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project	**Scoping study to assess the technical and economic feasibility of wheat production in southern Bangladesh**
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1 Acknowledgments

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2 Executive summary

Due to lack of irrigation infrastructure, an estimated 0.8 million ha of land in southern Bangladesh remains uncultivated during the dry (*rabi*) season. In the past, these lands were considered too risky for rice-wheat rotations because of the hot, short-season *rabi* environment and, in some districts, the saline soil profile and limited water resources. The aim of this study was to assess the long-term technical and economic feasibility of wheat production on currently fallow lands in southern Bangladesh.

The project combined data from on-farm trials with system modelling to generate the production potential for crop lands at three districts in southern Bangladesh. Field crop-soil-climate datasets collected from three years (2003-2006) of on-farm trials were used to setup and test the APSIM systems model for this production system. Utilising these data, the feasibility of *rabi*-season cropping systems were simulated using APSIM for 20 years of climate data (1985-2006) for three regions: a traditional wheat production area and two new areas being considered for cropping.

The three years of on-farm trials clearly demonstrated that irrigated wheat can be grown in these regions with measured yields close to those attained from more traditional wheat production areas. Limited irrigation water was sourced from surface storages close to participating farms. Wheat yields of 3 - 4 t ha^{-1} were achieved on farms across the region. Dryland crops grown solely on stored soil water reached 1.5 t ha^{-1} and a single irrigation raised wheat yields to 2.5 t ha^{-1}. Once parameterised for the local soils and genotypes, the APSIM systems model well represented this range in wheat yields (r^2 = 0.74, RMSD = 485kg ha^{-1}, n = 31).

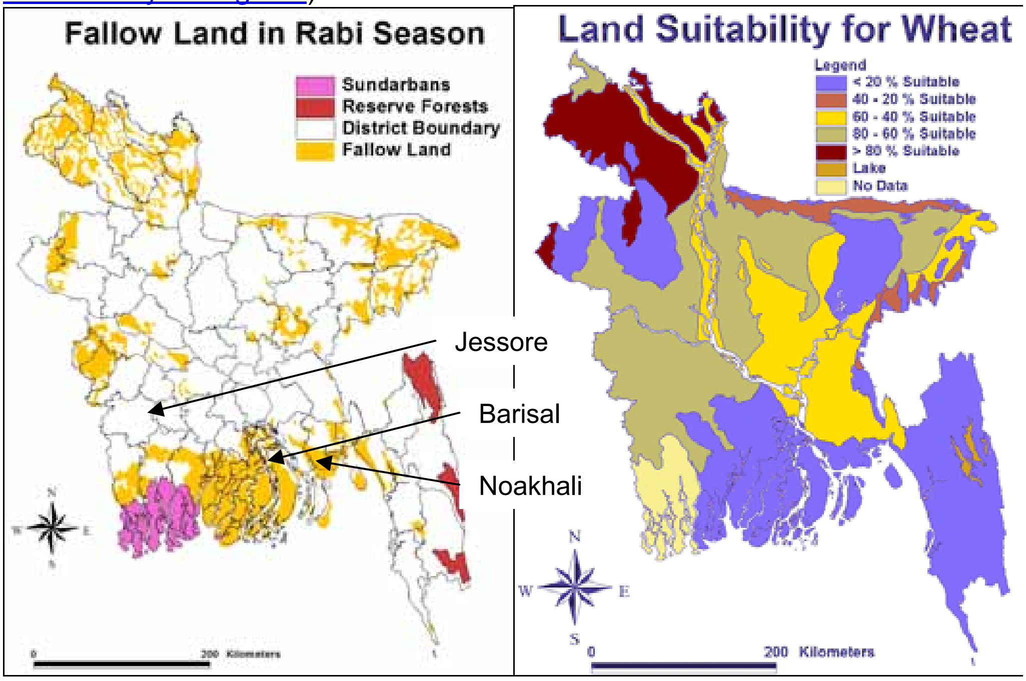
For the non-saline site, the average dryland yields over a 20 year period were simulated at 1.7 t ha^{-1} with an upper irrigated yield potential of 4.1 t ha^{-1}. More irrigation events resulted in increased and more consistent yields and gross margins, although profitable crops could be produced from a single irrigation. For a salinity-affected site, with assumptions on the likely impact of high salt levels, average simulated dryland yields were 1.1 t ha^{-1} with an upper irrigated yield potential of 2.6 t ha^{-1} on average. With these assumptions, simulated wheat production was only economic on saline soils over the 1985-2006 period if at least two irrigations could be applied each year.

This study provided promising argument for continued research and development investment into the production of *rabi*-season crops using available surface-stored water on currently fallow lands in southern Bangladesh.

3 Background

Currently Bangladesh produces almost 2.0 million tonnes of wheat annually but still requires 1.2 million tonnes on average of annual food aid as wheat imports (Kamruzzaman et al., 2006). In southern Bangladesh, there is an estimated 800,000 ha of land which produces rice in the wet (karif) season, but remains uncultivated during the dry (rabi) season (Figure 1a). If a proportion of the uncultivated land is realistically available and suitable for wheat, then potential new wheat production from southern Bangladesh may fill the current deficit in wheat production. However, a main reason for these lands remaining uncultivated is the unavailability of shallow and deep tube wells to provide water for dry-season boro rice production. In fact, a land suitability assessment of these southern lands suggested they are largely unsuitable for the production of wheat (Figure 1b).

Figure 1: (a) Identification of fallow land during the rabi season in Bangladesh (source: Bangladesh Country Almanac BCA v3.0; www.cimmytbd.org/bca); (b) Land suitability for wheat production in Bangladesh (Bangladesh Country Almanac BCA v3.0. www.cimmytbd.org/bca)



Timsina and Connor (2001) using several published sources, estimated irrigated wheat yields in the traditional rice-wheat growing areas of Bangladesh to average 2.2 t ha^{-1} – 2.9 t ha^{-1} as the average of research experiments, 3.5 t ha^{-1} from research experiments with high fertilizer inputs, 3.1 t ha^{-1} from experiments on farmers' land and 2.6 t ha^{-1} as average yields from farmer surveys. They provided no data for the previously untried and possibly unsuitable fallow lands of southern Bangladesh. However, in recent on-farm studies in southern Bangladesh, Rawson et al. (2007) demonstrated farmers can produce wheat yields averaging 2.5 t ha^{-1} using supplementary irrigation from surface water stored over from the wet season.

While likely constraints to wheat production in southern Bangladesh include high temperatures during grain filling and salinity in some regions, wheat does have advantages of being much shorter in duration than rabi-season (boro) rice and it requires significantly less irrigation water for acceptable yields. Rawson et al. (2007) demonstrated that, with the judicious application of irrigation and use of varieties that are more tolerant of salt and high temperature, acceptable yields of wheat are possible in southern regions. The issue of salt after anthesis and early grain set may not be of concern, as by this time the vegetative organs of the wheat crop are not growing and so are largely resistant to effects of high salt (Rawson, et al., 1988; Munns and Rawson (1999).

Agronomic management practices need to be finetuned to the southern regions. Foremost, is ascertaining and applying the most efficient utilisation of water resources, especially where irrigation is possible from limited supplies of surface water. Associated issues concerning timely planting, optimisation of N fertilizer rates and timing, availability of adapted varieties, tillage systems and availability of machinery have been progressed elsewhere in Bangladesh and on the Indo-Gangetic Plains (Ortiz-Monasterio et al., 1994; Humphreys et al., 2005) and should differ little for the southern regions (Rawson et al., 2007). For instance, the optimum planting date of wheat is considered to be mid to the end of November and the turn-around time between rice harvest and wheat sowing can be as short as 1 to 2 days by cultivating, sowing and fertilizing in one pass using light tillage by seeder or zero-till machinery powered by a 2-wheel tractor (Hobbs and Gupta, 2004; Rawson et al., 2007). Where traditional varieties of transplanted Aman (T. aman) rice were late, using slightly shorter-duration T. aman varieties in combination with these tillage-sowing practices enables wheat to fit into relatively short rabi seasons.

Assessing the technical and economic feasibility of crop production in a new region is difficult to achieve through experience alone. Experiments just can not be run for sufficient duration to sample the range of environmental constraints likely to occur over the long term. While the study of Rawson et al. (2007) augured well for future productivity, it focused on a limited area of southern Bangladesh and on two seasons which may not represent climate, water and soil constraints in the long term. A supplementary approach is to utilise crop simulation models combined with the historical climate record to analyse the prospects for innovation in crop production systems. Such approaches have been applied in investigation of rice-wheat cropping systems in the traditional regions of northern Bangladesh (Hossain and O'Callaghan, 1996; Timsina et al., 1998; Timsina et al., 2002; Mahmood et al., 2004). However, the ability to assess such innovation relies on the model's capability to simulate the key components of the system of interest.

This study aimed to assess the likelihood of long-term sustainability of wheat production in southern Bangladesh. The primary question addressed in on-farm trials conducted in the 2005-06 rabi-season was how much irrigation is required to produce economic yields of wheat? In addressing this question, one needs to bear in mind that, at the start of the season, farmers generally have a full soil-water profile, while only limited irrigation water is available, stored in shallow ponds or canals, remaining from the wet season. The specific question is whether an economic crop can be grown on water in the profile alone or would additional water be required? In scoping the long-term feasibility, the APSIM model (McCown et al., 1996; Keating et al., 2003) was first tested against the on-farm trial data collected in the 2005-06 season and by Rawson et al. (2007). Once validated, APSIM was employed to undertake a systems simulation analysis on the technical and economic feasibility of wheat production in specific regions of southern Bangladesh.

4 Objectives

Through collaboration with researchers in Bangladesh primarily from WRC (BARI) and CIMMYT, and building on the momentum gained from previous WRC/BARI/FAO/CIMMYT research, the overall aim of this study is to assess the long term technical and economic feasibility of wheat production in southern Bangladesh. Specific objectives are:

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

5 Methodology

5.1 On-farm trials in 2005-06

This study worked in three districts in southern Bangladesh during the 2005-06 *rabi* season (Figure 1). The Jessore (23.2°N, 89.2°E) district is in the south-west and is a traditional wheat growing area. It is included as a benchmark site against which wheat production in the southern regions is compared. Barisal (22.7°N, 90.4°E) is to the south and is representative of the regions with large tracts of *rabi* season fallow land, low levels of salinity and thus excellent prospects for wheat production. Noakhali (22.8°N, 91.1°E) is to the south-east and is also a potentially new wheat production region with significant fallow lands, although some with issues of salinity.

Sixty farmers collaborated in the project, providing their farms and labour for 60 on-farm trials in order to test the imposed treatments. Twelve farmers were selected at each of two villages in the Barisal area (Khanjapur 23.1° N, 90.2° E, 5m and Kasipur 22.7° N, 90.3° E, 7m), two villages in the Noakhali area (Hazirhat 22.7° N, 91.1° E and Char Zublee 22.6° N, 91.0° E, 5m), one control site in Jessore with a long history of growing wheat (Monirampur, 23.0° N, 89.2° E, 5m). There was a control research plot at the Bangladesh Agricultural Research Institute (BARI) headquarters near Dhaka (Joydebpur 23.9° N, 90.4°E, 5m). There were previous yield data for all locations except Khanjapur village (Rawson *et al*., 2007).

The imposed irrigation treatments were:

I_0 – no irrigation (dryland)

I_1 – one irrigation (at leaf 3 when the first tiller is emerging, late December to early January depending on sowing date)

I_2 – two irrigations (irrigation 1 plus one at early boot stage, end January to early February) and

I_3 – three irrigations (1 and 2 plus early grain filling end February, early March)

Approximately 100mm of water was applied as flood irrigation at each event. Each treatment was replicated on three farms at each village.

The cultivation, nutrition and seed broadcasting method of 'New Conventional' (Rawson *et al*., 2007) was employed. Here, a power tiller is used for one pass to cultivate the soil shallowly, seed and fertiliser is broadcast, then there is another light pass to cover the seed with soil. This process is completed within one day. For nitrogen fertiliser, urea was split between sowing (75 kg N ha^{-1}) and first irrigation (25 kg N ha^{-1}). For the zero irrigation treatment, the second fertiliser application was not made which meant that this treatment was also a reduced nitrogen regime. An additional zero irrigation treatment was tested in which all urea was applied at sowing (100 kg N ha^{-1}), but this was done only at Monirampur and the BARI research site at Joydebpur.

Replicated crop harvests were taken at anthesis (0.25m^2) for biomass estimation and at maturity (2.0m^2 quadrats sampled in three areas on each farm) for grain yield, its components and above-ground biomass.

5.2 Soil characterisation

Characterisation of soils for Plant Available Water Capacity (PAWC) and chemistry was undertaken at the five on-farm research sites and the BARI research station site. To characterise a soil for PAWC it is necessary to measure or estimate volumetric water content, at particular points on the water characteristic curve relating to saturation (SAT), drained upper limit (DUL) and crop lower limit (CLL) (Dalgliesh and Foale, 1998). Due to the wet soil conditions at the commencement of the wheat growing season (November 2005) and the homogeneity of soils within each of the locations, it was considered appropriate to use data collected as part of pre-season soil monitoring (from 12 farmers' fields at each location) to determine DUL. A similar rationale was used for the determination of CLL using data collected from the farmers' dryland treatment fields at crop maturity.

Prior to wheat sowing each field in the five villages was sampled using a 37 mm diameter driven coring tube to a depth of 1.5m in increments of 0-15, 15-30, 30-60, 60-90 and 90-120 and 120-150cm. Three cores were taken within each ~33 decimal (~1340m^2) field, bulked by layer, mixed and split into two samples for the estimation of water and nutrient content. 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), organic carbon (OC), electrical conductivity (EC), sodium and pH. Due to the small research plot size used in the Joydebpur BARI experiment, three sets of two cores were considered adequate to describe water and nutrient conditions at sowing.

Bulk density (BD) was measured at two sites per location with two replicates taken at each site to a depth of 60 cm (using the same depth layers as above). Driven rings with a volume of 45 cm3 (2.5 cm high x 4.8 cm diameter) were hammered into the soil, extracted, trimmed and the soil dried at 100 oC and weighed. The BD was estimated for depths below 60 cm, with the exception of Khanjapur where measurement was possible to a depth of 120cm.

5.3 Climate data

Long-term climate data (1984-2005) for the study sites at Jessore, Barisal and Noakhali (Maijdi station) were obtained from the Bangladesh Meteorological Bureau. Data included daily sunshine hours (h), maximum and minimum temperatures (ºC) and rainfall (mm). These data were supplemented by measured data using sensors and loggers located at each experimental site during the 2003-04 (temperature), 2004-05 (temperature) and 2005-06 (temperature, radiation) seasons. Data for the 2005-06 season at BARI Headquarters at Joydebpur were as measured from its official meteorological station.

Solar radiation (H, MJ m^{-2} d^{-1}) was calculated from measured sunshine hours (n, hours) using the Angstrom equation:

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

where H_o is extraterrestrial radiation (MJ m^{-2} d^{-1}), N' is daylength (hours) and a and b are fitted coefficients. The values of a and b recommended to estimate global radiation values for all Bangladesh were taken from a publication entitled "Measurement and study of solar radiation over Bangladesh" (sourced from www.lged-rein.org.htm). To include the seasonal effect, the fit was taken for 2 periods, March to September (a = 0.281, b = 0.383) and October to February (a = 0.241, b = 0.419).

5.4 APSIM Setup

In this study, APSIM-Wheat (version 4.2) was specified to simulate the three years of experimentation on wheat in southern Bangladesh. Data were accessed for the 2003-04 and 2004-05 seasons as presented by Rawson *et al*. (2007) and data from the 2005-06 as presented in this paper. The key parameters required to test APSIM for a new region are the phenology of the local wheat varieties, the characterisation of the physical and chemical properties for location-specific soils and measured climate data.

Experience in parameterising APSIM for new crops and regions indicates that establishing the appropriate phenology (dates of flowering and maturity) for the local variety will capture most of observed genotypic variation. Consequently, parameter values which influence photoperiod (*photop_sens* = 3.5) and vernalisation (*vern_sens* = 2.1) sensitivity, and the duration of grain filling (*tt_startgf_to_mat* = 520ºCd) were calibrated to ensure the local variety flowered and matured at observed dates in 2005-06 for the Jessore site (see www.apsim.info/apsim/Publish/apsim/wheat/docs/wheat_science.htm).

Soil characterisation data were collected as part of this study for the trial sites and these data were used to both estimate soil parameter values required by APSIM (Table 1) and determine starting soil water and nitrate nitrogen conditions. Other chemical data were also used as direct input to the model (OC and pH) or to inform researchers on potential sub-soil constraint issues (EC and Na).

Table 1: For each of the field trial sites, estimates of Plant Available Water Capacity (PAWC), bulk density (BD) and the volumetric soil water contents at saturation (SAT), drained upper limit (DUL) and crop lower limit (CLL).

Village	Layer	BD	DUL	SAT	CLL	PAWC	PAWC
	cm	g cm-3	mm mm-1	mm mm-1	mm mm-1	mm layer-1	mm profile-1
Monirampur	0-15	1.43	0.39	0.46	0.23	23.25	167
	15-30	1.42	0.39	0.45	0.24	22.34	
	30-60	1.42	0.39	0.45	0.26	39.57	
	60-90	1.41	0.39	0.44	0.29	31.65	
	90-120	1.40	0.40	0.45	0.31	27.36	
	120-150	1.39	0.40	0.45	0.32	22.83	
Khanjapur	0-15	1.35	0.41	0.46	0.21	30.89	167
	15-30	1.37	0.40	0.45	0.20	29.45	
	30-60	1.37	0.40	0.45	0.25	46.43	
	60-90	1.35	0.41	0.46	0.28	39.25	
	90-120	1.35	0.41	0.46	0.35	18.69	
	120-150	1.35	0.41	0.46	0.40	1.88	
Kasipur	0-15	1.32	0.42	0.47	0.22	29.72	169
	15-30	1.34	0.41	0.46	0.23	27.74	
	30-60	1.34	0.41	0.46	0.26	47.98	
	60-90	1.34	0.41	0.46	0.30	33.88	
	90-120	1.33	0.42	0.47	0.35	20.48	
	120-150	1.33	0.42	0.47	0.39	9.68	
Joydebpur	0-15	1.47	0.37	0.42	0.22	22.59	172
	15-30	1.55	0.34	0.39	0.22	18.09	
	30-60	1.45	0.37	0.42	0.22	44.31	
	60-90	1.38	0.40	0.45	0.28	35.96	
	90-120	1.37	0.40	0.45	0.31	27.17	
	120-150	1.37	0.40	0.45	0.32	23.88	
Hazirhat	0-15	1.26	0.44	0.49	0.26	27.40	154
	15-30	1.26	0.44	0.49	0.27	26.20	
	30-60	1.30	0.43	0.48	0.30	38.76	
	60-90	1.25	0.45	0.50	0.34	32.45	
	90-120	1.26	0.44	0.49	0.38	18.90	
	120-150	1.25	0.45	0.50	0.42	10.25	
Char Jublee	0-15	1.32	0.42	0.47	0.24	26.86	170
	15-30	1.34	0.41	0.46	0.25	24.60	
	30-60	1.33	0.42	0.47	0.27	46.42	
	60-90	1.33	0.42	0.47	0.30	35.61	
	90-120	1.33	0.42	0.47	0.33	26.20	
	120-150	1.32	0.42	0.47	0.39	10.55	

5.5 Simulation scenarios

Economic analysis of production risks for wheat can be assessed by generating annual wheat yields and associated gross margins over a range of seasons. By simulating wheat yields over long-term climate records, APSIM generates the yield probability distributions required to create a profile of economic returns and risks for wheat production in the regions of interest.

APSIM was configured to simulate crops grown at Jessore, Barisal and Noakhali using the soil data and agronomy collected for the trials conducted at Munirampur, Kasipur and Char Zublee respectively. At least 20 years of climate data (1985-2006) were available for these three sites to use in the long-term simulation scenarios described in Table 2. In addition to this scenario-specific information, most simulations were common in a number of parameter settings; for instance in using the same cultivar which was calibrated to the region during the validation process. Also, in each simulation, nitrogen fertilizer was applied as urea both at sowing and topdressed at the time of the first irrigation – dryland treatments received no added fertilizer either at sowing or as topdressing. Within each 20-year simulation run for a site, the soil water profile was reset to DUL at the nominated time of sowing – this represents the system status at the end of the *karif* season in most years.

Table 2: Description of long-term simulation scenarios for Jessore, Barisal and Noakhali.

	Issue	**Parameter**	**Jessore**	**Barisal**	**Noakhali**
	Common settings for wheat	Sowing date	25-Nov	25-Nov	7-Dec
		Population (plants/m2)	200	200	200
		Sowing N fertilizer (kg N/ha)	75	75	75
		Top-dressed N fertilizer (kg N/ha)	25	25	25
		Initial available soil water (mm)	190	170	170
		Initial soil N (kg N/ha)	60	45	10
		Irrigation /event (mm)	100	100	100
		Relative root front velocity (XF)	1.0	1.0	Table 4
1	No. of irrigations (0,1,2,3 or variable)	Irrigation dates (das) Deficit = irrigate when soil water deficit > 50% in the top 1m of soil	20 50 75 deficit	20 50 75 deficit	20 50 75 deficit
2	Impact of salinity	Relative root front velocity (XF)	-	-	Table 4
3	Timing if only one irrigation	Irrigation date (das)	-	20 or 35 or 50	-
4	Alternative crop rotations	Maize (i) 1 irrigation (das) (ii) 3 irrigations (das) Wheat-mungbean rotation (i) 1 irrigation on wheat (das) No irrigations mungbean (ii) 2 irrigations on wheat (das) 1 irrigation at mungbean sowing	-	 50 35,50,75 35 - 35,50 16 Mar	-

5.6 Economic data

Several farmers from the villages within the study region were interviewed to determine economic data for crops grown in the region. Where data were unknown because farmers had no experience of the relevant crops, data from established cropping regions were adapted to the new regions. Table 3 presents the cost data collected for wheat in the three regions of interest; all economic values are presented as Bangladesh Taka (1 Tk = $US 0.014). The official government price in 2006 for wheat was Tk14.50 kg^{-1}.

Table 3: Cost items for wheat production at three sites in southern Bangladesh.

		Jessore		**Barisal**		**Noakhali**	
Cost Items	Quantity ha-1	Price Tk	Value Tk ha-1	Price Tk	Value Tk ha-1	Price Tk	Value Tk ha-1
Labour (man-day ha-1)	106	70	7420	100	10600	100	10600
Ploughing (number)	3	865	2595	903	2709	836	2508
Seed (kg ha-1)	169	25	4225	25	4225	25	4225
Compost (kg)	3313	0.4	1325	0.4	1325	0.4	1325
Urea (kg)	161	6.25	1006	6.25	1006	6.25	1006
TSP (kg)	85	16	1360	16	1360	16	1360
MP(kg)	73	14	1022	14	1022	14	1022
Gypsum(kg)	44	4.5	198	4.5	198	4.5	198
Irrigation (number)	2	529	1058	529	1058	529	1058
Total Cost (Tk ha-1)			20,209		23,503		23,302

6 Achievement against activities and outputs/milestones

Table 1: Statement of how each output as listed in original project proposal was delivered.

Subprojects and/or Objectives	Outputs	Achievements
1 Collect field crop-soil-climate datasets attuned to modelling from on-farm trials in the 2005/06 dry season	1.1 Farmer participation in at least 40 on-farm trials	On-farm trials were conducted at Noakhali and Barisal sites using 2 blocks of 10 farmers at each site with a control 10-farmer block at Jessore (see Section 5.1)
	1.2 Comprehensive dataset collected from on-farm trials conducted at 3 sites	Soil, climate and plant data were collected from on-farm trials conducted at 3 sites (Section 7)
	1.3 Soil characterisation data measured for the principal cropping soils at each trial site	Soil characterisation data measured for the principal cropping soils at each site (Section 7.1)
2 Collect the long term minimum dataset required to quantitatively describe the current and proposed rice/wheat systems	2.1 Long-term climate data accessed for key sites	Climate data collated for Jessore, Noakhali and Barisal (Section 5.3)
	2.2 Irrigation water quality / availability described	Information on irrigation water resources collated for southern Bangladesh (Appendix 11.2)
	2.3 Crop cultivars & agronomic management specified	Cultivar & agronomic management was specified as part of the parameterisation of APSIM for this study (Sections 5.4 & 5.5)
	2.4 Data on past system performance (farmer & trial yields) collated	Data from past FAO study (Rawson et al., 2007) was accessed and utilised in model validations (Section 7.4)
2 Setup and test APSIM for current and proposed rice/wheat production systems	2.1 APSIM configuration files developed for southern Bangladesh	APSIM input files were established based on local data (Section 5.4)
	2.2 Validation report on APSIM performance against available trial data	APSIM simulation of available trial data and performance was quantitatively reported (Section 7.4)
	2.3 Log of missing critical data required for improved simulation accuracy	Identification and discussion of uncertain or unknown aspects of APSIM simulations (eg. impacts of high salinity; N x irrigation impacts) are fully discussed (Sections 7.3, 7.4)
3 Evaluate the technical and economic feasibility and risk profile of rice/wheat production systems in southern Bangladesh	3.1 Simulation analysis of wheat production potential over long-term climate records for key sites in southern Bangladesh	Production risk analysis using APSIM undertaken for a number of scenarios (Sections 5.5, 7.5)
	3.2 Economic analysis of production risks for an introduced wheat systems	Substituting fallow lands for wheat or wheat-mungbean crops is shown to add significant financial returns to farmers without great risks of economic losses (Section 7.6)
4 Recommendations on the research priorities	4.1 Final report containing ideas for further research investment	Conclusions incorporate seven recommendations (Section 9)

7 Key results and discussion

7.1 Soil characterisation

Each of the sampled soils from the six sites contained high proportions of silt (>50%) and so measured PAWC values were calculated as being similar assuming no sub-soil constraints are present (Table 1). An example of a typical water profile is presented in Figure 2a. The Monirampur soil has an estimated PAWC of 167 mm to 150 cm, although DUL and CLL do not converge in the 120-150 cm layer which indicates that there may have been extraction below this depth. At crop sowing, the soil sampling indicated that the profile was at full capacity for water storage. In fact, the soil was above DUL below 60cm depth. This was typical of many of the soils tested, a result of the short period of time between the end of the wet season and crop sowing. Measurement at anthesis shows that the wheat crop has extracted water to a depth of 60-90 cm with the deeper water still at DUL. By crop maturity, water had been extracted to a depth of 150 cm. This final soil water content was assumed to represent CLL.

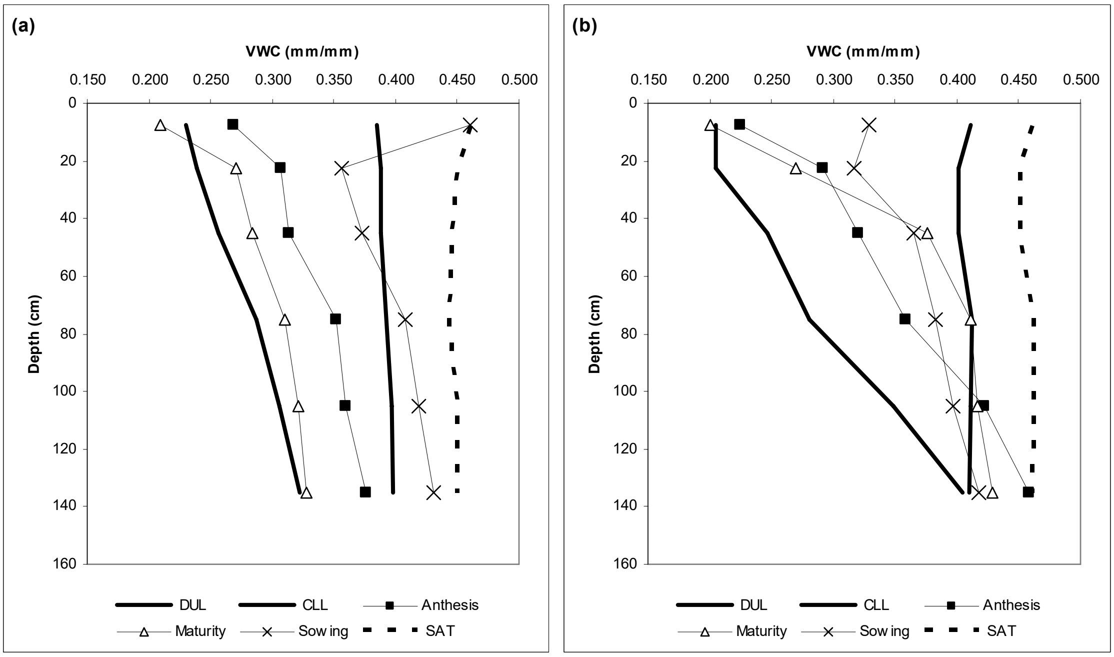
Soil chemistry was similar for all sampled profiles. The average soil pH was 7.5 and was relatively stable with depth and across sites (pH range 6.1 – 8.1). Likewise, across the six sites, OC averaged 1.14% (0.89 – 1.39%) in the surface 15cm and declined as expected with depth. Mineral nitrate-N varied across sites, with Monirampur (49kg N ha^{-1}) and Kasipur (41kg N ha^{-1}) having greater amounts of available N at the time of sowing than Khanjapur (8kg N ha^{-1}), Hazirhat (10kg N ha^{-1}) or Char Zublee (6kg N ha^{-1}).

Values for EC at all layer depths were low in the Jessore and Barisal districts (<0.45 dS m^{-1}), but high at both sites in the Noakhali district. At Char Zublee and Hazirhat, values of greater than 1.0 dS m^{-1} were recorded at all depths, with some individual layers being greater than 2 dS m^{-1} (Table 4). Given that such levels may affect soil water extraction and plant growth, values for CLL at depth at these two sites needed to be estimated by assuming PAWC values similar to the other sites. Therefore, further measurement is required to confirm these PAWC values.

Table 4: EC values (dS/m) measured prior to sowing for Char Zublee and Hazirhat and the calculated relative factor (XF) for root front velocity. Values for the surface layer are set to unrestricted development (XF=1.0).

	Char Zublee		**Hazirhat**	
Depth cm	EC dS m-1	XF 0-1	EC dS m-1	XF 0-1
0-15	1.9	1.00	1.3	1.00
15-30	1.3	0.22	1.0	0.34
30-60	1.6	0.14	1.1	0.29
60-90	1.9	0.08	1.2	0.25
90-120	2.0	0.06	1.4	0.19
120-150	2.1	0.05	1.8	0.10

Figure 2: Volumetric soil water contents (VWC mm/mm) measured at sowing, anthesis and maturity in the I0 dryland treatment for (a) Monirampur and (b) Khanjapur.



7.2 Climate in 2005-06

There was no effective rainfall during the 2005-06 season, however all locations had higher temperatures than in the previous three seasons. Considering only the 40 day period from the start of February 2006, at Joydebpur the average of max-min temperature of 25.1°C was 3.5°C hotter than the average for the previous 3 years. This period includes the booting stage through anthesis to mid-grain filling of wheat. This temperature rise equates to an increased day degree summation of 138°Cd for that period and consequent 5.5 days shorter duration in wheat development. In the Barisal and Jessore cropping regions, the 2005-06 season was 2.5° and 2.8°C hotter during this same grain determination and filling phase.

Radiation during the critical period, from late January through February, was also less this season compared with long-term means and recent seasons. This is the period from late boot stage to mid grain filling when grain numbers per unit crop area and grain size potential are dependent on high carbon gain.

7.3 On-farm trials in 2005-06

Measured wheat grain yields and above-ground biomass for the 2005-06 season are presented in Table 5. The traditional wheat site, Monirampur, averaged 3.0 t ha^{-1} this season under full irrigation compared with 4.0 t ha^{-1} yields in the previous two seasons (Rawson et al., 2007). Both sites in the Barisal district (Khanjapur and Kasipur) also achieved yields greater than 3.0 t ha^{-1} when provided with three irrigations. The two sites in the Noakhali district (Char Zublee and Hazirhat) produced low yields and biomass even under full irrigation. The relatively low yields for the control site at Monirampur and the research station site at Joydebpur indicated that the 2005-06 was a difficult season compared to previous seasons (cf. Rawson et al., 2007).

With no irrigations, dryland crops produced between 1.1 and 1.7 t ha^{-1} at four of the sites (Table 5) with the exceptions of the relatively high yield at Khanjapur (3.3 t ha^{-1}) and the low yield at Hazirhat (0.86 t ha^{-1}). At Monirampur and Joydebpur, an additional zero irrigation treatment was tested in which all urea was applied at sowing (100 kg N ha^{-1}).

Both sites showed some response to this additional urea, with grain yields of 1.63 t ha^{-1} (4.39 t ha^{-1} biomass) and 1.51 t ha^{-1} (3.13 t ha^{-1} biomass) respectively.

Table 5: Measured grain yields and biomass from irrigation treatments at six sites during the 2005-06 season.

Locations	**Treatments**							
	Dryland		1 irrigation		2 irrigations		3 irrigations	
	Yield t ha-1	Biomass t ha-1	Yield t ha-1	Biomass t ha-1	Yield t ha-1	Biomass t ha-1	Yield t ha-1	Biomass t ha-1
Joydebpur	1.15	2.78	2.58	5.51	2.73	6.52	2.37	5.90
Monirampur	1.34	3.63	2.77	7.96	2.71	7.96	3.03	8.64
Kasipur	1.58	3.87	2.27	5.99	2.56	6.62	3.06	7.73
Khanjapur	3.31	8.25	3.63	9.79	3.64	9.64	3.66	9.70
Char Zublee	1.38	3.48	1.76	4.63	1.89	4.90	1.40	3.67
Hazirhat	0.86	2.40	1.07	3.25	0.97	3.17	1.73	5.55

One irrigation doubled yields compared with dryland crops to over 2.5 t ha^{-1} at the Monirampur and Joydebpur sites by also doubling biomass (Table 5). Kasipur responded less with close to 50% increase in yield and biomass from a single irrigation. There was only a 10% response to irrigation at Khanjapur which is within 38 km of Kasipur. The poor Noakhali crops responded to irrigation by some 30%.

The general pattern of response to multiple irrigations was that beyond the first irrigation there was little further response as more water was applied. The lack of response to irrigation at Khanjapur can be explained by a high water table feeding water into the profile at depth. The measured soil water data for Khanjapur (Figure 2b) showed no water extraction below 90cm during the season and the water content at maturity was even higher than at the two previous sampling dates.

There remains some uncertainty as to the reason for the low yields observed at the two Noakhali sites. One hypothesis is that these crops may have been affected by the high measured salinity levels. Another possibility is herbicide damage, as all 24 trial farms at the Noakhali villages applied the pre-emergence herbicide glyphosate 24 hours before planting to control weeds and this short turn-around may effect seedling development. However, for the purposes of this study, APSIM validations and subsequent scenarios for Noakhali have assumed that crops at Noakhali were affected by salinity. However, caution should be exercised in drawing conclusions from these results given the relatively good wheat yield performance in Noakhali in preceding years and other possible confounding influences. More research is clearly required to understand wheat growth and its constraints at such sites with high levels of salinity.

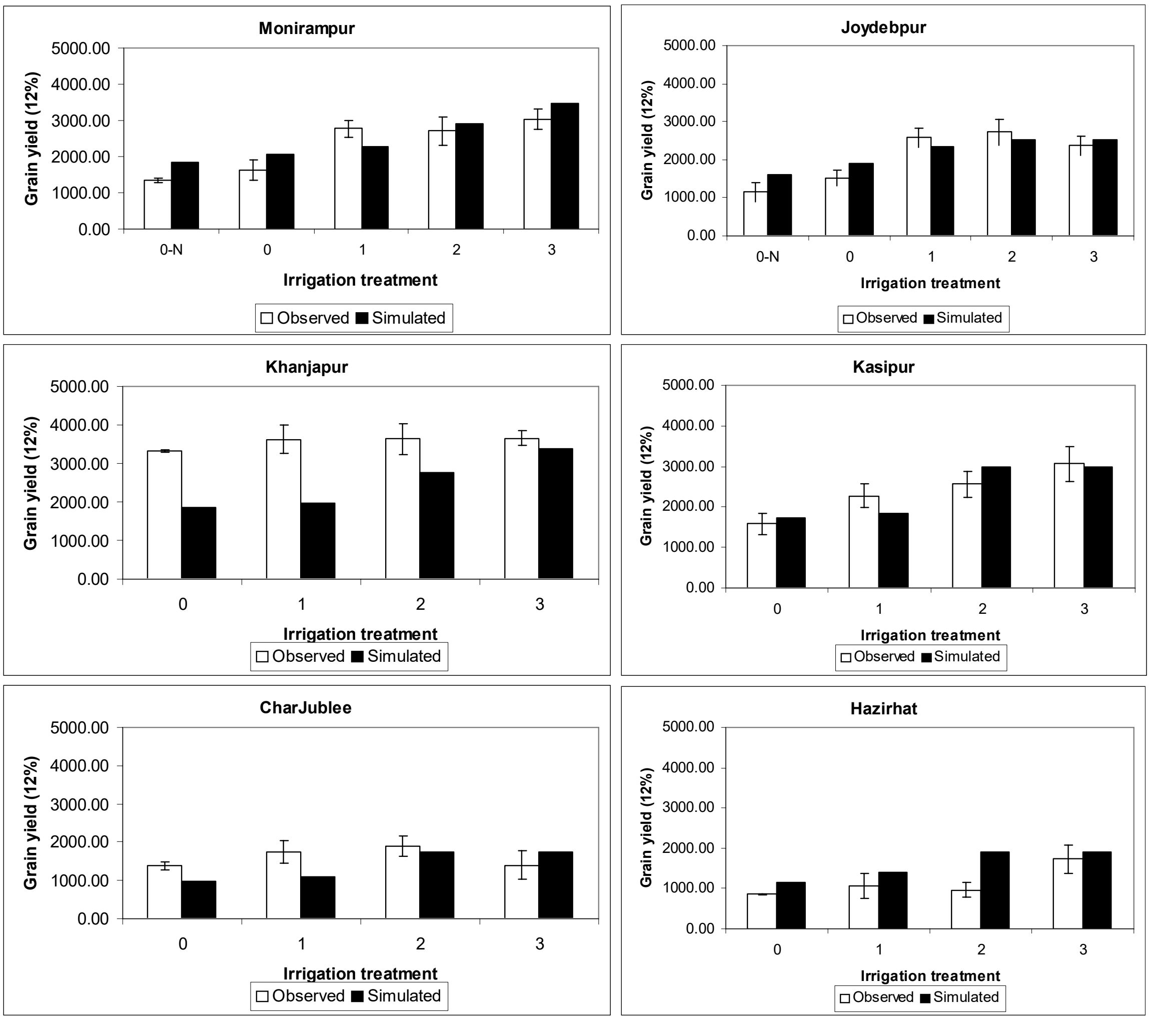
7.4 APSIM validation

The performance of APSIM in simulating wheat yields in the 2005/06 season at six sites in southern Bangladesh is presented in Figure 3. The simulations for the Joydebpur and Kasipur sites are presented using the setup as specified. The other four sites required further modification of input parameters as informed by the initial simulations.

The most obvious discrepancy in simulated and observed yields was at the Khanjapur site. Measured grain yields at Khanjapur demonstrated no response to applied irrigation yet the simulations indicated a significant response to increased water supply. Here the hypothesis is that a shallow water table likely provided the wheat crop with extra water not included in the simulation. Thus, results for treatments I_0-I_2 at Khanjapur were excluded from the overall validation assessment.

The simulated response to one irrigation at circa 21 days after sowing was less than the generally large response observed at most sites. Given soil profiles were close to DUL at sowing and water use in the first three weeks would be only a small proportion of the total available profile, this large observed response is hypothesised to be largely a response to N and not the added water supply. The one irrigation treatment benefited from the topdressed N fertilizer applied with the irrigation. However, it is also likely to have benefited from better availability of the N applied at sowing. In these experiments, seed and urea fertilizer were broadcast onto a dry soil surface then rotary-hoed into the soil on the date of sowing. Such sowing method clearly enabled the seed to germinate but it may have restricted urea hydrolysis, nitrification and N uptake which are all constrained as the soil dries. The possible lack of availability of N applied at sowing could not be adequately captured with the current APSIM configuration.

Figure 3: Simulated versus observed grain yields (kg ha-1 @12% moisture) for the six experimental sites run during the 2005/06 season. The irrigation treatment 0-N refers to no irrigation and no N fertilizer. Error bars represent ±standard deviation of observed yields for each treatment.



The depth of the soil profile at Monirampur was increased to 1.8m as crop extraction clearly occurred in soil layers below the measured depth of 1.5m (Figure 2a). This increased rooting depth provided an additional 22mm available water to the wheat crop and helped explain the relatively high yield for the one irrigation treatment. Deep water extraction (>150cm) was not so evident at the other sites.

Observed grain yields in 2005/06 were low at the two Noakhali sites, Char Zublee and Hazirhat. Initial simulated yields over-predicted the observed yields by more than 1 t ha^{-1} (data not shown) and one hypothesis for this over-prediction may be the impact of salinity. Rodriguez and Nuttal (2003) developed a relationship between measured EC (dS m^{-1}) and the relative root front velocity (XF) of wheat roots through a soil layer – an XF value of 1.0 equates to unconstrained root development and complete cessation of root development occurs with a value of 0.0. If the impact of salinity is imposed using the restricted root exploration rates calculated in Table 4, then simulated yields are of the same order as was observed at these two sites (Figure 3).

With the few modifications to the initial APSIM setup as informed by the 2005/06 season results, APSIM was then run for the wheat experiments conducted at the same sites in the 2003/04 and 2004/05 seasons (Rawson et al., 2007). Overall, simulated yields matched observed yields as well as the relative results between sites and seasons (Figure 4). The higher measured yields at Jessore and lower yields at other sites were represented by the simulations. Employing the factor to restrict rooting depth at the Noakhali sites worked in two treatments but not in the other two – and there was no consistency over sites nor seasons in this response. Temporal fluctuations in EC, moderated by irrigation management, may negate the assumption of constant EC values at each site in all years.

The overall validation of grain yields simulated by APSIM versus observed data for six sites and three seasons is presented in Figure 5. The validation resulted in a coefficient of determination (r^2) of 0.74 and RMSD of 485kg ha^{-1}.

Figure 4: Simulated versus observed grain yields (kg ha-1 @12% moisture) for the experimental sites run during the 2003/04 and 2004/05 seasons from Rawson et al. (2007). Note that there were two sowing dates at Barisal in the 2004/05 season. Error bars represent ±standard deviation of observed yields for each treatment

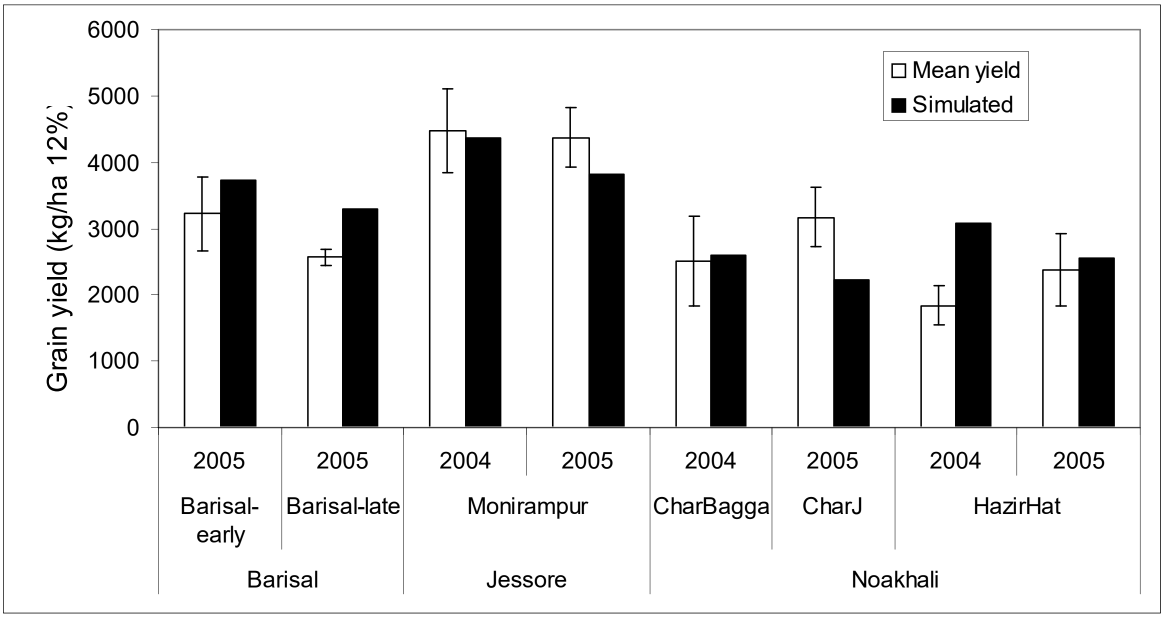
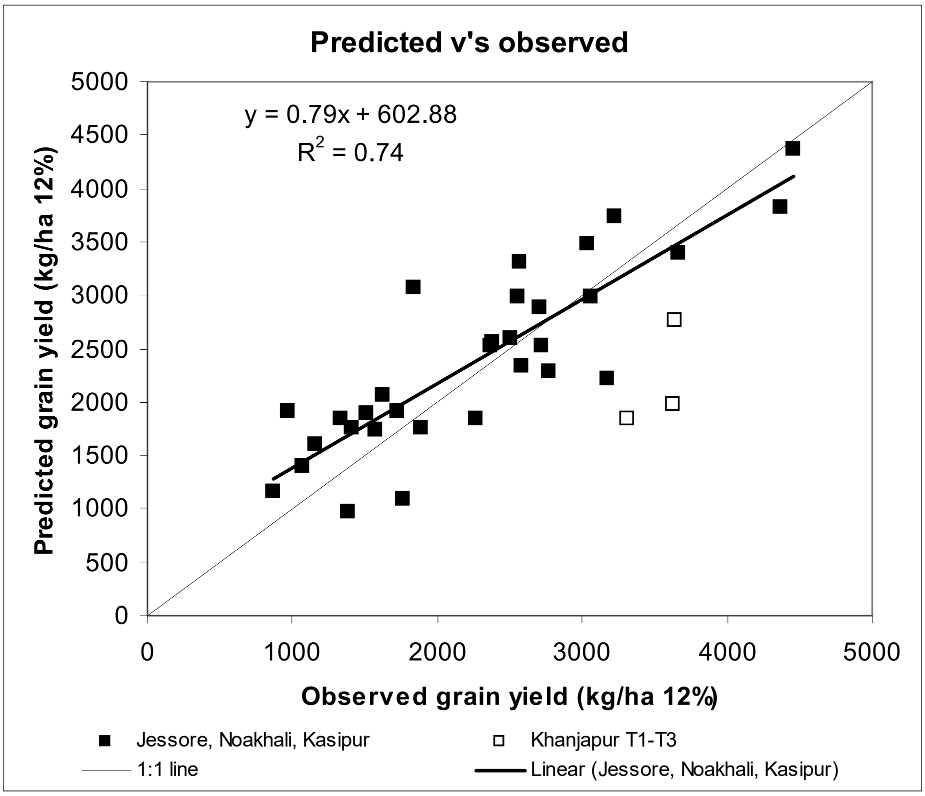


Figure 5: Simulated versus observed grain yields (12% moisture) for six sites and three seasons (n=31). Data for treatments I0-I2 at Khanjapur are shown (open symbols) but not included in the fitted regression line. The root mean square deviation (RMSD) between simulated and observed data is 485kg ha-1.



7.5 Simulation scenarios

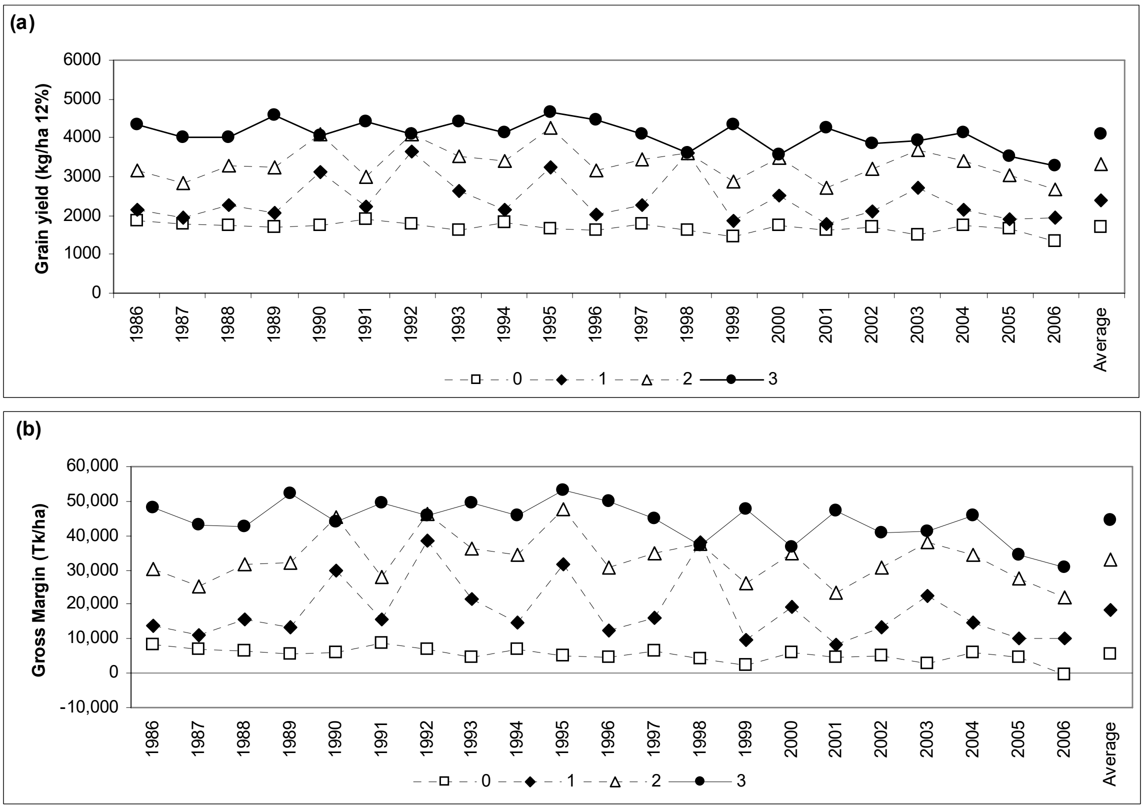
7.5.1 The 2005/06 season in perspective

Reports of the wheat crop in the 2005/06 season indicated lower than expected yields across all wheat growing regions of Bangladesh. This result is confirmed in the long-term simulations conducted in this study. At Jessore, the simulated grain yield for a wheat crop grown with two irrigations in the 2005/06 season was 2.9 t ha^{-1} (@12% moisture) which was the lowest simulated yield in the last 20 years (1985-2006). In contrast, the median simulated yield was 3.7 t ha^{-1} and the highest 4.9 t ha^{-1}.

7.5.2 Impact of number of irrigations

Simulated wheat grain yields, related gross margins and irrigation water use for five irrigation treatments are presented for the Barisal district in the period 1985-2006 in Figure 6 – simulations for Jessore and Noakhali are not shown. For Barisal, average simulated dryland yields were 1.7 t ha^{-1} with an upper irrigated yield potential of 4.1 t ha^{-1}. The impact of irrigation resulted in increases of 42, 40 and 22% for average yield and 240, 83 and 34% respectively for increased gross margins. At Jessore, dryland yields averaged 2 t ha^{-1} and increased by 42, 30 and 16% for each additional applied irrigation. The equivalent changes in gross margins were 108, 47 and 21% from added irrigations. A long-term average yield potential for fully irrigated wheat at Jessore was simulated at 4.3 t ha^{-1}. At Noakhali, assuming root restrictions from high EC values, average simulated dryland yields were 1.1 t ha^{-1} with an upper irrigated yield potential of 2.6 t ha^{-1} on average. Here, irrigation increased yields by 26, 46 and 27% and gross margins by 24, 47 and 25% respectively.

Figure 6: Simulated (a) wheat grain yields (kg ha^{-1} 12% moisture) and (b) gross margins (Tk ha^{-1}) for five irrigation treatments at Barisal in the period 1985-2006. The averages over the 20 years are represented by points to the right of the figure.



Irrigation clearly increases average yields of wheat, and reduces yield variability, when grown in the dry rabi season of Bangladesh. Consequently, an investment in irrigation will significantly increase gross margin for wheat production. However, the simulation of a tactical deficit irrigation strategy at Jessore and Barisal resulted in equivalent yields and gross margins to that for a fixed 3 irrigation strategy, but saved 130 and 110mm in irrigation water respectively at the two sites. This irrigation rule failed to work at Noakhali because of the assumed restricted root development at this site. These simulations indicate that irrigation water use efficiency could be improved for wheat production in southern Bangladesh by reviewing the frequency and amounts of irrigation applied to crops.

7.5.3 Impact of salinity at Noakhali

Long-term simulations for the Noakhali region, to date, have assumed significant impact of salinity (high EC) on root development and thus water availability to wheat crops. Simulated yields are significantly lower than determined for the other new wheat growing region at Barisal where high EC is not an issue. Simulated yields were also lower than the measured high yields (>3t ha^{-1}) achieved at Char Zublee in the 2004/05 on-farm trials (Rawson et al., 2007).

If the constraint of high EC on root development is removed (XF=1.0) for Noakhali, then simulated yields increase significantly – by 96, 76, 75 and 53% for the 0, 1, 2 and 3 simulated irrigation treatments. Without the imposed salinity constraint, simulated yields at Noakhali were equivalent to those estimated for Barisal, with dryland yields averaging 2.2t ha^{-1} and greater than 4.0t ha^{-1} with three irrigations.

Key issues, therefore, in determining the suitability of Noakhali for wheat production include the characterisation of the region's salinity status, both temporally and spatially, and quantifying the development and growth response of wheat to this environment. Until this further work is undertaken, conclusions on the suitability of Noakhali region are unresolved.

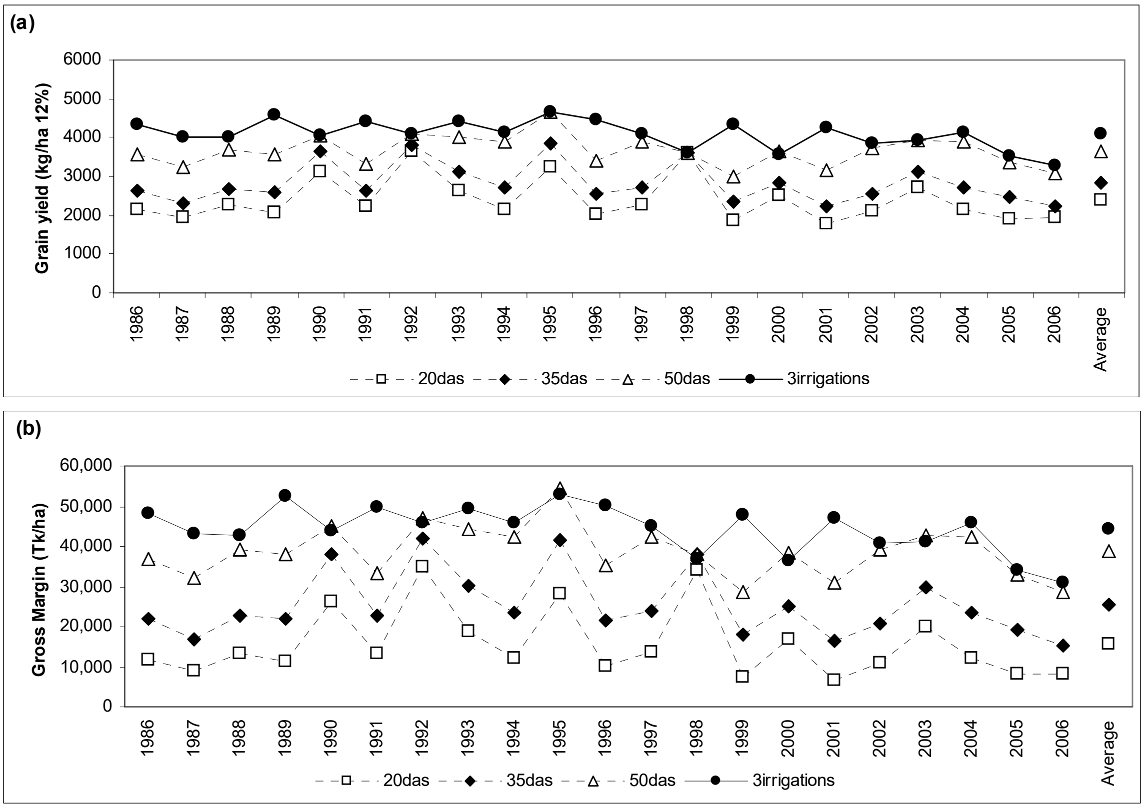
7.5.4 Impact of only one irrigation and its timing

In the real-world situation of limited water supply for irrigation, the question is how to utilise it most efficiently. The simulations presented in Figure 7 test the option of delaying a single irrigation from the recommended 20 days after sowing (DAS) to 35 or 50 DAS at Barisal. In this case, APSIM simulations indicate strong positive yield and gross margin increases from delayed irrigation in almost all years. Delaying a single irrigation from 20 to 50 days after sowing resulted in simulated yields reaching, on average, 90% of the yields for wheat grown under three irrigations. This result is understandable given the realistic assumption that wheat is always sown into a full soil water profile and so has access to enough water to optimally develop for the first 50 days after sowing. Supplying irrigation to a soil profile dry to depth and prior to wheat anthesis provides both efficient infiltration of irrigation water as well as good plant-water relations in the critical pre-flowering period.

The second assumption that there will be sufficient soil nitrogen available for early crop development, without an early irrigation and topdressing event, may be less realistic. An early irrigation, within 20 days of sowing, is used primarily to allow the crop to be topdressed with N as well as to enhance the availability of N applied at sowing. The success of delaying irrigation to 50 days after sowing will largely depend on the soil nitrate status at the completion of the T. aman rice crop. Strategies to ensure good soil N status at this time could be explored.

Clearly, the issue of when to utilize limited irrigation water supplies in these regions of southern Bangladesh requires further exploration from both technical and operational perspectives. A real question is whether irrigation water stored in a communal resource (canal, pond) can be left unused for any period without it being diverted to other uses or exploited by competing farmers.

Figure 7: Simulated (a) wheat grain yields (kg ha-1 12% moisture) and (b) gross margins (Tk ha-1) for one irrigation applied either 20, 35 or 50 days after sowing compared to three cumulative irrigations at those times at Barisal in the period 1985-2006. The averages over the 20 years are represented by points to the right of the figure.

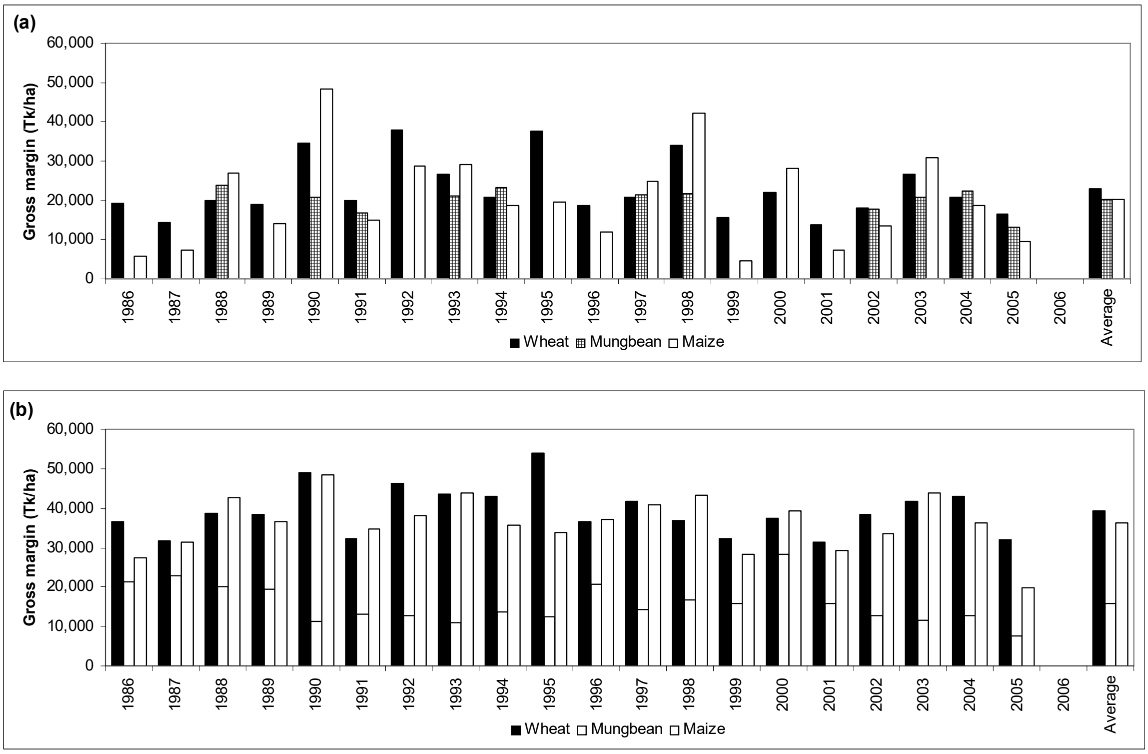


7.5.5 Comparison of alternative rabi-season cropping systems

In the rice-wheat systems of northern Bangladesh, wheat is traditionally sown in the dry rabi season following the T. aman rice grown during the wet karif season. In terms of alternative options for farmers in the rabi season, the two most common are following wheat with doubled-cropped mungbean or substituting maize for the wheat crop. These two options are assessed for Barisal by simulating the two alternative systems under conditions of either limited irrigation water supply (only one irrigation available) or good water supply (3 irrigations available).

For the wheat-mungbean system, wheat was sown as per previous simulations using historic meteorological data with irrigations applied at times listed in Table 2. In the one irrigation scenario, wheat received the added water and mungbean was grown dryland – it was only sown in that year if at least 25mm rainfall was received over a three day period between 1st March and 15th April. With three irrigations available, two were allocated to wheat and the third applied on the 16th March in order to establish a sown mungbean crop every year of the historical dataset. Note that these simulations were undertaken without parameterisation of indigenous maize and mungbean cultivars nor their testing against local data.

Figure 8: Simulated gross margins (Tk ha-1) at Barisal in the period 1985-2006 for two alternative rabi-season systems, wheat-mungbean or maize, assuming (a) only one irrigation is available or (b) three irrigations are available during the season. Economic data for wheat is given in Table 3; mungbean price is assumed as Tk35 kg-1 and growing costs of Tk14,616 ha-1; maize price is assumed as Tk8 kg-1 and growing costs of Tk22,803 ha-1 plus costs of N fertilizer and for irrigation as per Table 3.



Simulated gross margins for the crop components for three systems (wheat, wheat-mungbean and maize) can be compared for Barisal in Figure 8. With water available for only one irrigation, wheat produced the highest average gross margin and the least season-to-season variability. Maize produced highly variable returns; over Tk48,000 ha^{-1} in one year but <Tk10,000 in five of the 20 seasons. Mungbean was not grown in 9 years (47% years) due to no sowing rain but, when sown, its average gross margin rivalled both wheat and maize. The combined gross margin for the wheat-mungbean system averaged Tk43,000 ha^{-1}, which was 112% higher than the average return from the alternative maize system.

When more irrigation water is available and applied to the wheat and maize crops, gross margins increased and variability reduced significantly (Figure 8b). Nevertheless, wheat still produced the highest gross margin and the wheat-mungbean system averaged Tk55,000 ha^{-1} – 52% higher than the average return for a competing maize system.

7.6 Economic analysis

Using Barisal as a region representative of potential wheat expansion, the long-term average simulated dryland yields were 1.7 t ha^{-1} with an upper irrigated yield potential of 4.1 t ha^{-1}. Under the assumption of limited water availability (only one irrigation applied to wheat at 35 days after sowing), wheat averaged 2.8 t ha^{-1} with an associated gross margin of Tk23,000 ha^{-1}. If dryland mungbean was simulated to follow the wheat on likely rainfall, then combined gross margin for the wheat-mungbean system averaged Tk43,000 ha^{-1}. Given average farm sizes of 1ha, then substituting fallow lands for wheat or wheat-mungbean crops can add significant financial returns to farmers without great risks of economic losses – the simulations showed no failed crops in the past 20 years of rainfall records.

There is an estimated 800,000 ha of fallow or underutilized land during the rabi season in southern Bangladesh and much of this land is unaffected by high salinity or arsenic contamination. An assumption of 400,000 ha of available lands and average yields of 2.5 t ha^{-1} result in more than 1 million tonne of wheat as the production potential for these southern zones. Even assuming a conservative adoption rate, utilisation of fallow lands has significant potential to generate economic benefits in this depressed area while addressing a high proportion of the current Bangladesh wheat deficit. Whilst this economic analysis is only cursory, it does suggest that more detailed cost:benefit analyses are required to estimate the investment opportunities for utilising rabi lands currently fallow.

7.7 Discussion

Farmer-managed trials and simulation analyses indicate that the regions in southern Bangladesh proposed for introducing rabi-season cropping show promising potential for wheat production. This finding challenges the view that wheat production is largely unsuited to southern Bangladesh (Bangladesh Country Almanac, 2006) and support the contention of Rawson et al. (2007) that the historically fallow lands in the south could provide additional wheat production for the country.

The Barisal region, with significant fallow rabi lands, no salinity issues and some surface water resources, represents a promising area for investment in this cropping system. The Noakhali region, in contrast, has fallow rabi lands and surface water resources but the impact of salinity may be detrimental to cropping prospects in the rabi season. The on-farm trials produced yields up to 3.0 t ha^{-1} with three irrigations in the Noakhali region. The simulated dryland yields averaged 1.1 t ha^{-1} with an upper irrigated yield average of 2.6 t ha^{-1}, although these simulations assumed an impact of measured EC. Dang et al. (2006) demonstrated that subsoil constraints, such as high EC, can significantly decrease depth of water extraction, grain yield and plant available water capacity for field-grown wheat crops. Further clarification of the salinity status of the region, both temporally and spatially, and quantifying the development and growth response of wheat to this environment are essential precursors to further investment into this issue in the Noakhali region.

A key question to realising rabi-season cropping from southern lands is the extent to which production is dependent on access to irrigation water. While Zaman (2004) presented data suggesting much of the southern regions have significant amounts of accessible water, as surface water or shallow water tables of high quality at the start of the rabi season, access by farmers to irrigation will likely be limited. The dryland wheat crop at one trial site produced equivalent yields to the irrigated treatments (>3.0 t ha^{-1}), achieved by plant roots accessing a shallow water table. At other sites, dryland crops grown solely on stored soil water reached 1.5 t ha^{-1} and a single irrigation raised wheat yields to 2.5 t ha^{-1}. Associated modelling analyses suggest that consistently high yields and gross margins could be achieved by utilising limited surface water as a single irrigation, but delaying that irrigation beyond the locally-recommended 20-30 days to up to 50 days after sowing.

Fallow lands in the target zone can be roughly categorised into four types based on their water availability, namely those districts (i) with current irrigation infrastructure, (ii) where supplementary irrigation may be possible from surface water storages, (iii) where unirrigated crops may be viable either because of near-surface water tables or because of their soils have high water holding capacity, or (iv) those with poor quality ground water due to varying degrees of salinity but having high quality surface water available at the start of the rabi season. The quantification and spatial discrimination of the water resources of the region is a key first step in progressing the development of new crop systems for southern Bangladesh.

The performance of the APSIM model in simulating measured on-farm trial results was promising, with the r^2 of 0.74 and RMSD of 485kg ha^{-1} well within the validation outcomes for wheat simulation models developed and tested internationally (Timsina and Humphreys, 2006a). As a comparison, when the CERES-Wheat model was used to simulate wheat in northern Bangladesh, it resulted in a r^2 of 0.95 and RMSD of 467kg ha^{-1} for the one site at Nashipur (Timsina et al., 1998) and a r^2 of 0.59 with significant over-prediction bias at the three sites of Nashipur, Ishwordi and Joydebpur (Timsina et al., 2002). The impact of high salinity on wheat physiology and yield emerged from the study as a researchable issue in relation to APSIM development.

The simulation analyses provided added insight into the field trials conducted over three years. The 2005-06 season was confirmed as a poor season for wheat due to the combination of low radiation and high temperatures. Irrigation timing and its interaction with soil N supply and fertilizer N availability had large impacts on achievable yields and the simulations provided some evidence that efficiencies in resource utilisation may be gained from further research in these areas. Finally, calculated gross margins for wheat, based on long-term simulations, are mostly positive and compare favourably with competing land and water uses, such as maize production.

This study has ignored the possible impact of global warming which seriously threatens the productivity of Bangladesh’s traditional cropping zones (Faisal and Parveen, 2004; Timsina and Humphreys, 2006b). In expanding the area for rabi-season cropping in southern Bangladesh, probable changes in temperature and rainfall regimes and consequent impacts on crop choice, systems management and their viability cannot be ignored. Modelling analyses which address climate change scenarios are of interest to policy-makers and need to be included in any further analysis of crop production options in Bangladesh.

While supporting wheat production in southern Bangladesh as being technically and economically feasible, this study has not addressed the social feasibility of introducing new rabi-season practices for local farmers. Meisner et al. (2003) point out that smallholder farmers in Bangladesh are not easily reached by national extension services due to their large number and isolation. Furthermore, the adoption of innovations in wheat-producing households in Bangladesh is a whole family activity and requires access to all family members, including women. In achieving increased wheat production from southern Bangladesh, significant extension efforts are clearly required to introduce new practices to local farmers.

8 Impacts

Wheat production in southern Bangladesh appears both technically and economically feasible based on the results of three years of on-farm trials and associated simulation analyses as undertaken in this study. Wheat, and possibly other crops such as mungbean and maize, can be grown with current agronomic expertise and long-term simulations suggest that production is low risk and economically feasible, particularly if some supplemental irrigation is available. The evidence appears sufficient to encourage further investment into exploring greater utilization of fallow land during the *rabi* season in southern Bangladesh.

8.1 Scientific impacts now and in 5 years

Nil

8.2 Capacity impacts now and in 5 years

- At the start of the project, and prior to the season starting in Nov 2005, WRC staff provided training to participating farmers and extension staff on the on-farm trial procedures. This involved over 50 farmers.
- During the course of the project, WRC partners were trained in the characterisation of soils for water holding capacity. This involved in-field training supported by written instructions. A 10 minute demonstration video “Soil sampling using the hand coring kit” was produced in the local Bangla language and provided to WRC.
- Training to support collection of daily weather data from an in-field met station was provided to WRC staff.
- WRC and CIMMYT collaborators were exposed to the APSIM model. No formal training was provided but participants’ knowledge of and appreciation for modelling was enhanced.

8.3 Community impacts now and in 5 years

8.3.1 Economic impacts

- This scoping study demonstrated that crop production in southern Bangladesh appears both technically and economically feasible. The evidence appears sufficient to have encouraged institutions such as WRC and CIMMYT to further invest in exploring greater utilization of fallow land during the rabi season in southern Bangladesh.
- Non-project supported farmers in the new wheat regions grew wheat in 2005/06 in fields adjacent to project trials. This provides some evidence that project practices are disseminating out beyond participating farmers.
- The simulation analyses provided added insight into the field trials conducted over three years. Irrigation timing and its interaction with soil N supply and fertilizer N availability had large impacts on achievable yields and the simulations provided some evidence that efficiencies in resource utilisation may be gained from further research in these areas. These insights were largely new to collaborating in-country researchers.
- A key recommendation from the scoping study was for continued RDE investment into expanding the area for rabi-season cropping in southern Bangladesh.

8.3.2 Social impacts

The study confirmed 2005/06 season as a poor season for wheat due to the combination of low radiation and high temperatures. Such analyses were presented by WRC to high level Government and NGO policy-makers who were concerned by crop performances across the whole of Bangladesh.

8.3.3 Environmental impacts

Nil

8.4 Communication and dissemination activities

8.4.1 Communication activities

- At the start of the project, and prior to the season starting in Nov 2005, project staff provided training to participating farmers and extension staff on the on-farm trial procedures. This involved over 50 farmers.
- Results from the scoping study were presented back to WRC and CIMMYT collaborators in Bangladesh by Peter Carberry and Howard Rawson in May 2006.

8.4.2 Intended publications

Carberry, P.S., Saifuzzaman, M., Rawson, H.M., Sufian, M.A., Hossain, A.B.S., Dalgliesh, N.P., Siddique, M.A.B., Amin, M. and Kabir, J. Technical and economic feasibility of wheat production in southern Bangladesh. Experimental Agriculture (submitted)

9 Conclusions and recommendations

Wheat production in southern Bangladesh appears both technically and economically feasible based on the results of on-farm trials and simulation analyses as undertaken in this scoping study. The study indicated wheat, and other crops such as mungbean and maize, can be grown with low risk and long-term economic feasibility, particularly if supplemental irrigation is available. The evidence appears sufficient to encourage further investment into exploring greater utilization of fallow land during the *rabi* season in southern Bangladesh.

Recommendation 1: ACIAR support development of a follow-on project addressing the issue of intensifying land use in southern Bangladesh through wheat-based cropping systems introduced during the rabi season.

A key question to realising *rabi*-season cropping from southern lands is the extent to which production is dependent on access to irrigation water. The scoping study presented data suggesting much of the area has a significant amount of stored soil water, as surface water or shallow water tables of high quality at the start of the *rabi* season. Fallow lands in the target zone can be roughly categorised into four types based on their water availability, namely those districts (i) with current irrigation infrastructure, (ii) where supplementary irrigation may be possible from surface water storages, (iii) where unirrigated crops may be viable either because of near-surface water tables or because of their soils have high water holding capacity, or (iv) those with poor quality ground water due to varying degrees of salinity but having high quality surface water available at the start of the *rabi* season. The quantification and spatial discrimination of the water resources of the region is a key first step in progressing the development of new crop systems for southern Bangladesh.

Recommendation 2: The water resources in regions of southern Bangladesh be characterised for their potential suitability for irrigation in terms of surface and soil water availability, its distribution, types of water bodies and water quality.

At one trial site from the scoping study, the dryland wheat crop produced equivalent yields to the irrigated treatments (>3.0 t ha^{-1}), achieved by plant roots accessing the shallow water table. At other sites, dryland crops grown solely on stored soil water reached 1.5 t ha^{-1} and a single irrigation raised wheat yields to 2.5 t ha^{-1}. Associated modelling analyses suggest that consistently high yields and gross margins could be achieved by utilising limited surface water as a single irrigation, but delaying that irrigation beyond the locally-recommended 20-30 days to up to 50 days after sowing. Therefore, the focus for follow-on work should be in designing and disseminating management practices for systems with minimal irrigation supplies.

Recommendation 3: Future research investment into agronomic practices recommended for potential new rabi-cropping regions specifically address the issue of efficient utilisation of limited water resources.

During the course of this ACIAR scoping study, project partners within the Wheat Research Centre and CIMMYT-Bangladesh demonstrated strong capacity to develop training guidelines on wheat agronomy and extend these recommendations to regional extension officers and their farmer clients. The scoping study successfully involved over 50 farmers and 10 extension and technical officers in the 2005/06 season. The preceding FAO study left a legacy of farmers continuing to grow wheat in the new regions identified in this study. Further investment in capacity building of extension staff and in farmer training on practices relevant to each new cropping region will likely return greater adoption of *rabi*-season crop production.

Recommendation 4: Resources to train regional extension officers and their farmer clients are required for the wider extension of agronomy recommendations tailored to each new cropping region.

An extrapolation of simulation results for wheat cultivation in southern Bangladesh, assuming an adoption rate of 10 % within 5 years, estimated a benefit of approximately Tk1.4 billion ($A28 million) per annum. Such benefits appear attractive and may form the basis of a case put to policy-makers at regional and national levels for new investment in irrigation infrastructure and cropping in southern Bangladesh. However, more detailed socio-economic analyses are required for such policy initiatives.

Recommendation 5: A detailed cost : benefit analysis is required to estimate the investment opportunities for utilising rabi lands currently fallow in southern Bangladesh.

This scoping study has ignored the possible impacts of global warming which seriously threatens the productivity of Bangladesh’s traditional wheat zones. In expanding the area for rabi-season cropping in southern Bangladesh, probable changes in temperature and rainfall regimes and consequent impacts on crop choice, systems management and their viability cannot be ignored. Modelling analyses which address climate change scenarios are of interest to policy-makers and need to be included in any further analysis of crop production options in Bangladesh.

Recommendation 6: The impacts of global climate change need to be included in any project addressing the issue of intensifying land use in southern Bangladesh.

Australia shares many of the same research issues as identified for Bangladesh, especially in the production of crops limited by hot, dry environments, by diminishing irrigation water resources and by rising water tables and salinity. A core research capacity widely used to address such issues in Australia is the APSIM systems model and it was successfully employed in this scoping study. The impact of high salinity on wheat physiology and yield emerged from the scoping study as a researchable issue in relation to APSIM development. Thus, continuation of collaborative research between Bangladesh and Australia will provide benefits in three emerging domains: (i) exploring opportunities for greater in-season tactical management of resource inputs, especially N fertilizer and, if available, supplementary irrigation; (ii) quantification of the physiological response of wheat to salinity and incorporating relationships into APSIM; and (iii) adaptation of cropping systems to the negative aspects of global climate change.

Recommendation 7: In any follow-on project, the development and application of APSIM be targeted at issues of relevance to both Bangladesh and Australia.

In summary, this scoping study provided the groundwork necessary for continued investment in determining the regional prospects for crop production during the dry *rabi* season in southern Bangladesh.

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11 Appendixes

11.1 Irrigation water resources in southern Bangladesh

Irrigation infrastructure is not generally available in southern Bangladesh. There are no deep and very few shallow tube wells. However, surface water is potentially available for irrigation from canals and the scattered ponds throughout the region. While the limited supply of irrigation water restricts production of high water-use crops, there may be sufficient irrigation resources for wheat – rice requires 20-40 irrigations compared to only 2-4 per wheat crop. Stored surface water was utilised for irrigating wheat in the exploratory on-farm studies reported here. Two immediate issues requiring resolution are an assessment of the potential irrigation resources in the regions of interest as well as the consequence of accessing limited irrigation resources and thus the feasibility of growing wheat solely on stored soil water or with few irrigations.

11.1.1 Survey of irrigation facilities in study villages

A selection of farmers from two villages within the Barisal region were interviewed by Mr Jahangir Kabir (Agricultural Economist, WRC) to identify their irrigation resources. He found that the availability of irrigation water and systems for irrigation are perceived as major constraints for agriculture in the Kashipur and Khanjapur villages, although all villages had some access to water supply and storage infrastructure.

In Khanjapur, farmers mainly depend on surface water from canals and ponds for irrigation. People use this water for their every day household activities. Pond owners do not produce fish commercially in their ponds due to the excessive flood proneness of the area. In the rainy season some fish enter into the ponds with flood water. Owners of the ponds catch the fish during November and December by lifting the water to adjacent storage using Shallow Tube-well (STW) pumps leaving the fish behind. After catching the fish, the pond owner returns the water to the pond. Therefore there is no harm to fish culture even when pond water is used for small scale irrigation. In Kashipur, there are some ponds to meet the water requirement for every day household activities. Some farmers culture fish in their ponds for their own consumption. Ponds are situated within the village. There is no deep pond even for small scale irrigation. Farmers mainly depend on canal water for irrigation. There are some natural canals in both the villages. Water comes into the canals from rivers through tide surges of the sea. A problem is that the canals fill up with the silt coming with flood water during the wet season. Further digging of the canals is essential to make irrigation water more available in these villages.

In Bangladesh, the government has some development activities for digging canals under their “Food For Work” programme to make surface irrigation available where under ground irrigation facilities are absent. Some people in the villages collect water from main canals by STW and reserve this water in dry canals for sale. Farmers buy irrigation water from them. In Kashipur, however, the government has already taken the decision to dig more canals and so irrigation water will become more available.

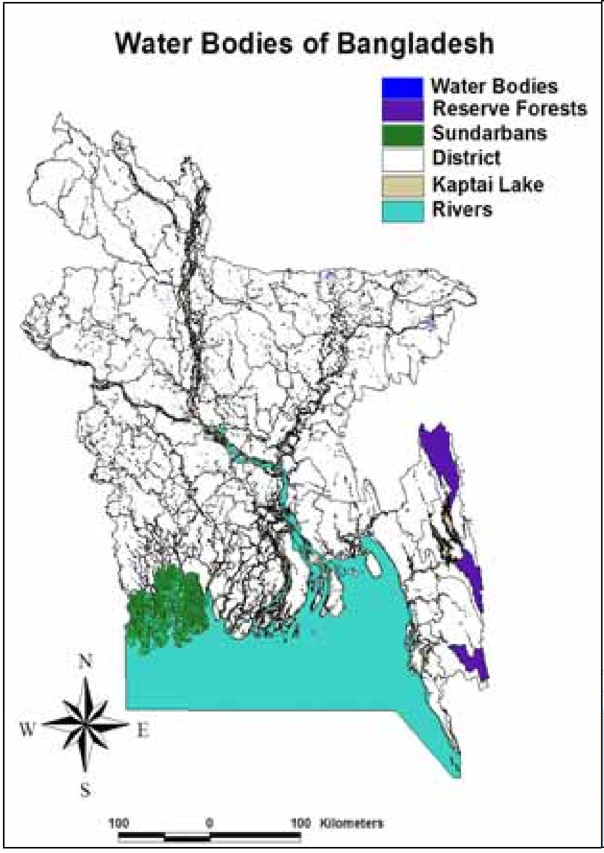
Low Lift Pumps and Treadle pumps are used for small scale irrigation even for Boro rice cultivation in Bangladesh. These types of pumps are suited to irrigation in wheat as well. There are some Hand Tube-wells for drinking water in both the villages. Underground water layer should also be investigated as to whether it is suitable for irrigation using Treadle or Low Lift Pumps.

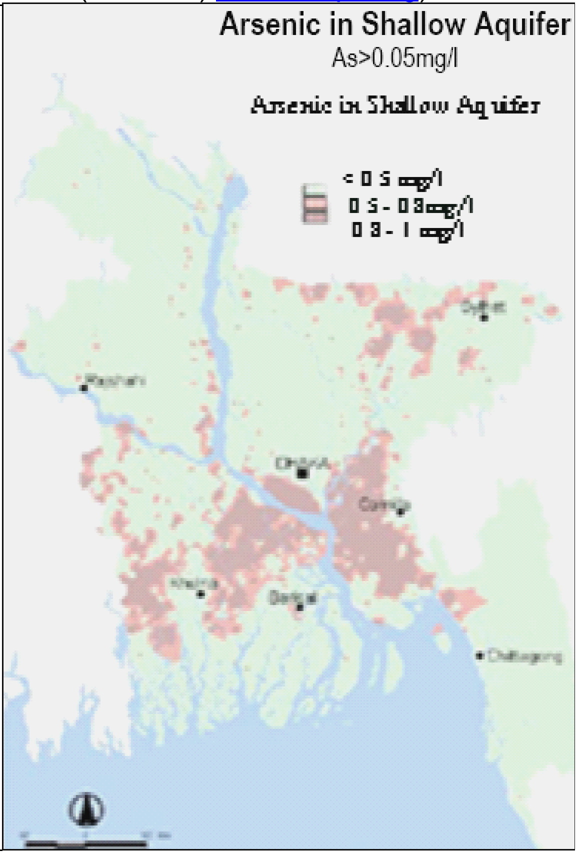
11.1.2 Water resource data

Information on the water resources of Bangladesh were extracted from three sources:
M. Asad uz Zaman, 2004. Databank: Groundwater and surface water resources, Bangladesh. Barind Multipurpose Development Authority, Ministry of Agriculture. 121pp.
Bangladesh Country Almanac BCA v3.0. www.cimmytbd.org/bca
Extracts from the National Water Resource Database. Water Resources Planning Organisation (WARPO) www.warpo.org

Being essentially a river delta, Bangladesh has extensive networks of major and minor rivers which cross the country north to south (Map 1). Added to these river systems, there is an extensive network of man-made canals, dams and ponds which store surface water from flooding during the wet season and thus make water available for use during the dry season. Arsenic contamination of groundwater is a major concern in Bangladesh but is less so within the study region of southern Bangladesh (Map 2).

Map 1: The main water bodies of Bangladesh (Bangladesh Country Almanac BCA v3.0. www.cimmytbd.org/bca).
Map 2: Areas with arsenic in shallow aquifers in Bangladesh (National Water Resource Database. Water Resources Planning Organisation (WARPO) www.warpo.org)





Tables 1-4 provide information on the status of irrigation water resources for southern Bangladesh compared to the traditional rice-wheat region of Jessore as at 1994-95 (Zaman, 2004). While the cultivated areas in southern Bangladesh are large their *rabi* season utilisation through irrigations is much lower than the traditional rice-wheat regions. Where *rabi* season crops are grown, irrigation is largely sourced from surface water, although there are prospects for area expansion by increasing access to groundwater resources.

Data from the WARPO databases are presented in Figure 1 and Table 5. The rapid linear expansion in the areas irrigated in the Jessore, Barisal and Noakhali districts between 1990-2000 are illustrated in Figure 1. The significant difference between sites is that the rate of expansion at Jessore has been much greater and is driven exclusively by access to groundwater through tube wells. Importantly in terms of this study, the two southern sites also shown linear expansion in irrigated areas but sourced almost exclusively from surface or near-surface water.

Table 1: Thanawise district statistics, 1994-95

	Thana	**Population (mil)**	**Area (M ha)**	**Cultivable area (M ha)**	**Irrigated area (M ha)**	**Irrigation %**
Bangladesh	466	106.3	14.76	9.33	3.40	36
Jessore	8	2.11	0.26	0.19	0.120	63.9
Barisal	10	2.21	0.28	0.16	0.036	22.7
Bhola	7	1.48	0.34	0.16	0.016	10.5
Noakhali	6	2.22	0.36	0.19	0.032	17.4

Table 2: Modes of irrigation, 1994-95

	Groundwater (ha)			**Surface water (ha)**	**Total (ha)**
	Shallow tube well	Deep tube well	Total (includes other methods eg. manual)	Total	
Jessore	91,611	26,314	116,812	3,658	12,0470
Barisal	42	10	4,374	32,244	35,618
Bhola	354	0	354	15,993	16,347
Noakhali	3,344	2,335	6,923	25,473	32,396

Table 3: Groundwater potential, 1994-95

	Available recharge (MCM1)	**Water duty ha/MCM**	**Max irrigable area with groundwater only (ha)**	**Max achieveable % of irrigation with available recharge (%)**
Jessore	540.5	1163	78,534	41.6
Barisal	248.6	1510	73,983	45.9
Bhola	0	1351	0	0
Noakhali	217.9	1108	39,754	21.4

[1] million cubic meters

Table 4: Annual rainfall and groundwater level fluctuations (actual & predicted), 1994-95

	Annual rainfall (mm)	**Nearest to GL water level (m) 1991**	**Deepest static water level (m)**				
			Measured		Predicted		
			1991	1995	2000	2010	Full use of GW
Jessore	1714	3.19	5.66	6.80	7.53	8.41	9.05
Barisal	2551						
Bhola	2551						
Noakhali	3198	1.00	2.65	3.25	4.00	5.75	6.90

Data in Table 5 add significant information to the question of whether water resources are available for irrigation in the prospective new regions. These data indicate that, as opposed to the deep water table at Jessore, readily accessible water are available close to the soil surface throughout the *rabi* season at both Barisal and Noakhali. WARPO predictions assess such water availability as being at least greater than 400mm of useable recharge per season.

Figure 1: Changes in area in (a) Jessore district (8 Thana, total cultivated area 192,021 ha), (b) Barisal district (10 Thana, 155,334 ha) and (c) Noakhali district (5 of 6 Thana, 90,747ha) irrigated by tube well or lift pump (includes manual & traditional extraction).

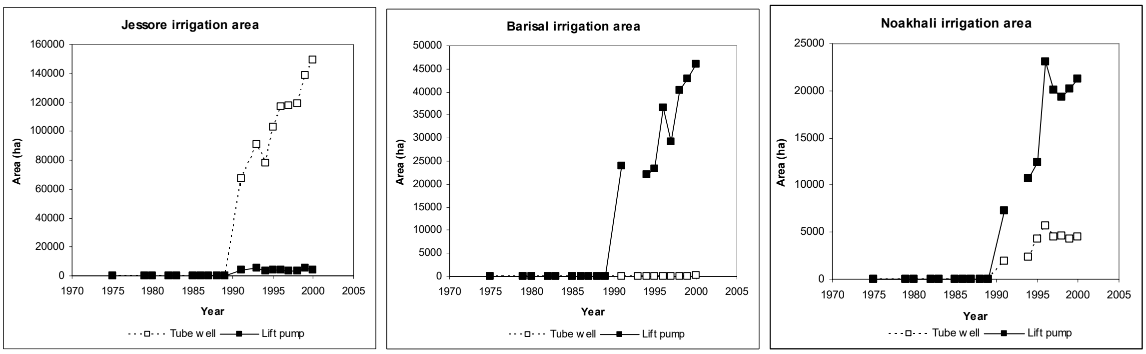


Table 5: Groundwater resources (WARPO data)

	Thana	Area	Depth to water table		Useable recharge		
			prior to irrigation	end of dry season	Low estimate	Medium estimate	High estimate
		ha	m	m	mm	mm	mm
Jessore	4	1248	1.70	2.48	188	235	282
Barisal	10	2569	0.18	0.62	426	533	639
Noakhali	4	892	0	0.75	675	844	1013

11.1.3 Conclusions on water resources

The data collated to date on water resources in southern Bangladesh indicate both that surface or near-surface water are in ready supply and that the irrigated area is expanding linearly. A key assumption is that such useable water can be sourced by farmers using available low cost technology, in the form of lift pumps drawing water from canals, dams, ponds or depressions close to their farm plots. The farmer survey, although restricted in scope and numbers, indicates that current availability is limited and further investment may be required in digging new storages plus in the maintenance of existing waterways. More effort is required to ascertain the feasibility and likelihood of such investment being allocated by governments.

In terms of this scoping study, and any follow-on work, the question mark over the availability of irrigation water resources necessitates that a key research issue will be crop growth and production under conditions of no or limited water supplies.

11.2 Plant available water capacity and soil chemistry

Characterisation of soils for Plant Available Water Capacity (PAWC) and chemistry was undertaken at five on-farm research sites and one research station in southern Bangladesh. Soil characterisation was necessary to enable simulation of the wheat systems using the APSIM model.

11.2.1 Soil characterisation and monitoring process

To characterise a soil for PAWC it is necessary to measure or estimate volumetric water content, at particular points on the water characteristic curve relating to saturation (SAT), drained upper limit (DUL) and crop lower limit (CLL). The DUL is measured after the profile has been saturated and allowed to drain to equilibrium. A CLL is measured after a particular crop has reached maturity or suffered terminal water stress under dry finishing conditions (or under an exclusion tent). However, due to the wet soil conditions at the commencement of the wheat growing season (November 2005) and the homogeneity of soils within each of the research locations, it was considered appropriate to use data collected as part of pre-season soil monitoring (from 12 farmers' fields at each location) to determine DUL. A similar rationale was used for the determination of CLL using data collected from the farmers' dryland treatment fields at crop maturity.

Prior to wheat sowing each field in the 5 villages was sampled using a 37 mm diameter driven coring tube to a depth of 1.5m in increments of 0-15, 15-30, 30-60, 60-90 and 90-150cm. Three cores were taken within each ~33 decimal (~1200m^2) field, bulked by layer, mixed and split into two samples for the estimation of water and nutrient content. Soil water samples were weighed immediately after sampling, dried at 100ºC for at least 48 hours and re-weighed to estimate water content.

Soil nutrient samples were air dried and analysed in the Joydebpur BARI laboratories for nitrate nitrogen (NO_3-N), organic carbon (OC), electrical conductivity (EC), sodium and pH. Due to the small plot size used in the Joydebpur BARI experiment, three sets of two cores were considered adequate to describe water and nutrient conditions at sowing. Figure 1 and Table 1 present the chemical data for each site. These data were used to both estimate DUL and determine starting soil water and nitrate nitrogen conditions. Other chemical data were used as direct input to the model (OC and pH) or to inform researchers on potential sub-soil constraint issues (EC and Na).

Figure 1: Soil chemistry for trial sites

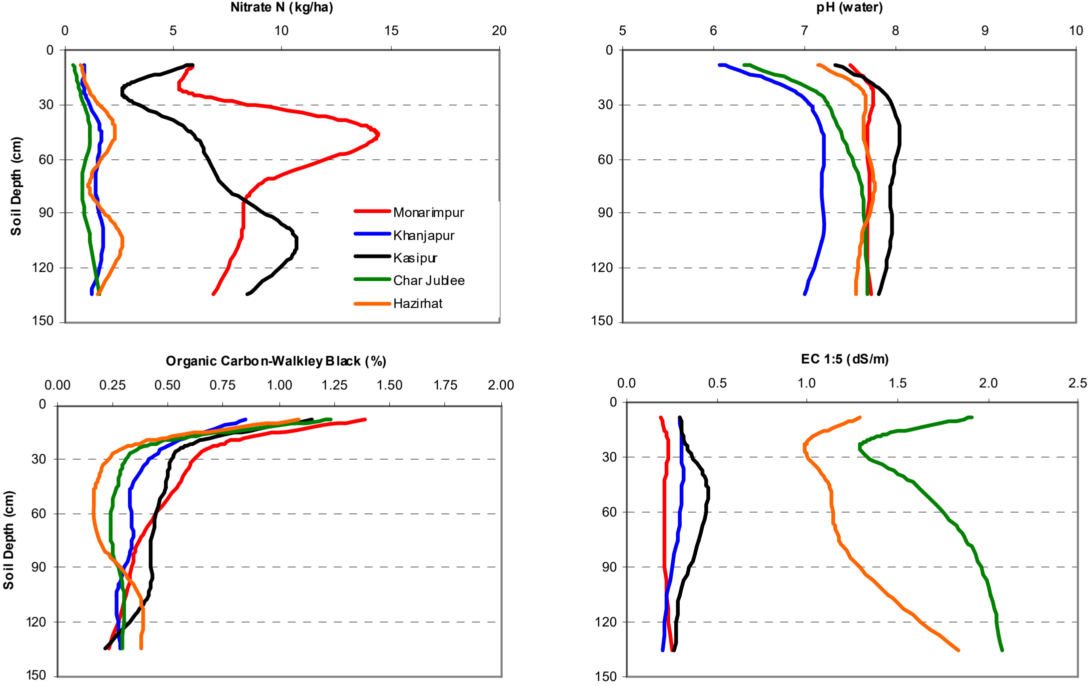


Table 1: Soil chemistry data for trial sites

Location	Depth (cm)	pH	OM (%)	Na (meq/100gl)	Ec (ms/cm)	NO3-N Layer (mg/kg)	NO3-N Layer (kg/ha)	NO3-N Profile (kg/ha)
Monirampur	0-15	7.50	1.39	0.41	0.20	2.77	5.9	49
	15-30	7.76	0.71	0.42	0.23	2.57	5.5	
	30-60	7.70	0.54	0.45	0.21	3.37	14.4	
	60-90	7.72	0.37	0.42	0.21	2.09	8.8	
	90-120	7.77	0.55	0.41	0.23	2.03	8.5	
	120-150	7.74	0.37	0.42	0.26	1.50	6.2	
Kashipur	0-15	7.35	1.15	0.48	0.30	2.97	5.9	41
	15-30	7.87	0.58	0.59	0.33	1.30	2.6	
	30-60	8.05	0.49	0.64	0.45	1.45	5.8	
	60-90	7.96	0.42	0.57	0.40	1.83	7.4	
	90-120	7.96	0.41	0.52	0.30	2.68	10.7	
	120-150	7.82	0.22	0.52	0.27	2.12	8.4	
Khanjapur	0-15	6.08	0.85	0.40	0.30	0.45	0.9	8
	15-30	6.90	0.50	0.39	0.31	0.45	0.9	
	30-60	7.20	0.34	0.40	0.31	0.40	1.6	
	60-90	7.20	0.34	0.39	0.28	0.35	1.4	
	90-120	7.20	0.27	0.41	0.23	0.45	1.8	
	120-150	7.00	0.29	0.39	0.21	0.30	1.2	
Char Jublee	0-15	6.35	1.24	0.97	1.91	0.20	0.4	6
	15-30	7.13	0.39	0.92	1.30	0.35	0.7	
	30-60	7.40	0.27	0.94	1.60	0.30	1.2	
	60-90	7.63	0.25	1.02	1.88	0.20	0.8	
	90-120	7.68	0.30	1.20	2.02	0.30	1.2	
	120-150	7.70	0.29	1.21	2.07	0.40	1.6	
Hazir Hat	0-15	7.15	1.09	0.83	1.29	0.40	0.8	10
	15-30	7.65	0.32	0.79	0.99	0.60	1.1	
	30-60	7.65	0.17	0.76	1.12	0.60	2.3	
	60-90	7.78	0.20	0.81	1.18	0.30	1.1	
	90-120	7.63	0.37	0.95	1.45	0.70	2.6	
	120-150	7.57	0.38	1.07	1.83	0.40	1.5	

11.2.2 Soil Texture

All sites were high in silt with the exception of Monirampur which had a clay content of ~50% (Table 2). It should be noted that these estimates are sourced from the FAO report referred to below and not to field texturing or other assessment. Consequently they refer to regional soil types and not site specific locations.

Table 2: Soil texture for regional soil types as sourced from www.fao.org/ag/agl/swlwpnr/reports/y_sa/z_bd/bdmp231.htm

District	Field Site	General Soil Types	Texture Sand:Silt:Clay
Jessore	Monirampur	Calcareous Dark Grey Floodplain soil	1:51:48
Barisal	Khanjapur	Non-Calcareous Dark Grey Floodplain	0:90:10
	Kashipur	Non-Calcareous Dark Grey Floodplain	0:90:10
Noakhali	Char Jublee	Calcareous Alluvium	0:98:2
	Hazirhat	Calcareous Alluvium	0:98:2
Joydebpur	BARI Station	Non-Calcareous Dark Grey Floodplain	6:79:15

11.2.3 Bulk Density

Bulk density (BD) was measured at two sites per location with two reps taken at each site to a depth of 60 cm (using the same depth layers as above). Driven rings with a volume of 45cc (2.5 cm high x 4.8 cm diameter) were hammered into the soil, extracted, trimmed and the soil dried at 100^0C and weighed. The BD was estimated for depths below 60 cm, with the exception of Khanjapur where measurement was possible to a depth of 120cm (Table 3).

11.2.4 Plant Available Water Capacity

As all soils contained high proportions of silt it could be expected that PAWC values would be similar, provided no sub-soil constraints were present. As indicated in Table 1 and Figure 1, EC values were high at CharJublee and Hazirhat. Values of greater than 1.0 dS/m were recorded at all depths with some individual layers being greater than 2 dS/m. It should be expected that such levels would severely affect plant growth, although the confounding issues associated with herbicide application may also have impacted on crop water extraction. Consequently it is recommended that CLL be again measured in the 2006/07 season. It should be noted that these two soils are currently being shown with PAWC values similar to the other soils; this may change considerably after further measurement (Table 3).

Figure 2 provides an example of a typical water profile. The Monirampur soil has a PAWC of 167 mm to 150 cm, although the open ended graph, where DUL and CLL do not converge and meet in the 120-150 cm layer, indicates that there may have been extraction below this depth. At crop sowing, the soil sampling indicated that the profile was at full capacity for water storage. In fact the soil was saturated in the top soil layer and above DUL below 60cm depth. This was typical of many of the soils tested, a result of the short period of time between the end of the wet season and crop sowing. Measurement at anthesis (T2-1 Ant) shows that the wheat crop has extracted water to a depth of 60-90 cm with the deeper water still at DUL. By crop maturity (T2-1 Post) water had been extracted to a depth of 150 cm and in some treatments at this site had extracted to what is now considered to be the crop lower limit.

Figure 2: Soil characterisation parameters for the soil at the Monirampur site.

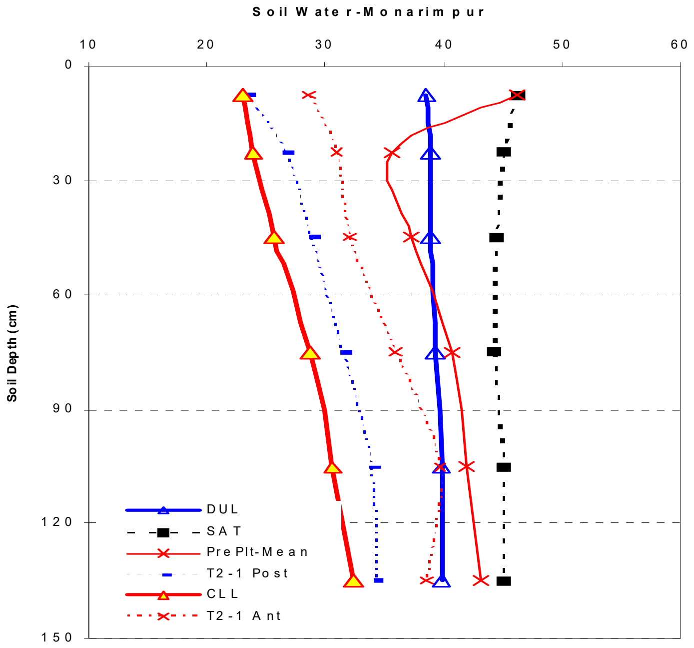


Table 3: Key soil parameters collected for the field trial sites

Location	Layer (cm)	BD (g/cc)	Estimated DUL	Estimated SAT	stimatedCL CLL (wheat	PAWC (mm)	PAWC (mm)
Monarimpur	0-15	1.43	38.5	46.1	23.0	23.3	167
Monarimpur	15-30	1.42	38.8	45.0	23.9	22.3	
Monarimpur	30-60	1.42	38.8	44.5	25.6	39.6	
Monarimpur	60-90	1.41	39.3	44.3	28.7	31.7	
Monarimpur	90-120	1.40	39.7	45.0	30.6	27.4	
Monarimpur	120-150	1.39	39.8	45.0	32.2	22.8	
Khanjapur	0-15	1.35	41.1	46.1	20.5	30.9	167
Khanjapur	15-30	1.37	40.1	45.1	20.5	29.5	
Khanjapur	30-60	1.37	40.1	45.1	24.6	46.4	
Khanjapur	60-90	1.35	41.2	46.2	28.1	39.2	
Khanjapur	90-120	1.35	41.1	46.1	34.9	18.7	
Khanjapur	120-150	1.35	41.1	46.1	40.4	1.9	
Kasipur	0-15	1.32	42.22	47.2	22.4	29.7	169
Kasipur	15-30	1.34	41.49	46.5	23	27.7	
Kasipur	30-60	1.34	41.49	46.5	25.5	48.0	
Kasipur	60-90	1.34	41.49	46.5	30.2	33.9	
Kasipur	90-120	1.33	41.83	46.8	35	20.5	
Kasipur	120-150	1.33	41.83	46.8	38.6	9.7	
Char Jublee	0-15	1.32	42.3	47.3	24.4	26.9	170
Char Jublee	15-30	1.34	41.3	46.3	24.9	24.6	
Char Jublee	30-60	1.33	42.0	47.0	26.5	46.4	
Char Jublee	60-90	1.33	41.8	46.8	29.9	35.6	
Char Jublee	90-120	1.33	41.9	46.9	33.2	26.2	
Char Jublee	120-150	1.32	42.2	47.2	38.7	10.5	
Hazirhat	0-15	1.26	44.27	49.27	26	27.4	154
Hazirhat	15-30	1.26	44.27	49.27	26.8	26.2	
Hazirhat	30-60	1.30	42.92	47.92	30	38.8	
Hazirhat	60-90	1.25	44.92	49.92	34.1	32.5	
Hazirhat	90-120	1.26	44.30	49.30	38	18.9	
Hazirhat	120-150	1.25	44.92	49.92	41.5	10.3	
Joydebpur-BARI	0-15	1.47	36.7	41.7	21.6	22.6	172
Joydebpur-BARI	15-30	1.55	33.7	38.7	21.6	18.1	
Joydebpur-BARI	30-60	1.45	37.2	42.2	22.4	44.3	
Joydebpur-BARI	60-90	1.38	40.0	45.0	28	36.0	
Joydebpur-BARI	90-120	1.37	40.2	45.2	31.1	27.2	
Joydebpur-BARI	120-150	1.37	40.2	45.2	32.2	23.9	

11.3 Weather parameters 2005-06

11.3.1 Temperature

All locations in the 2005-6 season had higher temperatures than in the previous three seasons. Figure 1 shows the situation at Joydebpur. This is a cropping area surrounded by a township. Here, the average of max-min temperature of 25.1°C was 3.5°C hotter than the average for the previous 3 years (3.6°, 3.4° and 3.4°C), considering only the 40 day period from end January. This includes the booting stage through anthesis to mid-grain filling. The temperature rise equates to an increased day degree summation of 138°Cd for that period. In other words, development was accelerated by equivalent to 5.5 days so the crop essentially lost 5.5 days of sunlight and photosynthesis (138/25=15% loss in carbon gain). In the Barisal and Jessore cropping regions, this season was 2.5° and 2.8°C hotter during this same grain determination and filling phase.

Considering long-term mean max-min temperatures from 1949 to the present for the critical February period, the average mean for these years was 21.7°C for Barisal, 21.4°C for Jessore and 21.7° for Noakhali, all similar values. For 2006 they were respectively 26.2°, 24.8° and 22.9°C. These were the hottest February months on record for Barisal and Jessore and fifth hottest for Noakhali (1954 and 99 were hottest). The pattern for Jessore is shown in Figure 2 as an example. January temperature was close to the long-term mean. Year to year values are very variable.

Figure 1: Average temperature during the rabi season at Joydebpur.

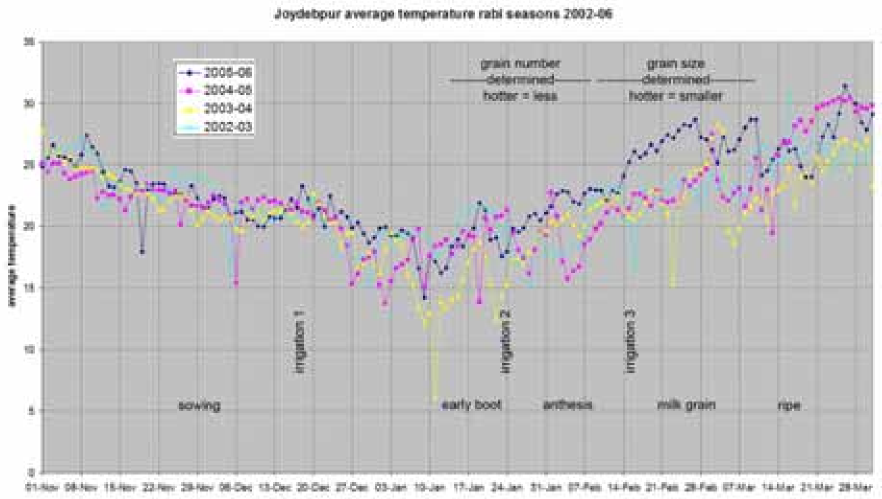
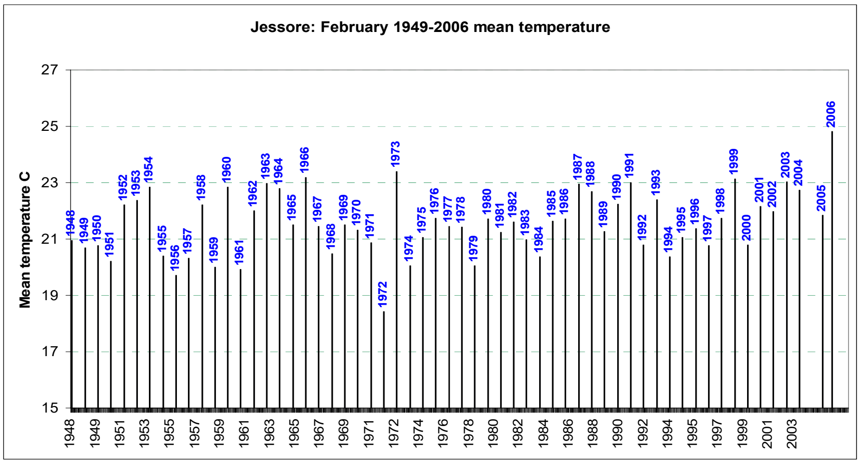


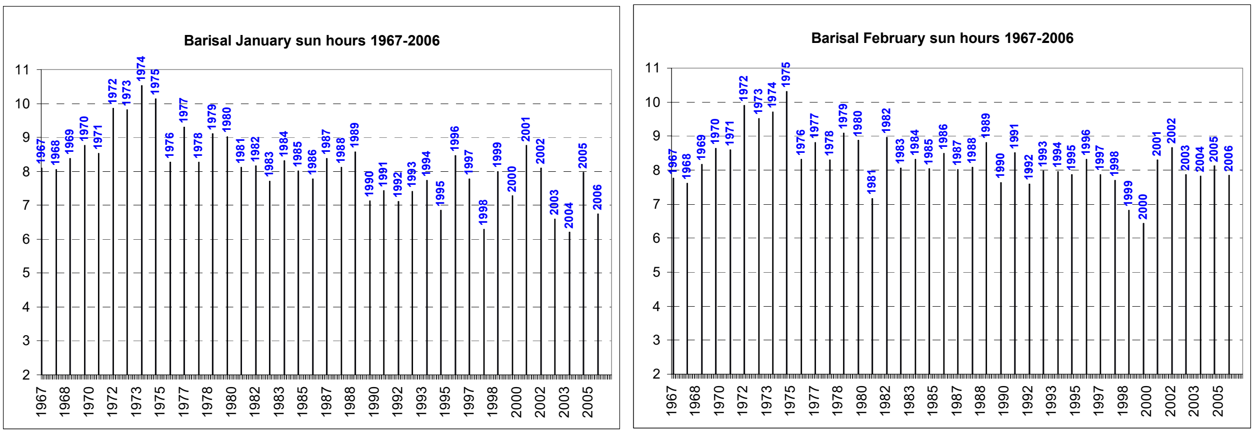
Figure 2: Average temperatures for February at Jessore.



11.3.2 Radiation

Radiation during the critical period, from late January through February, was also less this season compared with long-term means and recent seasons. This is the period from late boot stage to mid grain filling when grain numbers per unit crop area and grain size potential are dependent on high carbon gain. Data for Barisal for January and February are shown in Figure 3 as an example. The data also underscore the long-term downward trend in sunshine hours, presumably caused through increasing industrialisation and pollution throughout the Indian subcontinent, having a negative impact on potential crop production through reducing photosynthesis.

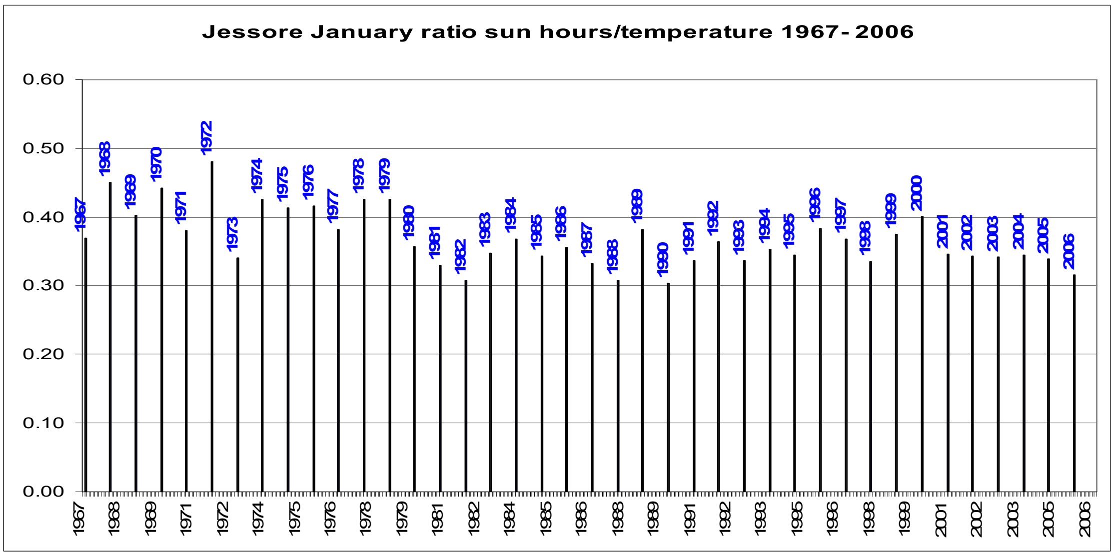
Figure 3: Average sunshine hours for January and February at Barisal.



11.3.3 Radiation and temperature together

If temperature rises and that rise is because of increased radiation, crop growth is relatively unaffected by that temperature rise, as long as water is not limiting. The worst situation for crop yield is if temperature rises and radiation reduces as happened in the 2005-6 season. The ratio of sunshine hours to mean temperature for Jessore in January is shown in Figure 4.

Figure 4: Ratio of sunshine hours / temperature for January at Jessore.



11.3.4 Pan evaporation

Another environmental factor that can affect crop fertility is pan evaporation. If pan evaporation is low (less than 3 mm) for several days covering pollen meiosis (flag leaf ligule emergence to heading), pollen can be sterile and grain numbers reduced. If low pan evaporation is accompanied by low radiation and high temperatures, the effects can be dramatic at sites that have low boron soils. Boron moves in the transpiration stream and once incorporated into cell material can not be re-translocated (except minimally in some varieties). It is essential for pollen development. Poor transpiration whether due to stomatal closure or low pan evaporation means low boron flux and sterility.

In late January to early February 2005-6, pan evaporation was low (data not shown) and could have contributed to the poor grain numbers at some sites. External farms that were sampled at Monirampur had extremely low harvest index of 12-17% from biomass production of over 20 t/ha. High biomass may have depleted soil boron as well as leading to soil water depletion and stomatal closure during pollen meiosis.

11.3.5 Rainfall

There was no effective rainfall this season.