divisions) over 7 seasons 2000-06. Based on cv. Shatabdi sown on the 20th Dec, with 50 kg ha^{-1} N applied at sowing and another 50 kg 20 DAS. One irrigation of 100 mm applied at 20 DAS.

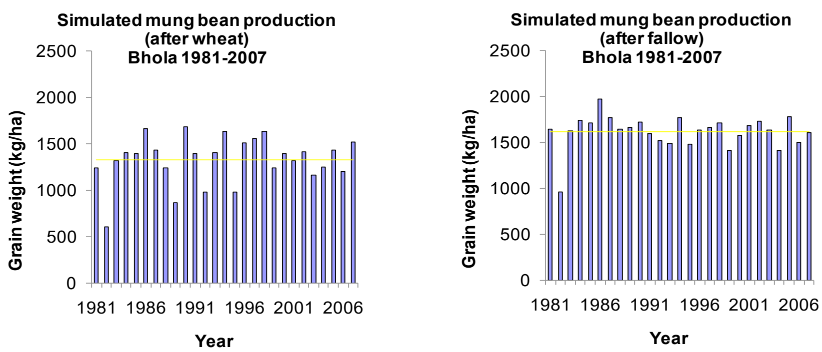


Figure 35: Simulated annual mungbean yields and mean grain yield (yellow line) at Bhola following (a) wheat sown in December and (b) after a fallow following late harvested T. Aman (1981- 2007). Based on the variety BARI Mung 6 (60 days duration) sown on the 1st April after wheat sown in Dec.

7.6 Training and extension

7.6.1 Farmer and extension staff training

1195 farmers, extension and research staff were trained by the project in the various aspects of Rabi-season crop production. Pre-season regional training was critical to the success of the on-farm activities including the SMT program and the regionally located research trials. Whilst the majority of those attending were farmers from participating villages (830), around 360 DAE and NGO extension agents and regionally based WRC scientists also participated. An example of where this worked particularly well was in the North Joynagar and South Balia Unions in Bhola where the impact of good local support to farmers by DAE and project staff resulted in a 30% increase in wheat and mungbean production area in the second year of Rabi cropping (2008/09). Late- and post-season field days to demonstrate the potential for Rabi cropping were also useful in extending the message, as were the more specialised workshop programs undertaken specifically for the WRC and NGO extension staff based in 4 districts to increase skills in pulse production (2008/09) and in wheat agronomy (2009). On a number of occasions the media (both TV and paper) attended field events which resulted in promotion of southern wheat production at both the regional and national levels. The knowledge of the project scientists and their ability to communicate across stakeholder groups within the agricultural community was a major contributor to the success of the training and extension programs.

7.6.2 Change manager communication

It was recognised by the project that change would not occur in southern farming systems unless there was informed knowledge and will at the political level to promote future expansion of production. A communication plan was implemented in 2009 that targeted Bangladesh policy makers and the heads of relevant government departments. Preliminary meetings were held in October 2009 between Bangladesh and Australian researchers, senior government minister and heads of department. This resulted in the convening of the workshop *“Wheat cultivation in southern Bangladesh: The potential for expanding the Rabi season cropping”* which was designed to inform policy makers and international funding agencies on the project. It was held in Sept 2010 and hosted by the Chairman of BARC (Dr Wais Kabir). Over 80 delegates attended including the Minister for Agriculture (Motia Chowdhury), the Australian High Commissioner and representatives of international aid agencies including FAO, USAID (United States Agency for International Development) and DANIDA (Danish International Development Agency).

Whilst it would be premature to suggest that these interactions resulted in significant and immediate changes to the research and extension of southern Rabi-season cropping, it can be said that the interactions were significant in changing the views of senior policy makers in terms of the potential for new varieties and systems to contribute to southern production. This has already resulted in a marked increase in government investment in southern agricultural extension which commenced after the first round of meetings but gained impetus after the workshop when the Director General of DAE met with project researchers to discuss his vision for expansion in the regions of Barisal and Noakhali through the partnering of DAE and BARI. This increased interest by DAE was evident over the past 2 years of the project with increasing collaboration in project activities and the increased development of ‘block’ trials for broader demonstration of the technologies. Whilst the project ended in February 2011 the USAID funded project *“Cereals Systems Initiative for South Asia”* (CSISA) (IRRI/CIMMYT), which is currently increasing its activity in southern Bangladesh, provided short term funding to CIMMYT consultants to work with WRC scientists to continue field research until the end of the 2010/11 Rabi season (April). Whilst this support has now finished it enabled the completion of an additional season of research. In the absence of further funding the teams have been disbanded and the focus for further research brought by international (ACIAR) involvement has now disappeared.

7.6.3 Development of extension resources

Rabi season cropping manual

The manual *"How to grow wheat in southern Bangladesh and fit it in a timely sequence with other crops"* was launched in 2010 by the Bangladesh Minister for Agriculture, Mrs. Motia Chowdhury. The document aims to provide information to farmers who want to learn about the operational aspects of increasing the intensity of Rabi-season cropping and agronomists who require a deeper understanding of the underlying science. The manual has been distributed by WRC and is now in use by farmers and extension agents in southern Bangladesh.

ACIAR Technical Report

The ACIAR Technical Report *"Sustainable intensification of Rabi cropping in southern Bangladesh using wheat and mungbean"* describes the outcomes of the social, agronomic and systems research undertaken during the 5 seasons of project research. The report, which is planned for release in June 2011, contains contributions from over 30 researchers to 19 papers which discuss the potential for increased southern Rabi-season production. Whilst the report is aimed primarily at informing future research and extension in southern Bangladesh, it also has a potentially broader audience in countries where rice based farming systems form the basis of agricultural production and where there is an imperative to increase the intensity of cropping to meet the food security demands of an increasing population.

7.6.4 Staff training

Skills development

Regionally based scientific officers and technical staff employed by both WRC and PROSHIKA (later FoRAM) have been critical to the success of the research and extension programs. The aim has been to employ young graduates and to train them in the skills necessary to manage the research and to act as interface between the project and the farmers and extension personnel. Initially, 6 Masters level scientific officers and 10 technical staff with bachelor degrees in agriculture were employed. Three of the scientific officers and all of the technicians were employed by the NGO PROSHIKA with the intention that they would be trained during the life of the project and then continue as extension personnel with the NGO. Due to the demise of PROSHIKA their employment was transferred to the NGO FoRAM which commenced as a project collaborator in 2009, however it is unlikely that future employment will be offered through this organisation.

Whilst the concept of employing scientific staff supported by technicians worked well there has been great difficulty in retaining staff over the longer term. This has resulted from the uncertainty surrounding PROSHIKA and the ability to negotiate higher wages in private enterprise after training by the project. As a result of the high staff turnover, annual training of staff has been critical. New staff received training in soil and crop monitoring, piezometer installation and monitoring, use of GPS devices and data management. A short video was developed on soil monitoring techniques to facilitate training and has been used more recently in projects in Cambodia, Bangladesh, Indonesia and China. Training was undertaken by a combination of Bangladesh and Australian research staff.

7.6.5 International training

Post graduate studies

Ms Nasrin Sultana was awarded a John Alwright fellowship in 2007 to undertake PhD studies at the University of Queensland. She is being supervised by Professor Rob Cramb and is researching the topic "Women in rural agricultural livelihoods". Nasrin is on track to complete her studies in 2012.

Short term training

Drs Saifuzzaman, Shakhawat and Sufian, plant breeders and crop physiologists with WRC (and later CIMMYT) and employed on the project visited Australia in 2008 to interact with Australian wheat breeders and physiologists on salinity and heat tolerance. They also visited a number of farms on the eastern seaboard to gain an understanding of the role of wheat and pulses in the dryland and irrigated farming systems of Australia

Agricultural economist, Mr Jahangir Kabir visited Toowoomba in 2009 to work with project colleagues on the economic analysis of southern Bangladesh farming systems. This work was based on his evaluation of the economics of the southern farming systems determined through extensive survey. Whilst in Australia he was trained in the use of the APSIM model and undertook simulation of potential rotational sequences. A report on this work was written and forms part of the ACIAR Technical Report *"Sustainable intensification of Rabi cropping in southern Bangladesh using wheat and mungbean"* (Due for release in mid-2011).

Crawford Fund support provided the opportunity for 2 of the longer serving regional Scientific Officers to visit Australia for 3 weeks in 2009 to train with Australian colleagues and technical staff on the routine monitoring of wheat and pulse experiments. This included experience in mechanical and hand soil coring, GIS tools, crop phenology monitoring and a one day familiarisation course in simulation modelling.

7.7 Socio-economic research

Understanding the drivers of technology adoption by farmers is critical to the success of projects interested in improving the livelihoods of farmers, in this case through the modification of the farming system. Whilst the success of the introduction of a new crop may seem obvious to the agricultural scientist who sees yield and system fit as being determinants of success, there is an overarching social dimension to the issue which will often determine overall success or failure of adoption. This section describes outcomes of the social and economic analysis of the research undertaken using a rural livelihoods analysis framework (Section 5.6.1). Outcomes were used to inform the continuing research process and should form part of the planning for future research or extension activity. Qualitative and quantitative social and economic analysis of farmer attitude to the inclusion of a new crop within the farming system was undertaken at 2 villages in each of the districts of Noakhali and Bhola in 2007 and 2008. One village in each district was involved in project activities.

7.7.1 Cropping preferences and constraints to adoption of wheat

The existing livelihoods of farmers depend on their current level of capital assets and ability to transform one form into others (human, financial, social, physical and natural). 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 only of 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 relied in part on wheat, (because the community ate wheat bread), it could supply both a portion of essential food security and profit.

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 followed by the others if the opportunities arise. 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, though 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 than the individual within his long-standing social network.

Farmer suggestions for expediting the adoption of wheat

Whilst farmers indicated that they understood the financial opportunities provided by the inclusion of wheat in the farming system they indicated that they would not be inclined to adopt until other constraints to their livelihood capital support were enhanced. These included:

Enhancing human capital:

Farmer feedback related in particular to the need for broader village level training in wheat cultivation and seed preservation that was more inclusive across socio-economic groupings and included women. The need for on-going technical support, the need for equity in access to extension personnel and the provision of training resources were seen as issues constraining adoption.

Enhancing physical capital:

Even though the SMT program utilised commercial size fields (~1000 m^2), it was considered by farmers that there were insufficient demonstration sites and their individual size too small for meaningful impact within a village of 1000-1200 farmers. There was also concern that extension staff favour the land owners when locating demonstration plots, when in fact around 50% of the farming community are tenant farmers. It was considered that being more inclusive of this group, through increased involvement in the process and provision of training and technical support would be beneficial to adoption. It was also suggested that the wider distribution of seed and the provision of wheat threshing capability at the village level would improve uptake.

Enhancing financial capital:

Discussion around financial capital focussed almost entirely on the need for improved access to cash for the production of crops (Figure 36). Farmers indicated that the main reason that crop inputs such as fertiliser were often applied at sub-optimal rates was as a result of a lack of funds to purchase the inputs. Whilst NGOs are seen as a major supplier of credit, some do not provide loans for crop production. In addition government loans are not available to the 50% of farmers who are tenants which results in a reliance on local money lenders who provide loans at higher rates of interest.

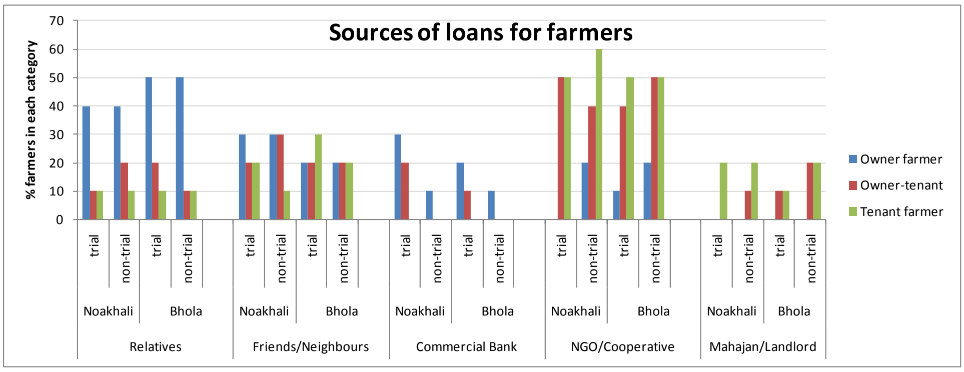


Figure 36: Financial capital: sources of loans for farmers.

Enhancing social capital:

There seemed to be a widespread view amongst those interviewed that the relationship between farmers and extension officers needed to be improved. Complaints centred on the lack of access to technical expertise in the village as well as inequity in provision of service, with land owners having preferred access to extension staff and to events such as field days. Farmers indicated that they needed to know more about the agronomy of particular crops, as well as a broader understanding of the farming system and the advantages of using particular rotational sequences in terms of disease, weed control and nitrogen contribution.

Enhancing natural capital:

Fallow land often remains fallow in the Rabi season due to difficulties in irrigating the high and medium high lands. Whilst these are the land classes particularly well suited to wheat production farmers indicated that due to their lack of knowledge of the crops requirements this opportunity has not been identified. There is therefore a need to include identification of suitable land and irrigation management, including the fact that wheat requires less irrigation than rice, into any extension programs planned in the future.

The role of women in agriculture

The traditional view, as espoused by the male farmers interviewed for this study, was that they undertook the majority of the farming work with the women responsible for the kitchen, raising the children and undertaking post harvest jobs such as threshing and winnowing. Whilst the role of men should not be underestimated this view does not tell the full story. Interviews with a comparable number of female farmers showed an 80 to 90% involvement in agricultural production at both the operational and decision making levels. This divergence of views is partly one of perspective and the definition of 'work' in the minds of the farmers. The men see their role as undertaking the larger scale paid activities and heavier jobs such as land preparation and irrigation whereas the women undertake a range of jobs related to agriculture which are considered, by both the men and women, as part of the unpaid household chores even though they include the production of vegetables, the tending of animals, tree planting, fish production and post harvest crop processing.

In terms of decision making within the farming family there was, again, a divergence in views. Men thought 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 37). Interestingly women considered that overall, men 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.

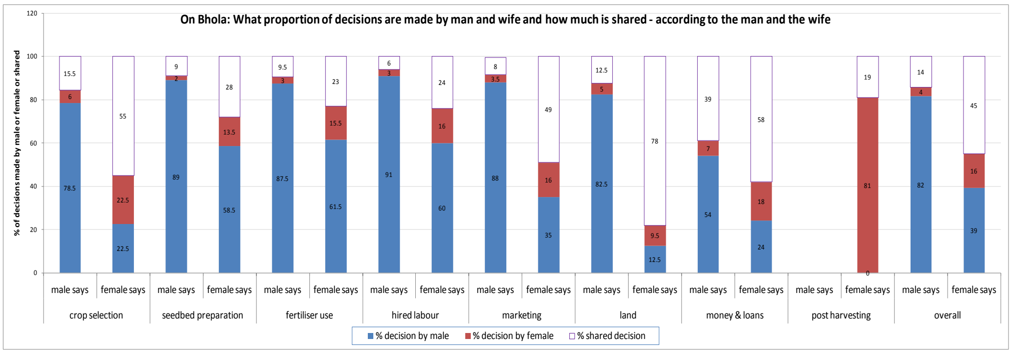


Figure 37: Percentage of decisions about different activities that are made by men and women in the farming community according to the men and according to the women who were interviewed separately. These data are averages of trial and non-trial villages on Bhola. The patterns were very similar in Noakhali.

For example on crop selection, women said the decision was 55% shared while men ranked it as 15% 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, as the women run the household and know what is needed by the family, they instruct the male on 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 negotiation while the woman knew and communicated to him what was required, so again the male was in part her agent.

The data appears to show that either women were overplaying their importance or men were vastly overplaying their power in the household. 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.

Discussion

Whilst many of the issues raised by the farmers were outside the remit of the current project and more relevant to the longer term, broad scale extension of project outcomes, it is, never the less important to reinforce the need to consider these issues when designing strategies for engagement with farmers. In particular the recognition of the importance of women in agriculture, both at the operational and management levels, the need to design training programs that are inclusive of the socio-economic groupings present in villages, the comprehensive training of extension specialists and the need to ensure that all farmers have access to them. Issues of access to production inputs such as seed, fertiliser and equipment were raised and whilst they are important in terms of the broader expansion of wheat, they are decisions that would need to be made in the context of any future extension program.

Insights gained through socio-economic evaluation also informed internal project process. This was particularly related to the way in which the project approached the training of farmers. In the first 2 years of activity, training was undertaken at the Upazila level with mostly male farmers. It is thought that this contributed to the farmers' view that training was for the selected few and it certainly did not engage the important female farmer group identified through social research. As a result, training was moved to the individual village, larger numbers of farmers were involved and women actively encouraged to attend. This resulted in 115 farming couples being trained in 2009 and 145 women in 2010. The complaint that information on wheat production was lacking at the village level and that extension personnel were not easily accessible has recently been addressed to some small degree with DAE increasing focus on wheat extension in the south and the publication of the Rabi season cropping manual "*How to grow wheat in southern Bangladesh and fit it in a timely sequence with other crops".* This document will be available for future extension activities from the WRC. The publication of the ACIAR Technical Report "*Sustainable intensification of Rabi cropping in southern Bangladesh using wheat and mungbean"* in mid-2011 will also contribute to the training of extension staff involved in any future extension activities undertaken by DAE or an NGO.

7.7.2 Economics of increased Rabi season crop intensity

As mentioned in 5.6.3, economic analysis of the potential to increase Rabi-season crop production was based on farmer surveys undertaken in 2 sets of villages in Bhola and Noakhali districts during the 2007/08 season. The surveys showed that the production of rice was paramount in terms of food security with the monsoon crops (grown in the Kharif 1 and 2 seasons) being of most importance due to a lack of sufficient irrigation for Rabi season Boro rice production. In the surveyed villages Rabi season cropping emphasis was placed on the production of rain fed crops, particularly pulses and chillies, although potatoes, wheat, cowpea and grass pea were also cultivated. Under normal seasonal conditions the farmers indicated that all of these crops were profitable although chilli had the advantage of multiple harvests which improved family cash flow. Wheat was not a significant crop in the villages of Noakhali, although farmers in Bhola had grown it in the past. Farmers reported that they had become disheartened with wheat due to the low yields of the old variety Kanchan, but were interested in the new, higher yielding varieties such as Shatabdi, Bijoy and Prodip.

Comparative gross margins and costs of various Rabi season crops

Gross margin analysis of Rabi season production in Bhola indicates that farmers, in a normal[1] Rabi season, obtained the highest gross margin from the production of wheat (Tk 17,000 for a 250 decimal farm), and followed by grass pea, boro rice, mung bean and last by cowpea (Tk 8,400). The high production cost for boro rice and its relatively poor price at market impacted negatively on its gross margin, a disappointing outcome for such a high-yielding crop. In bad seasons, grass pea 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 of good seasons.

Comparative gross margins and costs of various crop sequences

An annual crop rotation of wheat/mungbean/T. Aman rice was the most profitable sequence for farmers in a normal year, realising gross margins of Tk 37,000 for a 250 decimal farm (Figure 38). Wheat/Aus/T. Aman was a close second followed by grass pea/Aus/T. Aman and by mung bean/Aus/T. Aman at Tk 28,000. The Boro/fallow/T. Aman combination was poorest.

The optimised APSIM systems analysis provided different results to that of farmers' reality. Systems including mungbean in the sequences produced the best outcomes with wheat/mungbean/T. Aman having the highest gross margin (Tk 88,000/250 decimal farm) followed by mungbean/Aus/T. Aman (Tk 66,000), wheat/Aus/T. Aman (Tk 64,000), cowpea/Aus/T. Aman (Tk 61,000) and boro/fallow/T. Aman (Tk 43,000/250 decimal farm).

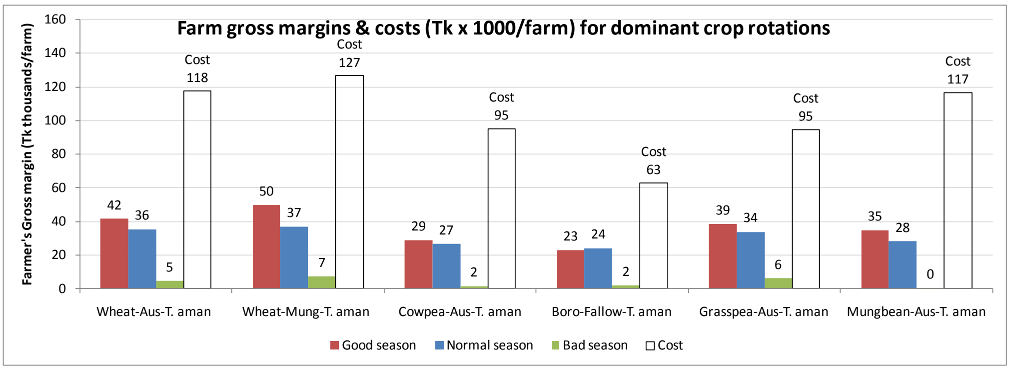


Figure 38: Farm gross margins and costs (Tk x 1,000 per 250 decimal-2.5 acre farm) for common crop sequences in good, average and poor seasons.

Both the farmers' reality and APSIM-simulated output indicates that wheat/mung bean/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

[1] A good year is described as having favourable weather for crops and maximum yields. A normal year indicates average weather conditions and reasonable yields and a bad year indicates unfavourable weather conditions and low yields.

not know how to best manage the crops. The other possibility is that farmers are risk averse as a result of past failures through poor establishment, a result of dry soil conditions, or late season catastrophic climatic events (7.3.3). Differences in gross returns between the farmers' experience and yields predicted using APSIM are an indicator of the impact of sub-standard farmer on yields and the potential to move yields closer to the APSIM derived optimum through improved training and mentoring.

This study confirmed the economic viability of Rabi cropping in southern Bangladesh. While the current Rabi season crops are profitable under most seasonal conditions, this study confirmed that wheat adds a profitable and low economic risk option to the system.

8 Impacts

8.1 Scientific impacts – now and in 5 years

The major scientific impacts resulting from the project relate to an improved understanding of the availability of natural resources (land and water) for increased production and of the role of crops such as wheat and mungbean in the system. This understanding has come through the integration of information gained through detailed agronomic research, spatially diverse on-farm trialling and the ability to use simulation modelling to investigate the riskiness of farming system modification through space and time. The outcomes of the research have then been used to inform policy makers, farmers and the research and extension fraternity of the potential of the region. These outcomes have also been integral to the development of scientific capacity and understanding within the NARS and improved capacity within CSIRO to model the farming systems, in particular, those based on rice.

8.1.1 Extending research findings

One of the major constraints to acceptance of research outcomes were the long held negative views of many on the potential for the south to contribute to national food security through the introduction of crops such as wheat. This was as a result of the region being considered too hot and too saline for viable production, in particular with the older less well adapted wheat varieties. To be able to show that things had changed and that profitable yields were possible with the new varieties and improved agronomic practice proved to be the turning point. This had led to an increase in government focus on the south, as shown by the commencement of the Government of Bangladesh funded project "*Farmers' level seed production of rice, wheat and jute*". This initiative is a direct result of intervention at the policy level, with DAE using the findings of the research as the basis of their extension effort. This includes the use of the Rabi-season production manual "*How to grow wheat in southern Bangladesh and fit it in a timely sequence with other crops".* The USAID funded project *"Cereals Systems Initiative for South Asia"* (CSISA) (IRRI/CIMMYT), which is currently increasing activity in southern Bangladesh, plans to mainstream selected findings of the project into its on-going research and extension strategies.

8.1.2 Varietal selection for salinity tolerance

As a result of the project southern salinity tolerance evaluation sites were included in the WRC national wheat breeding and evaluation program for the first time. Over 5 seasons a small number of lines have been identified that exhibit improved salinity tolerance compared to the existing recently released varieties. Whilst the final selection of lines for release depends on a broad range of criteria, it is possible that some will eventually be released. It could be expected that any such release would contribute positively to the already significant yields being achieved in the more saline regions of the south.

8.1.3 Monitoring soil water

The introduction of appropriate tools for the sampling of soil water was a major innovation in a country where its monitoring was not considered of great import. Whilst this work was integral to the ability to model the farming system, it also led to an understanding of the importance of capillary rise in crop production, one of the major findings of the project. These tools are now being used by other researchers and projects involved in climate change adaptation research (LWR/2008/019) and in soil chemistry monitoring (Dr Bodruzzaman, WRC). The ability of local engineers to fabricate the equipment provides confidence that it will be used into the future.

8.1.4 Developing databases of soils and climate

Twenty nine soils were characterised for Plant Available Water Capacity (PAWC) across southern Bangladesh. These data are now publicly available as part of the APSoil database (www.apsim.info). Bangladesh has excellent meteorological data for regional locations across the country. Data from 13 of these sites have been collated and converted into the required format for use in APSIM. Both the soil and climate data form important data sets for continuing work being undertaken as part of LWR/2008/019, the SAARC project and through possible linkages with the CSISA project.

8.1.5 Contributing to systems understanding

The APSIM model is an integral component of farming systems research in Australia and increasingly in other countries around the world. The development of modelling capacity often comes from the involvement in projects such as this where different crops and different systems are required to be modelled. At the outset of this project the ability to model ponded rice based farming systems within APSIM was limited. This project has provided the on-farm data sets necessary for initial testing of the IRRI developed ORYZA model which has been integrated into the APSIM modelling framework. Further development of this capability is now continuing in LWR/2008/019 *"Developing multi-scale climate change adaptation strategies for farming communities in Cambodia, Laos, Bangladesh and India".*

This project has also provided the opportunity to develop Australian skills in the modelling of water balance in systems where water tables are close to the soil surface and potentially contribute to crop production through capillary rise. Using the data collected from approximately 70 piezometers installed by the project across southern Bangladesh, and longer term water table data provided by Bangladesh government agencies, allowed the development of simulation capability to successfully model the contribution of ground water to crop production using the water balance model SWIM (Verburg 1996; Paydar 2005).

8.2 Capacity impacts – now and in 5 years

8.2.1 Policy implications

The identification of the importance of engaging with senior policy makers was realised part way through the project when the national media were reporting the political desire to increase national food security through the expansion of southern crop production. Whilst this was a positive move, it was disquieting that wheat was not one of the crops being seriously considered for expansion. This was a result of the commonly held view that the environment was unsuited to wheat and farmers were inexperienced in its production. It is fair to say that these were widely held views at all levels of government which required modification if widespread adoption was to occur. A number of communication activities, culminating in the 2010 workshop *"Wheat cultivation in southern Bangladesh: The potential for expanding the Rabi season cropping"*, aimed to inform policy makers, senior public servants and senior government scientists of the availability of fallow land and the potential for recently released wheat varieties with superior heat and salinity tolerance to contribute to the rice based farming system.

Whilst it is not possible to quantify in dollar terms the impact of this initiative, it is possible to observe the changes which were noted on the ground during the 2008/09 and 2009/10 seasons and which are reported to be continuing. As a result of direct intervention by the agriculture minister and discussions with WRC and BARI, DAE has expanded its extension of Rabi season cropping both within, and beyond areas of project activity. Technical competency has been achieved through close collaborative ties with the project which has included DAE staff involvement in regional training and research activities and access to the scientific expertise of WRC.

Changes in understanding of the potential for southern agriculture at the policy level are also being seen in the research funding sector with requests for further discussion after the above workshop from both national and international funding and research agencies including USAID, DANIDA and CIMMYT. To date this has resulted in CIMMYT providing short term funds to complete research commenced by the project and the use of project experience in the design of the USAID funded project *“Cereals Systems Initiative for South Asia”* (CSISA) (IRRI/CIMMYT), which is currently increasing activity in southern Bangladesh.

8.2.2 Research and extension capacity

Farming systems research training

Half of the scientific officers (3) and all of the technical staff (10) funded by the project were employed by the NGO PROSHIKA, and later FoRAM, with the remainder employed by the WRC. Two scientific officers, one from each organisation, worked jointly to manage the research programs in each of the districts (initially Noakhali, Barisal and Bhola and later expanded to include Jhalakathi and Patuakhali) with the support of the technical staff. This model worked well in building technical capacity within the NGOs and forming links between government and non-government organisations. The immediate impacts of this team approach were apparent in well run field research and communication activities with the longer term implications including increased skill levels at the junior science and technical levels of research.

Training of these staff was critical to the success of the project. Annual training in farming systems research and access to international training opportunities through the Crawford Fund, mentoring by senior staff and the provision of good technical documentation formed the basis of skills development. As a result of their project experience a number of staff were sought out for employment by private sector employers which resulted in a high turn over of experienced personnel. Whilst the continuing loss of staff, and the on-going need for training, was frustrating, the fact that these staff are now employed across the agricultural research and extension sectors should be viewed as a positive contribution to the development of the skills base of the broader agricultural community. Around 15 scientific officers and 30 technical support staff held positions within the project with many of these now working for plant breeding companies and non-government organisations.

Training of scientific and technical staff covered a broad range of topics including crop and resource (water, nutrients and climate) monitoring and the use of equipment such as the hand held GPS for the spatial identification and area measurement of research sites. Training was supported through the development of reference manuals on topics including electronic weather monitoring (the manual-*Setting up a met station for the measurement of temperature, radiation and rainfall*) and the agronomy of crops (the manual-*How to grow wheat in southern Bangladesh and fit it in a timely sequence with other crops*). The comprehensive development of field research pre-schedules and data sheets provided the basis for field data collection. Training of WRC engineers in the fabrication of hand held soil coring equipment resulted in an increase in local fabrication capacity and the production of 4 sets of coring equipment which were utilised by the project and are now being used by other research groups within WRC. Some of the sampling equipment was redesigned to better meet local conditions with these designs now being used by Cambodian engineers to produce equipment for use in local projects (LWR/2008/019). A short video on soil monitoring was developed for use in training and has since been used to train staff in ACIAR projects in Cambodia (LWR/2008/019), Indonesia (LPS/2006/003) and India (LWR/2008/019).

Post graduate training

Ms. Nasrin Sultana, a social researcher with the NGO PROSHIKA was awarded a John Alwright Fellowship in 2007 and is currently studying for her PhD at the University of Queensland. She is researching the topic “Women in rural agricultural livelihoods” and is expected to complete her studies in 2012. Her work has contributed to understanding the social aspects of technology adoption through direct input into research planning, the presentation of seminars to Australian researchers and authorship of a paper (Sultana, 2011) which forms part of the ACIAR Technical Report "*Sustainable intensification of Rabi cropping in southern Bangladesh using wheat and mung bean*" due for publication in mid-2011. Whilst her future plans are as yet unclear she has indicated a commitment to future research in her area of expertise.

Mr. Jahangir Kabir, an employee of the Bangladesh WRC, worked as an economist on the project (2006-10). Whilst his expertise lay in the economic analysis of crop production, he expanded his skills to include the social drivers that contribute to farmer decision making. This resulted in his senior authorship of 2 papers that form part of the ACIAR Technical report (Mid-2011 release) (Kabir and Rawson, 2011 and Kabir et al, 2011). In 2010 Kabir transferred to the Bangladesh Rice Research Institute (BRRI) where, as a result of the experience gained in this project, he has been engaged as an economist on the ACIAR Project LWR/2008/019 "*Developing multi-scale climate change adaptation strategies for farming communities in Cambodia, Laos, Bangladesh and India*". He has recently been awarded a John Alwright Fellowship and will be commencing his PhD at the University of Queensland in mid-2011.

8.2.3 Farmer capacity

Whilst there are many instances of increased capacity at the farmer level two stand out as prime examples of the potential.

Khanjapur, Barisal

During the ACIAR scoping study in 2005/06 3 fields in the village of Khanjipur, 40 km north of Barisal were planted to the recently released wheat variety Shatabdi. The village farmers had no prior experience of growing wheat but were interested because of their desire to identify a Rabi season crop which complemented wet season jute production. Their farming skills, in conjunction with project technical support, resulted in yields of over 3 t/ha with the grain sold in the local market or kept as seed. No further project involvement occurred until 2008/09 when visiting researchers found that wheat production had doubled and the original farmers were now acting as technical advisors to their neighbours. An important aspect of their continuing success was that they had not deviated from the use of WRC recommended rates of fertiliser and seed which are higher than those generally used by farmers. In 2008/09 the farmers were invited to host 3 SMTs sites of the varieties Prodip, Bijoy and Sufi. On visiting the village after harvest the farmers indicated that the 3 trial crops had yielded on average 3.27 t/ha. What was particularly pleasing was that the market differentiated between the varieties and was in fact prepared to pay a premium for the bolder seeded varieties Bijoy and Prodip. The 2010/11 season was the 6th season that Khanjapur farmers have grown wheat which they now consider as an integral component of their system. This example shows that not only had the farmers identified a crop which was a good fit within the existing jute based farming system but that they understood that it was necessary to invest money into inputs such as seed and fertiliser if they were to realise the full potential of the crop.

North Joynagar, Bhola

Whilst there is a long history of wheat cultivation on the island of Bhola, its popularity has waned in recent years as a result of the poor yields achieved with older varieties and the increasing interest in Boro rice production. In 2007/08 2 SMT sites in the village of North Joynags were sown to Bijoy and Prodip using WRC fertiliser recommendations and technical support from the project and local DAE extension staff. These fields yielded an average of 3.26 t/ha. In 2008/09 almost the whole of the village lands were planted to wheat or to Rabi season pulses including mungbean and cowpea. The 2 SMTs in this season yielded on average 3.79 t/ha. The DAE block supervisor, who has responsibility for extension in the union indicated that wheat production in North Joynags had increased from 105 to 150 ha as a result of the impact of the demonstration sites in the previous year. It was a similar story in the adjacent union of Mid Joynags where production area increased by 40 ha. The ability to source local high quality seed, from the previous years SMT sites, supplemented with supplies from the Bangladesh Agricultural Development Corporation (BADC) allowed the expansion to take place.

When the North Joynags farmers were asked why they preferred to grow wheat and pulses in preference to Boro rice, they indicated that whilst they had plentiful water to irrigate rice, the costs of application were much higher for rice which required 15-30 applications compared to wheat which required no more than 2 irrigations.

The combination of motivated farmers with the agronomic skills required to grow wheat (as a result of the SMT program), the availability of high quality seed and support from motivated and well trained DAE extension staff has resulted in the development of a successful, financially attractive, alternative crop to Boro rice. Rabi season production of wheat and pulses continued during the 2009/10 and 10/11 seasons and it is expected that it will continue into the future.

8.3 Community impacts – now and in 5 years

8.3.1 Economic impacts

The benefits of capillary rise to southern Rabi-season cropping

The significant contribution to crop water supply from capillary rise was one of the major findings of the project. It has major implications for the development of Rabi season cropping in southern Bangladesh and in particular for wheat. The potential to grow wheat crops which yield >3 t/ha with only one irrigation in non-saline environments significantly outperforms rice and its requirement for between 15 and 30 irrigations. Yields of wheat of >2 t/ha in unirrigated conditions are also common. These findings have major implications for infrastructure investment at both the regional and farmer levels, not only in terms of provision of irrigation infrastructure but also in the supply of electricity for pumping. Reliable electricity supply is a major issue in northern Bangladesh where tube wells supply 70% of irrigation water to Boro rice production and electricity load shedding is common. It would therefore seem logical to assume that farmers, who are limited in their ability to produce Boro rice through lack of irrigation water and/or supply infrastructure, should be considering crops such as wheat or Rabi-season mungbean. This was the decision made by the farmers of North Joynags who commenced growing wheat and pulses as a response to the high costs associated with the irrigation of Boro rice. In the village of Senbagh, in a salinity affected region of Noakhali, farmers chose to produce wheat as a result of the death of their rice crops after irrigating with water that was becoming increasingly saline. This was a consequence of drought but it is likely that this situation will become more prevalent as climate change increasingly impacts on this part of Bangladesh.

The economic impacts to farmers

As a general rule it can be said that the majority of those farmers involved in the project as research hosts or who decided to grow wheat after seeing demonstration sites, benefitted financially from the activity when agronomic management and levels of inputs, such as fertiliser, were adequate. Failures in wheat production were generally the result of a lack of understanding of the need for good weed control or through an aversion to the risk associated with input investment. Whilst the production of mungbean as a post-wheat crop was severely impacted by poor agronomic practice there was the added risk of adverse weather conditions that required farmers to be very specific in their management of the crop, particularly regarding the time of planting.

In the village of Khanjapur, which is described in detail in 8.2.3, wheat production was obviously a lucrative addition to the farming system with 2 or 3 new, two story brick houses being built from the proceeds of wheat sales during 2008. Village farmers had also learnt to optimise their returns by meeting market demand for larger seeded wheat varieties which attracted a price premium over smaller seeded lines. Another example of the economic impact of Rabi-season cropping on livelihoods was the case of Nasima Begum, a farmer at Babugonj, Barisal who achieved a yield of 3.7 t/ha from wheat grown as part of the SMT program in 2007/08. She then double cropped the land to mungbean and sold the majority of production to neighbours. In the subsequent season Nasima doubled her area of wheat production to 0.16 ha whilst her neighbours produced 0.24 ha using seed purchased from her. In the salt affected village of Senbagh in Noakhali the wheat crop grown by Nural Alam Jahangir and his wife in 2007/08 yielded 3.5 t/ha (350 kg from 0.1 ha). They sold 100 kg of their production to neighbours at a price of T40/kg, kept 45 kg for seed and consumed and gifted the rest. In the following season 0.22 ha was sown to wheat using 27 kg of the stored seed with the remainder being sold to neighbours at a price of T50/kg.

Policy impacts on production

At this point in time the impacts of policy initiatives resulting from project activity have been limited due to the short time frame involved. Whilst an increasing investment in extension activity by DAE and small pockets of increased wheat production are tangible outcomes of the project and critical to long term success it will take a number of years of continuing investment and on the ground effort by both policy makers and farmers to show tangible impacts on domestic production and overall national food security.

8.3.2 Social impacts

Evidence from the socio-economic surveys undertaken in the Bhola and Noakhali districts indicate that in times of increased overall crop production, such as the case when a new crop is introduced to the farming system, that financial resources increase within a village. This then improves the resilience of the community through increased family savings, access to education for their children, purchase of labour saving farming equipment and increased access to work for landless labourers. However, whilst all socio-economic groups within the village are likely to receive benefits under these circumstances, resources are not spread equally, with land owners receiving more benefit than owner/tenants and tenants.

Whilst the timeframe of the project makes it difficult to identify widespread social change there are examples where the types of changes identified in the survey work have occurred. These include the village of Khanjapur where increases in financial capital have flowed through to an improvement in housing and life style. There is also evidence that farmers who grow a new crop such as wheat or mungbean, and do it successfully are accorded increased social status within the community. This has occurred in the villages of Khanjapur, Babugonj and Senbagh where collaborating farmers are sought out by their peers for advice on growing the new crops. At the individual farmer level, involvement in the project has contributed to food security and family well being with one Barisal farming family consuming all of their wheat production due to the failure of other crops, and a Noakhali family, using their wheat to provide the necessary dietary supplementation for an ill family member.

8.3.3 Environmental impacts

The most important finding of the project in terms of environment has been the development of understanding of the contribution of ground water, through capillary rise, to Rabi-season crop production. In southern Bangladesh financially viable yields of wheat are achievable under dry land conditions and near optimal yields achievable with only 1 irrigation, compared to 3 in the north and 15-30 for Boro rice. This is an important finding and a major positive for the expansion of southern Rabi-season production. This finding impacts on sustainability of system in a number of ways including:

- Increasing the potential for farmers without the benefits of irrigation to grow financially rewarding Rabi-season crops
- Extension of the life of the finite ground water resource
- Provision of an alternate cropping option for farmers when groundwater becomes too brackish, or unavailable through drought for prolonged use in the production of Boro rice
- Availability of an alternate crop for farmers on medium high land which is logistically difficult to irrigate for prolonged periods
- Reduction in irrigation infrastructure costs for individuals and government and reduced demand on an already over-stretched electricity supply network
- Reduction in on-farm labour demand and the opening up of off-farm opportunities
- Minimisation of leaching of nutrients to the groundwater

8.4 Communication and dissemination activities

Rabi season cropping manual

The manual *"How to grow wheat in southern Bangladesh and fit it in a timely sequence with other crops"* was launched in 2010 by the Bangladesh Minister for Agriculture, Mrs. Motia Chowdhury. The document is targeted at providing the operational and agronomic information required by the farmer to grow the crop, as well as the more detailed science required by extension staff and researchers. 5000 copies of the manual have been printed by WRC and are being distributed, as part of training activities, to farmers and extension agents in southern Bangladesh.

ACIAR Technical Report

In 2010 a request was made of ACIAR that research papers describing the results of the 5 years of social, production and systems research undertaken in Bangladesh be compiled into a technical report. The resulting report "*Sustainable intensification of Rabi cropping in southern Bangladesh using wheat and mung bean*" is aimed at informing researchers and extension agents of both the methodologies used in the research and its outcomes. The majority of project researchers have contributed to the 19 papers which cover the integration of new crops into an existing farming system from the perspectives of production and cropping systems, economics and the social systems in which farmers operate. Publication is expected in mid-2011 with the document targeting researchers in both Bangladesh and other countries interested in the approaches and findings of the research.

9 Conclusions and recommendations

9.1 Conclusions

9.1.1 Natural resources

- Land: There are over 800,000 ha of land in southern Bangladesh currently under utilised which is suitable for Rabi-season crop production.
- Irrigation: Water availability can often be a constraining factor in the production of Rabi season crops with precedence of supply going to Boro rice. The provision of between 60 and 100 mm of water from shallow water tables through capillary rise allows water-constrained farmers to produce significant crops under dryland conditions or with 1 irrigation.
- Salinity: Whilst soil salinity is an important issue in the more recently formed lands adjacent to the Bay of Bengal heavy rainfall during the monsoon season leaches salts to depth allowing the successful establishment of Rabi season crops. However, as a result of capillary rise, the salt moves upwards through the profile as the Rabi-season progresses impacting on crop water uptake and ultimately, yield.

9.1.2 Agronomic

- Wheat varieties: 5 varieties of wheat developed and released by the WRC have consistently produced yields of >3 t/ha over 5 seasons of on-farm trials when grown under non-saline conditions, using WRC recommended rates of fertiliser and 1 irrigation. As a general rule dryland wheat yields between 500 and 1000 kg/ha less than when irrigated. Yields from salinity affected soils varies more widely but when grown using good agronomic practice exceeds 2 t/ha.
- Time of wheat sowing: Wheat is able to be planted in southern Bangladesh from the middle of November through until the middle of December without significant yield reduction. In late finishing monsoon seasons this allows time for the rice to be harvested and the soil to dry before the planting of wheat.
- Maturity: Compared to northern Bangladesh, wheat varieties in the south mature 5 days earlier from a November sowing (100 days to maturity) and 15 days earlier from a late December plant (90 days to maturity).
- Fertiliser and time of sowing: WRC recommended rates of fertiliser for northern wheat production (Urea 220kg/ha; TSP 132kg/ha; MP 100kg/ha; Gypsum 111kg/ha; Boric Acid 7.5kg/ha) are relevant to the south when the crop is sown from mid-November to mid-December. Later planted crops require two thirds of WRC recommended rates.
- Bed planting: Planting of wheat in rows on formed beds provided no yield advantage compared to broadcasting, however farmers did consider that row planting was worthwhile in regards to efficiency of weeding and irrigation.
- Mungbean: When grown under good agronomic conditions mungbeans yielded between 500 and 1200 kg/ha. However, significant yields were achieved in only 29% of fields over the 3 seasons of research. This was attributed to poor agronomy (particularly lack of weed and insect control) and variable climate. Dry soil conditions at planting are a major constraint in non-irrigated systems and late planted crops (after the end of March) are highly susceptible to losses from tidal flooding, cyclones and early monsoonal rainfall.

9.1.3 Farming systems

- Wheat is a viable option in southern rice based farming systems provided it is able to be planted between mid November and mid December. Provision of adequate fertiliser and good agronomic practice are critical if optimal yields are to be achieved.
- Mungbean should be treated as an opportunity crop and only grown if able to be successfully established before the end of March. Farmers unwilling to risk growing mungbean after wheat may consider growing them in place of wheat as a Rabi crop.

9.1.4 Social

- Extension services are key to promoting better livelihoods in communities.
- Building the adaptive capacity to enable the adoption of a new crop should be based on holistic programs that encompass livelihood support and poverty mitigation and alleviation strategies. To enhance the adaptive capacity, requires external assistance and multi-faceted cross-sectoral partnerships of government, NGO and community.
- Whilst the introduction of new cropping options is considered financially profitable and a preferred farmer livelihood option, adoption will not occur unless knowledge and experience are developed through the provision of extension strategies that cater for the social and gender diversity found in villages.
- Availability and access to resources including quality seed, equipment (such as threshers) and financial services are important to longer term adoption.
- Adoption of new technologies will not occur if farmers perceive the risk to be higher than that associated with current enterprises.
- The capacity to adopt a new crop depends not only upon the amount of labour available to a social group, but also the quality, capacity, education and health of individuals.

9.1.5 Economic

- The production of rice is paramount in terms of farmer food security.
- Based on farmer interviews the most profitable cropping sequence was wheat/mungbean/T. Aman rice with Boro rice/T. Aman rice being the least profitable.
- Where water is not available for Boro rice production current practice is to grow chillies and pulses.

9.2 Recommendations

Project activities have shown the potential for Rabi season production of wheat, and to a lesser degree mungbean, to contribute to the livelihoods of individual farmers, their communities and to national food security. Whilst there are still unanswered agronomic and social questions relating to the production of these crops the reality is that it is time to promote their production as viable and profitable alternatives to Boro rice, particularly as the availability of irrigation water becomes more constrained as a result of climate change.

This requires a concerted extension effort, taking into consideration the findings of social research to ensure that communities are engaged in an holistic manner that includes both government and non-government services providing advice, support and inputs across the social spectra of the community. If meaningful impact is to be achieved this is a job that will require commitment from the highest level of government to the field workers engaging with the communities. The seeds of success have been sown, however, any extension effort has to also involve the non-government sector which, in many cases is the face of support at the community level. Promotion of increased Rabi-season cropping also has to go hand in hand with infrastructure development to ensue that crop inputs such as fertiliser are available when required and local markets available for sale of product.

Whilst the first signs of increased national investment in extension are being seen, there is a need, if the current impetus is to be continued, for broader funding to ensure maximum, timely promotion. It is likely that this will require international support.

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ACIAR Technical Report (due June 2011). Sustainable intensification of Rabi cropping in southern Bangladesh using wheat and mung bean. Report includes the following papers:

Section 1 Background to wheat in southern Bangladesh

1.1 The challenge to increasing wheat production
H.M. Rawson, Peter S. Carberry, A.B.S. Hossain and M. Saifuzzaman

1.2 Farmers' perceptions
Iqbal Alam Khan, Sharmin Afroz and Himu Bain

1.3 Women in rural agricultural livelihoods
Nasrin Sultana

Section 2 Physical constraints to cropping in southern Bangladesh

2.1 Climate
Perry L. Poulton and H.M. Rawson

2.2 Soil and water
Neal P. Dalgliesh and Perry L. Poulton

2.3 Land availability
Perry L. Poulton

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

3.2 Cooperating with farmers of southern Bangladesh
A.B.S. Hossain, N.C.D. Barma, M. Saifuzzaman and M. Amin

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

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

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
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

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
4.2 Potential yields of wheat crops
Peter S. Carberry, Perry L. Poulton and Neal P. Dalgliesh
4.3 Potential for mungbean in sequence with Rabi-season wheat in southern Bangladesh
Neal P. Dalgliesh and Perry L. Poulton
4.4 Economics of Rabi crops and common rotations
Md. Jahangir Kabir and H.M. Rawson

Section 5 Future of Rabi cropping and livelihoods in southern Bangladesh
5.1: Farmers' livelihoods: reality and options
Iqbal Alam Khan and Sharmin Afroz
5.2 Impact of intensified Rabi cropping on social dimensions of livelihood
Iqbal Alam Khan and Sharmin Afroz

Conclusions
Increased Rabi season cropping in southern Bangladesh: an overview of this ACIAR project
Peter S. Carberry