Expl Agric. (2007), volume 43, pp. 21–40 © *2006 Cambridge University Press*
doi:10.1017/S0014479706004224 *Printed in the United Kingdom*

ON-FARM WHEAT TRIALS IN BANGLADESH: A STUDY TO REDUCE PERCEIVED CONSTRAINTS TO YIELD IN TRADITIONAL WHEAT AREAS AND SOUTHERN LANDS THAT REMAIN FALLOW DURING THE DRY SEASON

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(*Accepted 12 June 2006*)

SUMMARY

This research set out to find ways to increase wheat production in Bangladesh. The approaches were (1) to increase the area planted to wheat, concentrating on developing a suitable management system for the very hot, often saline and hitherto largely untested fallow lands of the south; and (2) to increase economic and sustainable yield of wheat in the traditional rice-wheat zones. Five mechanized reduced tillage and planting systems were compared. They were used to enable 200 co-operating farmers at 11 locations to plant on time and avoid the reduction in yield that accompanies delays, found in this study to average 2 % d^{-1}. Methods that placed seeds in rows were zero tillage, full or strip surface shallow till, and raised beds. A partially mechanized version of the traditional manual system called New Conventional, in which seeds and fertilizers were broadcast, was also tested. Farmers' wheat yields averaged more than 3.5 t ha^{-1} for the two seasons of the study. Farmers in the untested lands averaged more than 2.5 t ha^{-1} on their farms, well above the 0.5 t ha^{-1} needed to cover all costs and equal to normal production levels in traditional wheat areas. Surprisingly, full and strip till did not produce higher yields overall than New Conventional in either season. Reasons for the lack of difference are discussed in relation to other aspects of management and variation between the farmers themselves. Farmers had varying opinions and mixed success with zero till and beds. The economic consequences to farmers of using the different systems are also discussed with the suggestion that the low-tech New Conventional method will be preferable for novice wheat farmers in the historically fallow lands where the study indicated potential production is 1 million tonnes.

INTRODUCTION

This study began with a request from the Bangladesh Government to the Food and Agriculture Organization of the United Nations (FAO) for assistance to find some way to increase wheat production in the country through applied research. Consumption in Bangladesh was around 4 million t increasing at 3 % per annum whereas production

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was only 1.5 million t and decreasing. The situation was creating serious concerns for food security and diminishing foreign currency reserves.

There are two standard approaches to increasing production: first to look for unused or under-utilized land that might be adapted to wheat cultivation and second to explore ways to increase yield per unit area in current wheat cropping areas. In the second approach yield is increased by reducing perceived environmental and genetic limitations.

The paper presents the research activities designed to address the two approaches and meet the original request for assistance. At the outset basic requirements had to be fulfilled. Local crops researchers, agricultural extension workers and farmers had to commit to the project and be actively involved throughout. This would ensure that the project would build on best regional and local agricultural knowledge and avoid naïve suggestions that might have been tested previously and failed, or might otherwise be inappropriate. Researchers from the Wheat Research Centre (WRC) of the Bangladesh Agricultural Research Institute (BARI) in association with the Department of Agricultural Extension (DAE), together with individuals of CIMMYT Bangladesh provided this network of expertise. Agricultural experts from other countries acted as consultants.

Of interest to the study was land in southern Bangladesh that normally remains fallow during the dry season, so is potentially available to wheat. Constraints of high temperatures, salinity and available season length of less than 100 days had been commonly thought to preclude economic returns for wheat in that region. Further, water for irrigation is very limited thus making alternative crops like dry-season rice impractical. Could wheat be grown by working around the constraints in some way? Fallow land is estimated at more than 400 000 ha in southern Bangladesh. This land grows rice during the several months of the wet season during which time it remains largely submerged by monsoon waters.

The primary requirement was to identify the main constraints to high yield in both the southern and traditional wheat lands, and then to ask farmers to test a range of methods on their farms to minimize those constraints. CIMMYT Bangladesh and WRC researchers had already concluded from many field trials in the traditional wheat growing areas of Bangladesh that the success of a rice-wheat rotation depended on meeting the optimum planting and harvesting dates for both the rice and the wheat (rice was usually transplanted aman, T. aman, grown during the wet season). The optimum planting date for wheat in the region had been estimated as the end of November (Ortiz-Monasterio *et al.*, 1994). Despite this knowledge, wheat was commonly planted too late, so constraining vegetative growth and pushing the grain-filling phase into the very high temperatures of late March; because of the consequent short season and rapid maturity of the crop, yields were low and uneconomic. Sometimes wheat could not be planted at the optimum time of late November because the T. aman rice had still not been harvested. In the south this could be because the wet-season monsoon waters had not yet drained away. Even if the harvest was complete, preparation of the land for sowing the wheat could take up to three weeks using bullock-drawn implements. The researchers had demonstrated that the turn-around between T. aman harvest and wheat sowing could be brought back to one or two days by cultivating, sowing and in some cases fertilizing in one pass using light tillage or zero-till machinery powered by a Chinese two-wheel tractor (Hobbs and Gupta, 2004). Where traditional varieties of T. aman were late, using slightly shorter-duration T. aman varieties in combination with these tillage-sowing practices meant wheat could become a profitable component of a profitable system.

It seemed the researchers had solved the problems, but their logical recommendations were being adopted very slowly by farmers. Indeed wheat was declining in area. Resistance to uptake was due to many factors. First, in the traditional wheat-growing areas, wheat was losing the competition for land with the dry-season rice crop (boro rice). This was increasing in popularity with the rapid spread of irrigation water availability from shallow tube wells sunk mainly in the past decade. Boro rice is a profitable crop though the inputs required are large (20 to 40 irrigations depending on soil type and significant fertilizer inputs). Many rice farmers are comfortable with continuous rice and that system is being questioned only in areas where heavy use of water is creating health and environmental problems, particularly those associated with arsenic poisoning (see Huq and Naidu, 2003). Second, there was a stigma attached to wheat. Wheat was regarded as a poor crop requiring limited inputs and attention. Conceptually, it could not produce the economic returns of rice and certainly not the farmer satisfaction of a good rice crop. Third, wheat was progressively declining in yield because of the increasing susceptibility to leaf diseases of Kanchan, the standard variety for two decades (Malaker *et al.*, 2004).

Clearly, the FAO-assistance study would have to include ways to ensure planting on time, preferably using an inexpensive single-pass reduced tillage and planting method, a disease-resistant variety and adoption of best practice agronomy using water and fertilizer inputs at optimum times determined by crop stage. For acceptance, the system(s) would have to work without complications in the hands of farmers and the crop should produce at least the same profit for less effort than alternative crops like boro rice. Thus, the study required farmers to have a leading role in the research if a viable system was to be found and the wheat stigma erased.

There were five cultivation and seeding methods tested at all sites. All were reduced tillage systems but varied in cost and approach. They were chosen based on the success of trials in the region and on the likely availability of the machinery within Bangladesh. Uptake of any system would depend on cost, availability of the machine and spares, yield produced and what farmers thought of them.

The project asked the questions: Which cultivation and planting method would provide the highest yield if associated with good general agronomy? Would that method be superior in all areas of Bangladesh and in the hands of all farmers? Would the ranking for methods remain the same over the two seasons of the project? Would the actual yields achieved by the best method be greater than observed in previous on-farm surveys? Finally, and importantly, would the fallow lands of the south be a potentially new bread basket for Bangladesh using these methods to minimize perceived constraints?

Timsina and Connor (2001) using several published sources, estimated wheat yields in the traditional rice-wheat growing areas of Bangladesh to be 2.2 t ha^{-1}, although

Table 1. Locations of co-operating 15-farmer groups in Bangladesh. A location number is shown on the maps. Numbers 10, 11 and 12 are within areas where wheat had not been grown before. Other numbers are within traditional wheat growing areas.

North (Dinajpur)			North centre (Jamalpur)		North west (Rajshahi)	
(1)	(2)	(3)	(4)	(5)	(6)	(7)
Thakurgaon 26.03°N 88.40°E	Bhognagar 25.91°N 88.59°E	Rajuria	Melandah 24.98°N 89.85°E	LakkhirChar 24.88°N 90.02°E	Paba 24.40°N 88.66°E	Eusufpur 24.34°N 88.71°E
West (Jessore)			Southeast (Noakhali)		South (Barisal)	
(8)	(9)		(10)	(11)	(12)	
Jikkorgachha 23.09°N 89.06°E	Monirampur 23.03°N 89.29°E		HazirHat 22.76°N 91.12°E	CharBagga 22.65°N 91.05°E	Kasipur 22.45°N 90.21°E	

farmer surveys indicated 2.6 t ha^{-1}. Their estimate from all research experiments was 2.9 t ha^{-1}; from experiments using high fertiliser inputs, 3.5 t ha^{-1}; and from research trials on farmers' land, 3.1 t ha^{-1}. There were no data for the previously untried and possibly unsuitable fallow lands. The Timsina and Connor study acted as a benchmark for yields for the current project.

MATERIALS AND METHODS

Sites and growing conditions in Bangladesh

The trials reported here were run in the 2003/4 and 2004/5 rabi (dry) seasons. The farmer blocks, each of 15 more or less adjoining farms, were sited throughout Bangladesh (Table 1 and Figure 1). Wheat had not previously been tested on any scale in the south. The southern blocks of Noakhali (12 m asl), with villages at Char Bagga, Char Jublee and Hazir Hat, were selected for their visually saline soils (Ec at planting between 1.3 and 1.8 ms cm^{-1} in the top 15 cm soil, see Figure 1). Barisal (9 m asl), with a village at Kasipur, was selected for its proximity to a BARI outstation, originally established for coconut research. The Barisal region is not saline (Ec 0.27–0.34 ms cm^{-1}). The soils in all these southern blocks are slightly alkaline (pH 7.1–7.8) with low organic matter (0.4–0.5 %) and NO_3-N (0.3–2.0 μg g^{-1}) and had plant available soil water content at the beginning of each season of between 140 and 200 mm (N. Dalgliesh, personal communication). All are within the region identified as less than 20 % suitable for wheat in the Bangladesh Country Almanac available from CIMMYT (www.cimmytbd.org/bca). Wheat has been grown for many years at all other locations, but at one of the supposed traditional wheat-growing sites, Lakkhir Char in Jamalpur, farmers were new to the crop. This was a sandy block, essentially an island in a river that dried up in the dry season.

Temperatures were measured in the second season at most sites using Hobo Temp and Hobo U12 Temp/RH loggers located in mini Stevenson Screens and these data were complemented by long term data from the nearest Bangladesh Meteorological

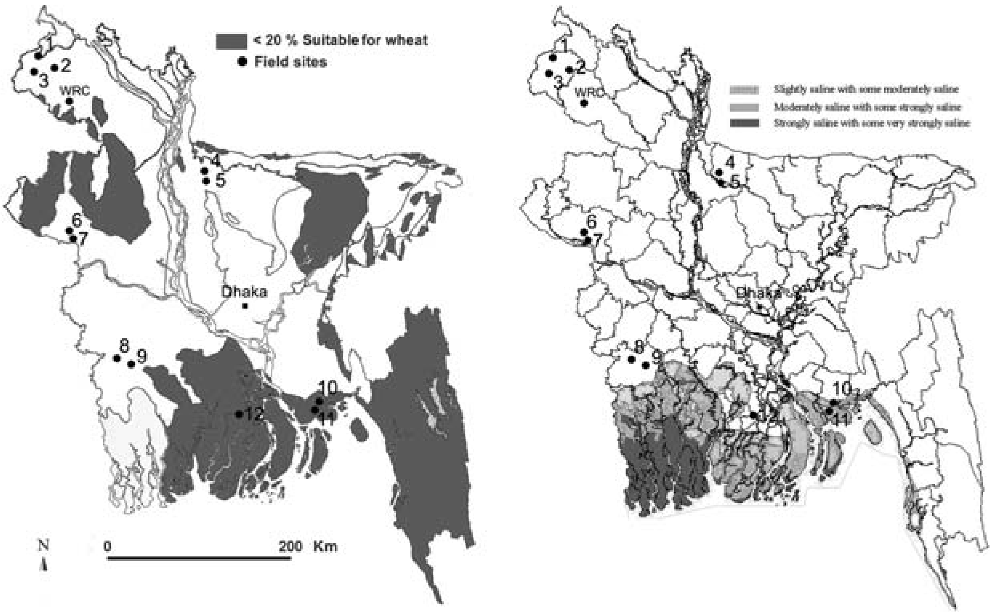

Figure 1. The filled-in areas on the left-hand Bangladesh map are identified as less than 20 % suitable for wheat in the CIMMYT Bangladesh Country Almanac v 3.0. The right-hand map, also from the Almanac, shows areas of salinity in Bangladesh; the more heavily shaded areas indicate higher levels of salt. Location 12 (Barisal) is salt-free whereas 10 and 11 (Noakhali) are within a salt-affected zone. WRC is the Wheat Research Centre of BARI (Bangladesh Agricultural Research Institute).

Department sites. Only rabi (dry) season data of Dinajpur (north) and Noakhali (south) are shown (Figure 2) as these locations represent the temperature range for all sites. The south was about 3 °C hotter than the north and remained so throughout the season. For the whole rabi season, average maximum and mean temperatures were 26.5 and 20 °C for the north and 30.5 and 23 °C for the south. Comparisons of official meteorological data for the two seasons showed that 2004/05 was hotter than 2003/04. The northern site averaged 19.8 and 18.4 °C, while in the south values were 23.4 and 22.2 °C. For the critical month of February when anthesis and early grain growth occurs (Figure 2), mean temperatures for 2004/5 and 2003/4 respectively were 19.8 and 18.4 °C (north) and 24.3 and 22.2 °C (south). To put these temperatures into an historical context, February average temperatures for 2003–2005 seasons were exceeded only 14 times in the past 57 years. Minimum temperatures did not fall below 6 °C at any stage or location during the study.

Sunshine hours were low in both seasons in January, the month leading up to heading, particularly compared with immediately preceding seasons (Figure 3). This may be part of a general downward trend reflecting increasing industrialization in the Indian subcontinent and associated atmospheric pollution.

Organizational structure and farmer support

The project was directed from WRC in the far north of the country (Figure 1, Nashipur in the Dinajpur region). A core team of researchers was established at WRC

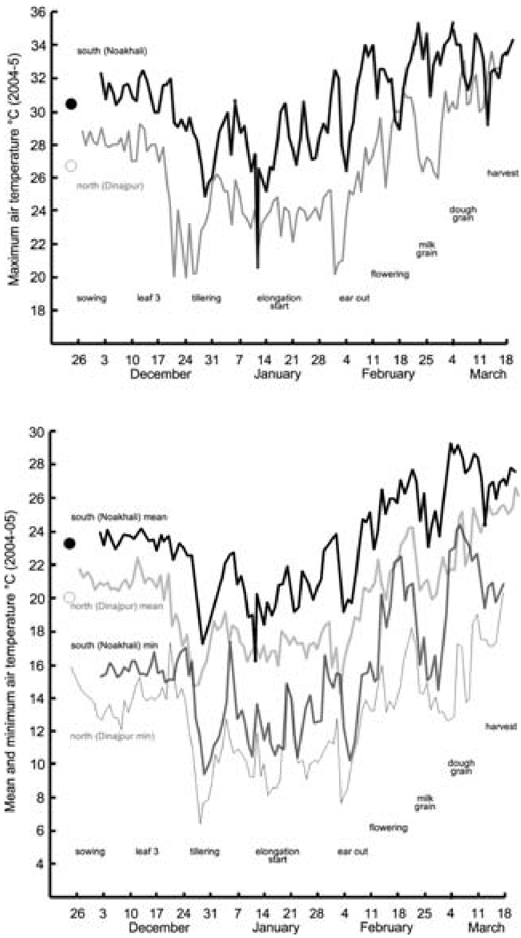

Figure 2. Maximum (top figure), minimum and mean of maximum and minimum temperatures (lower figure), averaged over each week, for Dinajpur (north Bangladesh, dark lines) and Noakhali (southeast Bangladesh, pale lines) during the 2004/2005 dry (rabi) season. Average temperatures for the whole season are the large symbols by each vertical axis. Crop developmental stages are from Jessore (8, 9) site.

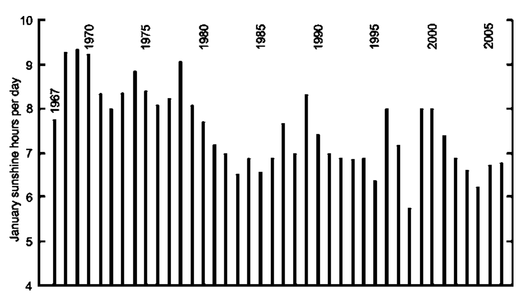

Figure 3. Sunshine hours for January for 1967–2006 in southern Bangladesh. January is when the wheat crop is in the jointing phase leading up to heading (see Figure 2 for crop stages). Data from Bangladesh Meteorological Department.

to co-ordinate and guide regional teams that in turn interacted directly with more than 200 collaborating farmers divided into blocks associated with villages. To ensure that methods practised at the blocks were common, teams from each region were trained together at WRC. These regional teams then returned home and trained their selected groups of farmers, initially with training personnel from the core WRC team being present. A major component of every training session was discussion. Regional teams interacted with their farmers throughout the two seasons of the project and reported back to the core trainers and other site teams through regular workshops at WRC. Farmers became familiar with the core trainers as they also visited every block on a regular basis. They learned that they were part of a country-wide project and that their input and feedback were essential to its success. They were encouraged into the programme by free seed and fertilizers for their trial plots and were interested in producing high yields because the crops were their own to sell. This initial inducement was critical in the new lands as farmers thought the chances of success were small even though they had not grown wheat before or seen it growing.

Field days were held at each site close to crop maturity to give co-operating farmers the chance to demonstrate their crops to colleagues and neighbours and discuss practices. These were family affairs with local dignitaries and attracted around 150 farmers.

The regional teams included at least two WRC researchers, a research assistant and a field assistant. Also included were extension officers from DAE. Teams were responsible for two farmer blocks each made up of 15 farmers and a block supervisor. The responsibility of the assistants was to maintain field sheets of crop development, and management dates and actions for all farms (Rawson and Gomez-Macpherson, 2000) and to alert farmers when critical dates for action were close. They assessed crop components weekly to check whether yield targets were on track. A vital component of the project was to ensure that all participants, researchers, assistants and the farmers, particularly, saw themselves as experimenters, making their contribution to developing new methods for growing successful wheat crops in Bangladesh. CIMMYT Bangladesh members were also very active, providing training in maintenance and use of all machines (one of each machine type was located at each block, donated by the project) and providing backup at sites whenever required.

Tillage, sowing methods and crop management

The five reduced tillage treatments compared at each 15-farmer block were:

- New Conventional: This uses a two-wheel Chinese hand tractor with rotovator, known as a power tiller, for shallow cultivation after rice harvest, followed by manual broadcasting of seed and fertilizer, and a final light surface cultivation with a ladder levelling device to incorporate the seed and fertilizer. The method was developed by farmers, being a mechanized but very rapid variant of their traditional bullock and single-tooth plough system. It reduces the traditional six to 11 passes to less than four and cultivates less deeply.

- Power-tiller-operated seeder (PTOS): This method tills shallowly (3–5 cm) with a power tiller, places the seed and fertilizer at a managed rate in rows 20 cm apart and covers them with soil all in one pass (Hossain *et al.*, 2002).
- Strip tillage: This is similar to PTOS, but tillage is restricted to alongside the 20 cm planted rows by removal of tines from the rotovator (Justice *et al.*, 2004).
- Zero till: This chisels continuous shallow slots in the untilled soil 20 cm apart, places the seed in them and back-fills with soil. This is done in one pass with power from the hand tractor (Hobbs *et al.*, 1997). Herbicides may be required to control weeds. Fertilizer is broadcast.
- Bed former-planter: This generally requires full tillage with the power tiller before raised beds can be formed by pushing a shaper through the loosened soil and simultaneously sowing (Sayre and Hobbs, 2004). Two rows of seeds were planted on each bed. Bed centres were 65 cm apart in the first season, reduced to 60 cm in the second. The number of initial tillage passes required depends on the soil.

Tillage and planting were always completed in one day for the single pass methods, PTOS, Strip and Zero till. Some farmers took two to three days to make beds or up to two days when following the New Conventional method. Most plantings were between late November and 6 December, but there was variation between farmers and sites, with the latest sowings occurring at the southern sites of Noakhali and Barisal, some into late December because of the need to wait for the previous rice crop to be removed and the soil to dry down for cultivation. Variation in planting date was often determined by soil water content. Most field units were approximately 0.15 ha in area. Farms ranged from field size to approximately 1 ha.

All treatments used the same fertilizer levels applied at sowing of 147 kg urea ha^{-1}, 120 kg triple super phosphate, 100 kg muriate of potash, 110 kg gypsum and 1 kg boron ha^{-1} if considered necessary by the regional team (see boron map of Bangladesh, Bodruzzaman *et al.*, 2005). At the three-leaf stage, when the first tillers were appearing, a top-dressing of 73 kg urea ha^{-1} was applied with irrigation. The fertilizer costs ha^{-1} respectively were Tk 882, Tk 1680, Tk 700, Tk 550 and Tk 80. (The exchange rate was approximately Tk 60 per USD in 2005.) The cost of the 100 kg seed spread per hectare was Tk 1400. Total cost of inputs including seed was Tk 7300 ha^{-1}. Note that urea is heavily subsidized by the Bangladesh Government. Since the study, the cost of wheat grain for consumption at the market has risen to Tk 16 kg^{-1} or Tk 16000 t^{-1}, so the farmer needed to harvest more than 0.5 t ha^{-1} to break even with these high inputs.

Boron was not applied at some blocks in the first season. This was an oversight at Rashahi sites where occasional gaping-glume sterility was evident in 2003/4. Boron was applied at all blocks in season two regardless of perceived need. This was important in the current study as the new variety Shatabdi used in all trials is sensitive to low boron, much more so than the old variety Kanchan (Bodruzzaman *et al.*, 2005).

After tillering, two further irrigations were scheduled for awn peep and water grain, but they did not happen at all sites. In the first season the shallow tube wells at Rajshahi were empty for the final irrigation and stored surface water was exhausted at Noakhali farms after the first irrigation. Farmers applied approximately 100 mm water at each irrigation.

Arrangement of treatments within the farmer blocks

Treatments were allocated to farms within each block so as to group them spatially in three replicates. This was so that the farmers could visually compare their treatment with other treatments carried out by their neighbours. This was primarily to stimulate discussion amongst neighbours, which it did. A few farmers were not interested in applying some treatments in the second season as they had already decided which practice was best, so after allocation they exchanged with other farmers. Consequently, the positioning of treatments within replicates was not always the same.

Harvesting procedure to estimate yield and yield components

Three areas each measuring 1 m × 2 m were cut from all farmers' fields to estimate yield at crop maturity. Equivalent cuts were also taken from three neighbouring but non-participating farms at each block; these farmers had used their own practices. All 2 m^2 cuts were made by farmers in the presence of a trainer and the measure was an iron rod bent with right angles to have three sides, each 1 m long. The rod was pushed into the crop and the enclosed 1m^2 crop cut at ground level by sickle. The rod was pushed forward through the cut area for the second cut of 1 m^2. The three cut areas on each farm were selected by eye to be, first, the best for the farm indicating what the tillage technology can achieve on the farm (and avoiding the often subconscious selection of a best area average); second, the average of the farm; and third, another average of the farm. All cuts were made at least 2 m within the farm perimeter and were from different parts of the farm. This approach was considered the minimum to achieve an acceptable estimate of yield for the purposes of the study, and provide an estimate of variation within each farm. For the beds three areas six rows wide by 1 m long were cut. The measurement of width was made from the centre of a ridge, between the two crop rows, to the centre of the ridge, three ridges away. This width varied between 1.9 and 2.1 m. The measurement for each cut was used in the calculation of yield.

From each cut plot bundle, 30 average culms were removed as three grab samples of 10 culms. Weights of the 30 culms and full bundle were measured fresh in the field as soon as they were cut. The ratio of fresh weight of the 30 culms to the whole bundle gave culms m^{-2}. The 30 culms were dried for 24 h in an oven to determine their moisture content. By the initial ratios of fresh weight for the 30 culms and the bundle, whole bundle dry weight could be estimated to give biomass production m^{-2}.

The fresh plot bundles were threshed. The grain was weighed and its moisture content measured by calibrated moisture meter so that all yields could be expressed and compared at 12 % moisture. Weights of 200 grains were used to assess individual grain weight at 12 % moisture. In the calculations of yield and other parameters data for the grab samples were added back to the bundles. Harvest index was estimated using the grain weights of the bundles adjusted to 12 % moisture and the non-grain matter adjusted back to dry weight using the moisture content of the 30 culms. This slightly overestimated harvest index. All components of yield could be estimated using this very simple and rapid procedure. Data were available from 200 farms country-wide (600 samples) within 10 days of harvest and calculated and summarized on prepared computer spread sheets 2–3 days later.

RESULTS

Were yields changed by the methods tested?

Comparing yields of co-operating farmers with those of their neighbours who were using their own methods gives an indication of the effects of the treatments. Only experienced neighbouring wheat farmers from the traditional wheat areas (farmer blocks 1 to 9 in Table 1) were included in comparisons. These farmers represent the group captured by Timsina and Connor (2001) in 'yields from farmer surveys' (2.6 t ha^{-1}). They commonly used half the recommended fertilizer levels applied by co-operating farmers and irrigated when they considered it necessary. Over all treatments and traditional locations the co-operating farmers produced 3.6 (*s.e.* = 0.06) and 3.8 (*s.e.* = 0.05) t ha^{-1} for the two seasons, while their neighbours produced 2.4 (*s.e.* = 0.22) and 2.8 (*s.e.* = 0.21) t ha^{-1} (data not shown). The 2.6 t ha^{-1} average matches yields from farmer surveys (Timsina and Connor, 2001), while 3.7 t ha^{-1} is slightly higher than expected from well-fertilized research trials. Nevertheless, co-operating farmers produced around 50 % more yield than their neighbours in both seasons, so in real terms they increased their normal farm output by 1 t ha^{-1}, worth around Tk12 000 at local markets in 2005 (Tk20 000 in 2006). Co-operating farmers were very pleased with the outcome.

In the fallow lands of the south there were no farmers growing wheat other than the co-operating farmers so comparisons were not possible. However, co-operating farmers averaged 1.9 and 2.8 t ha^{-1} in the respective seasons, demonstrating a significant improvement as they gained experience with the crop despite even higher temperatures. The 2003/4 to 2004/5 season yield increment by novice wheat farmers in the south of 0.9 t ha^{-1} was greater than the 0.2 t ha^{-1} increment achieved by experienced farmers in the traditional wheat lands.

Which cultivation/seeding system performed best?

Over all 11 farmer blocks for the two seasons (21 comparisons), New Conventional generated the best yield six times, PTOS six times, Beds four times, Strip Till three times and Zero Till twice (bold numbers in Table 2). Considering how many times each technology produced the poorest yields, Zero Till was worst ten times, Beds worst nine times, Strip Till and New Conventional once each and PTOS never.

This ranking indicates that PTOS and New Conventional were the most reliable technologies. They worked well in the hands of most farmers. Beds and Zero Till can work well for experts but were problematical for some farmers. It was observed that

Table 2. Yield (g m^{-2}) for each tillage/sowing practice at each 15 farmer block in two seasons. The practice with the highest yield at each block is in bold. The final four columns summarize results from the traditional wheat areas (blocks 1 to 9) and the normally fallow south area (blocks 10 to 12). See Table 1 and Figure 1 for locations of the blocks in Bangladesh.

	Dinajpur (blocks 1, 2, 3; traditional)				Jamalpur (blocks 4, 5; traditional)			
	Thakurgaon	Rajuria	Bhognagar		Melandah		Lakkhir Char	
Region Block	2003/4	2004/5	2003/4	2004/5	2003/4	2004/5	2003/4	2004/5
NConv	305 (31)	379 (22)	**406** (25)	**403** (18)	365 (15)	309 (13)	**370** (18)	**362** (12)
PTOS	323 (35)	410 (15)	367 (21)	388 (17)	**381** (11)	**323** (10)	361 (17)	354 (11)
Strip	284 (39)	**427** (25)	344 (38)	366 (29)	368 (8)	294 (17)	367 (21)	357 (21)
Zero	250 (44)	424 (15)	353 (27)	330 (20)		314 (37)		339 (13)
Bed	**355** (27)	396 (14)	397 (10)	357 (21)	283 (41)	265 (21)	323 (22)	344 (8)

	Rajshahi (blocks 6, 7; traditional)				Jessore (blocks 8, 9; traditional)			
	Paba 1	Paba 2	Eusufpur		Jikkorgaccha		Monirampur	
Region Block	2003/4	2004/5	2003/4	2004/5	2003/4	2004/5	2003/4	2004/5
NConv	362 (11)	505 (17)	351 (15)	422 (18)	397 (15)	258 (9)	396 (13)	403 (12)
PTOS	352 (23)	505 (22)	351 (11)	427 (17)	407 (10)	266 (9)	446 (16)	**437** (14)
Strip	358 (8)	502 (24)	364 (10)	382 (27)	**418** (19)	**303** (14)	438 (23)	429 (11)
Zero	**364** (24)	492 (18)	333 (21)	358 (22)	284 (31)	262 (8)	**451** (13)	406 (23)
Bed	351 (13)	**539** (15)	**371** (17)	**448** (23)	357 (20)	234 (13)	370 (14)	300 (13)

	Noakhali (10, 11) – new south fallow lands – Barisal					Summary			
	HazirHat		Char Bagga	Char Zublee	(12) Kasipur	Traditional		South	
Region Block	2003/4	2004/5	2003/4	2004/5	2004/5	03–04	04–05	03–04	04–05
NConv	**201** (16)	227 (11)	206 (19)	**387** (12)	290 (18)	369	380	204	**301**
PTOS	184 (14)	**238** (13)	**251** (24)	317 (15)	**306** (15)	**374**	**389**	**217**	287
Strip	170 (23)		232 (44)			368	382	201	
Zero	114 (28)	227 (24)	194 (36)	364 (26)	194 (12)	339	366	154	262
Bed	143 (13)	172 (28)	198 (28)	269 (14)	258 (16)	351	360	170	233

NConv: New conventional: PTOS: Power-Tiller-Operated Seeder.
Numbers in parentheses are standard errors of the means.

some Zero Till crops failed because farms were planted too early when the soil was too wet and the slots did not close; others did poorly because of uncontrolled weed infestations. Beds were sometimes poorly formed and collapsed, particularly in light soils or during irrigation. In spite of these problems, some farmers were optimistic about the potential use of Beds and Zero Till (discussed below).

Considering the whole traditional wheat-producing area, there was very little to choose between New Conventional, PTOS and Strip Till with a non-significant range in average yield across the technologies of less than 100 kg ha^{-1} in either season. The range across technologies increased to 300 kg ha^{-1} when Beds and Zero Till were included, but significant differences still only occurred in four of the 16 comparisons. The lack of significance occurred at each farmer block mainly because farmers or

Table 3. The best and worst farms compared for yield (g m^{-2}) for New Conventional (NConv) and PTOS tillage/sowing systems using data from each block over two seasons. Comparisons are how much better best farms are than worst farms in percentage terms.

	Traditional		South lands	
	NConv	PTOS	NConv	PTOS
2003/4				
Best	402 (10)	426 (17)	245 (3)	276 (66)
Worst	330 (14)	332 (14)	145 (6)	167 (25)
% better	23	29	70	63
2004/5				
Best	407 (28)	444 (34)	343 (53)	383 (15)
Worst	349 (26)	334 (18)	263 (47)	237 (18)
% better	17	32	32	63

Numbers in parentheses are standard errors of the means.

farms themselves varied more than the technologies, surprising considering the farms were only 0.15 ha and grouped together.

Best farmers and less successful farmers

We were interested to know what range in performance there might be amongst wheat farmers and whether novice wheat farmers might vary in competence more than experienced operators. At each farmer block we calculated how much better the best farmer performed than the worst farmer in relative terms. This was examined only for farmers using the more consistent technologies, PTOS and New Conventional.

In the first season (2003/4), there were indications that levels of competence amongst experienced wheat farmers in the traditional wheat lands were more similar than amongst new wheat farmers in the south. The yields achieved by best and worst traditional wheat farmers ranged by only 26 %, while the novice wheat farmers of the south ranged by 67 % (Table 3). In the second season of the study (2004/5), the overall range within traditional farmers was unchanged at 25 %, but the southern farmers became more uniformly competent in using the New Conventional technology that depends on manually broadcasting the seed (a fall from a range of 70 % to 32 %). However, they did not become uniformly competent in using PTOS with its mechanical seeding system that requires the operator to keep a close watch on seed delivery. Overall, these data indicate that there will usually be a 25–30 % range in yield amongst experienced farmers, all ostensibly following the same practice. Interestingly, the best farmers in the first season invariably performed in the top 20 % in the second season.

Did yields differ amongst sites?

Considering only the New Conventional and PTOS practices, yield for the two respective seasons were 3.71 and 3.84 t ha^{-1} in the traditional areas and 2.52 and 2.94 t ha^{-1} in the normally fallow lands of the south, both increases.

While yields increased overall from seasons 1 to 2, the rankings for yield changed amongst locations, some falling and some rising. Yields at the Jikkorgaccha block in the Jessore region (Block 8, Table 2) were severely reduced in season 2. The best farmer there harvested 4.8 t ha^{-1} in season 1 but could only produce 3.1 t ha^{-1} in season 2. A large number of small grains was produced. Site teams indicated this was due to very high temperatures in season 2 during grain filling at this block. Yields were also much reduced at Melandah (Block 4 in the Jamalpur region), while there was a smaller but still negative trend at nearby Lakkhir Char (Block 5, cf New Conventional, PTOS and Strip Till). Temperatures at Jamalpur were higher in season 2 than season 1, as in Jessore, according to Meteorological Bureau data.

Against this negative trend there was large improvement in yield in the second season in the traditional wheat region Rajshahi where many farmers exceeded 5 t ha^{-1}. This was explained, not by any change in temperature, but by the application of boron in these blocks which increased grain set by 27 % in season 2 compared with season 1 with no change in spike number m^{-2}. Boron was inadvertently not applied at these blocks in season 1.

In season 1 the historically fallow sites of the south produced the poorest yields of any area irrespective of cultivation and sowing method. This was predicted by researchers because of the high temperatures in this zone (Figure 2), water pooling in the fields during early tillering after rain showers, and white salt crystals being visible on the soil surface, particularly late in the season. It was also expected because the region had been listed as less than 20 % suitable for wheat (see map). In season 2, the farmers of one saline southern block surprised everyone by producing better yields overall than two blocks in traditional areas. A second southern block of farmers in their first attempt to grow wheat (Kasipur in Barisal, not saline) also produced higher yields than one of the traditional blocks.

In keeping with variation in temperatures across Bangladesh (Figure 2), sowing to anthesis took longer for northern than southern sites, respectively 76 days after sowing (DAS) for Rajuria (north) and 69 DAS for the hotter Barisal and Noakhali (south). Heat sums from sowing to anthesis were 1390, 1480 and 1495 °Cd > 0 °C for the three respective locations, thus supporting the observation that at high temperature an increase in temperature slows development in thermal time (Rawson and Zajac, 1993) and more so when radiation is limiting (Rawson 1993). Dates of estimated physiological maturity were 112–114 DAS for the north (Rajuria), 99 DAS for Barisal and 103–105 DAS for Noakhali.

Yield components: were any particularly limiting?

At the beginning of the research project we calculated what crop components would be required for a 4 t ha^{-1} yield and then compared actual numbers collected throughout crop development and at the final harvest against those calculated. For example, when using 20 cm row spacing there should about 40 seedlings established per m row length (200 m^{-2}), about 120 shoots per m row at completion of tillering, 60–70 spikes per m row at anthesis (about 300 m^{-2}), and so on. This assumed 40 mg

Table 4. Components of yield for traditional and prospective new wheat-growing areas of the south for two seasons. Numbers are averages for all tillage/sowing systems and for all farming blocks within the category.

	2003/4		2004/5	
Season	Traditional	South lands	Traditional	South lands
Grain (g m^{-2})	361 (11)	189 (27)	375 (26)	271 (34)
Spikes m^{-2}	295 (16)	182 (8)	287 (18)	273 (10)
mg $grain^{-1}$	41 (1)	37 (2)	42 (1)	40 (1)
Grain $spike^{-1}$	31 (1)	26 (1)	32 (1)	25 (3)
Grain m^{-2}	8884 (331)	4743 (372)	9072 (608)	6707 (808)
Harvest index (%)	39 (2)	41 (1)	40 (1)	38 (3)

Numbers in parentheses are standard errors of the means.

grain as is usual for variety Shatabdi, and around 15 spikelets per ear with an average of two grains per spikelet.

In the first season, targets for yield components were reached at most blocks in the traditional wheat areas (Table 4) with the exception of Thakurgaon (Block 1) where crop establishment and general management were poor, and at Rajshahi where grain set was reduced due to boron deficiency. In the new areas of the south where yields were much lower, the main limitation was in the number of spikes which averaged less than 200 m^{-2}, well below the target of 300 m^{-2}. There yield (g m^{-2}) was linearly related to spikes m^{-2} (yield $= 1.42\times$spikes $- 20$, $r^2 = 0.77$) in a similar relationship to that at high-yielding blocks such as Monirampur.

In the second season, the hot southern blocks came much closer to achieving targets particularly in spikes m^{-2}, which rose to similar levels to those in traditional blocks. Attention to sowing at the correct soil moisture there resulted in good stands early on and full ground cover by the time flag leaves emerged. Unfortunately grains per unit area did not rise to those in traditional areas because grains per spike declined with increase in spikes m^{-2} (Table 4). This occurred in all southern blocks whether saline or not. There is little evidence that high temperature *per se* induces sterility (Rawson, 1986), but when in association with reduced radiation and high humidity during the period leading up to heading, sterility can be high (more than 20 % in Rawson *et al.*, 1996, where boron was adequate in the growth medium and see Saifuzzaman *et al.*, 2004, for large radiation effects). However, the reduction in grains per spike noted here may not be due to sterility, rather to a higher production of late small spikes with few spikelets and potential grain sites. Observations of grab samples supported this, but the effect was not quantified.

Was planting date important for yield?

Farmers in all blocks were encouraged to plant as early as conditions allowed after they had harvested their previous crops. It was suggested the crop should be in by the end of November as the expected loss of yield with delay of planting after that time is approximately 1.5 % per day for the region (see Introduction) and 1.3 % per day in

Bangladesh specifically (44 kg ha^{-1} for each day's delay after 30 November, Ahmed and Meisner, 1996, quoted by Timsina *et al.*, 2001).

In the second season (2004/5), almost all farmers in the traditional wheat-growing areas planted during the recommended period with a range within each block of seven to 10 days. All southern blocks were delayed into December, waiting for optimal soil moisture for tillage.

Despite planting on time in 2004/5, regression analysis using data only from New Conventional and PTOS farms pointed towards yield declining with lateness of planting. The average for all sites was 2 % day^{-1} equivalent to 70 kg ha^{-1} day^{-1}. Though trends were mostly negative, they rarely reached significance, perhaps because planting dates covered so few days. For Jessore the loss averaged 2.0 % per day with coefficients of determination (r^2) for the two blocks of 0.13 and 0.41. At Jamalpur the loss averaged 2.5 % per day ($r^2 = 0.32$ and 0.21). The northern blocks of Dinajpur averaged a loss of 1.6 % per day, while Rajshahi averaged 0.9 % per day. These trends are in general agreement with percentage reductions found by Timsina *et al.* (2001) at Nashipur, in northern Bangladesh, when planting date was delayed from early-mid November to early-mid December. Barisal in the south had a three week range in planting date. There the regression indicated a loss of 1.2 % or 33 kg ha^{-1} d^{-1} ($r^2 = 0.30$). Other southern blocks had only a four-day range in sowing date across farms so could not be assessed. Together these data imply that planting earlier than the end of November would have been beneficial at some sites in this season.

What did farmers think of the technology?

A questionnaire was given to farmers asking about their preferences for the cultivation and sowing methods. Commonly the farmers favoured PTOS. They liked being able to cultivate and plant in one pass with clear savings in fuel (that cost was their responsibility). They were happy with the high resultant percentage emergence and the uniformly spaced rows that allowed access for any weeding and irrigation. They commented that with the full surface cultivation of PTOS weeds were generally controlled. Strip till was regarded as being much the same as PTOS though presumably it required less fuel as less of the soil surface was cultivated. All other methods had their enthusiasts and opponents.

New Conventional received least discussion even though it produced good results. Farmers were unimpressed because it was close to their normal methods. It was considered less good because it required more passes, so more fuel was used, and the farmers had to broadcast seed and fertilizer manually.

Beds and Zero Till produced most discussion. Both had been presented in training sessions as new technology and were successful in India and Mexico for reasons that were specified (Sayre and Hobbs, 2004). The bed enthusiasts who produced high yields particularly in Rajshahi emphasized the speed with which irrigation could be done and the lack of damage by rats during grain filling. The opponents mentioned high fuel use and the time and many passes required for bed formation.

Zero Till had excited farmers. Successful exponents specified low fuel use and more rapid planting even than PTOS. All were surprised to find that high yields could be produced without cultivation. In fact, descriptions of the new method were published in local newspapers when yields became apparent (*The Independent*, March 11 2004; *The Financial Express*, March 21 2004; *Bangladesh Today,* March 28 2004). Farmers were also very impressed with the effectiveness of herbicides and their saving in labour. By contrast, some farmers were very unhappy with Zero Till mentioning poor emergence, seedling death, weeds and low yields. These were farmers who had planted when the soil was still very wet or too dry or had not controlled their weeds.

DISCUSSION

Our primary questions at the outset of this project were first, could we find unused land in Bangladesh to grow wheat economically and reliably, and second, could we find ways to increase yields of wheat in the traditional rice-wheat regions? Underlying the questions was how could we overcome the perceived limitations to yield that had been identified in previous research.

Do the fallow lands of the south have potential for wheat?

Farmers' yields in the southern zone, normally remaining fallow during the dry season, produced almost 3 t ha^{-1} on average across the three blocks of the zone in the second year of the trials. These yields were achieved using one irrigation in early tillering and one during early grain fill. The best farmers reached 4.3 t ha^{-1} at the saline site Char Jublee in the Noakhali region and 4.1 t ha^{-1} at the non-saline site Kasipur in Barisal in a crop season of around 100 days. There the temperatures were high during grain filling, a normal situation for wheat in Mediterranean zones, but were also high during seedling establishment right into the tillering stage (Figure 2). During this early growth stage, maximum temperatures rarely dropped below 30 °C. Because these yields were achieved by farmers on their farms, not by researchers operating on research stations, it seems reasonable to extrapolate from these trials to what farmers could achieve throughout the fallow zone, conservatively estimated at 400 000 ha.

Assuming figures of 400 000 ha and 2.5 t ha^{-1} yields are realistic, the fallow lands have the potential to provide 1 million t wheat to Bangladesh.

While the study, contrary to reasonable expectations, indicated that these fallow lands do have considerable yield potential for wheat, would farmers be interested in realising the potential by using the practices tested? Or would they have constraints that have not been fully addressed by the study?

The farmers were aware of the necessity to plant on time or lose yield. All the machinery options trialled by farmers allowed for rapid cultivation and planting, so all allowed planting at or near the approved date. Thus all overcame the historic constraint of slow bullock power. All allowed high and similar yield production as long as planting occurred at correct soil moisture contents, with appropriate sowing rates, and crop management was good. The machinery seemed to provide high potential, but could farmers afford it?

Farmers in these fallow lands depend for income on one crop of rice a year, so they are usually poor. A 2.5 t ha^{-1} wheat crop is worth between Tk 30 000 and Tk 40 000 ha^{-1} depending on market price. With the cost of seed and fertilizer inputs of over Tk 7000 ha^{-1}, the farmer must produce more than 0.5 t ha^{-1} before making a profit from wheat. Assuming the farmer owns the planting machinery, a likely profit would therefore be more than Tk 20 000 ha^{-1}.

As the farmers are primarily rice growers, they invariably depend on manual labour to do most farm activities but increasingly they own a power tiller. To buy a wheat planting machine to attach to their power tiller would cost them Tk 35 000 (PTOS) or Tk 13 000 (Zero Till, 2005 prices). A common field size is 0.15 ha so the field earnings from wheat each year would be not much more than Tk 3000. For a farmer to buy a PTOS from wheat production on one field would take equivalent to 10 years' production and a Zero Till machine four years.

So while the research project showed that PTOS is an effective and desirable tool for farmers to grow wheat, and Zero Till machines in association with herbicides can produce high yields when used correctly, fallow-land farmers cannot realistically afford them. A solution is that farmer groups could share machinery, as in our study with several farmers per machine. Seven farmers producing 2.5 t ha^{-1} could together buy a Zero Till machine from the profits of one wheat crop and have enough money left over for all their crop inputs for the second season. Alternatively, some farmers could become service providers. In India, Hobbs and Gupta (2004) have estimated that a farmer/operator could pay for a zero drill in one year if the service is provided to at least 80 ha. For this to happen in Bangladesh, the demand for the service would have to increase first. Many farmers would need to be exposed to the technology.

The conclusion is that if wheat production is to be adopted by farmers in the fallow regions, it must be done initially with minimum outlay, and for most farmers this means using the New Conventional practice, which requires only a power tiller for cultivation. Wheat profit then begins at yields above 0.5 t ha^{-1}. Dedicated wheat planting machinery can come later.

The surprise in this research was that New Conventional could compete for yield production with the methods that produced crops in rows and sowed the seed at controlled depth. The guess was that broadcasting would not be uniform so would lead to thick and thin patches of crop, also that the power tiller would bury seeds at variable depth resulting in uneven emergence and a proportion of weak seedlings. With such a short season, crops would never recover from this poor start. These guesses were largely wrong. Most farmers broadcast uniformly, particularly in season two, so emergence and establishment were good and numbers of yield components generated were not limiting. The New Conventional method also controlled weeds adequately at many sites, obviating the need to use costly herbicides.

One argued limitation of the New Conventional method with its full shallow tillage is that in using two or three passes, it wastes soil moisture, particularly when compared with Zero Tillage. In the fallow zone the planting of wheat follows three to four months of the soil being covered with monsoon waters. Providing farmers plant shortly after their rice is harvested when the land has dried down sufficiently to become trafficable, the wheat crop starts on a full profile of soil water ranging between 140 and 200 mm plant available water, despite cultivation.

Though much of the foregoing discussion has been about cultivation and seeding techniques, it must be emphasized that those techniques were all superimposed over best practice agronomy with high nutrition and water applied at appropriate crop development times to a good variety of wheat. At this stage, prospective wheat farmers in the fallow lands do not have the training to follow these optimized practices. Any new farmers must learn why and how to apply the full management package, otherwise there will be failures.

Can yields be increased in the traditional rice-wheat regions?

Average yields at sites in the traditional wheat–rice areas rose above levels previously reported from well-fertilized research trials (Timsina and Connor, 2001) and were more than 50 % higher than yields achieved by neighbouring farmers. These were trials over two seasons by more than 120 farmers on their own farms, not trials by researchers on their stations. If this increment could be achieved generally in the zone, country production would be increased by around 800 000 t annually.

As with novice wheat farmers in the southern, normally fallow blocks, these experienced wheat farmers preferred the tillage-planting method they were testing, and as in the south, the success of the method depended on the farmer's judgement. There was no outright winning method though Zero Till had produced lots of excitement. All could produce high yields if used in association with timely planting of good seed of a premium variety into soil with the right moisture content, timely irrigation and fertilizer applications and weed control. These components were all vital in increasing yields beyond those of non-participating farmers.

But would the methods being tested successfully be followed in upcoming years because they were economically advantageous? In addition to following best practice in crop management, particularly in the timing of activities, participating farmers were using more fertilizer than their neighbours, often twice as much urea. Urea is subsidized by the government in Bangladesh. Twice the amount of urea cost around USD12 ha^{-1} leading in the best areas to an improved profit of USD300 ha^{-1}. Despite this benefit from urea, there is no assurance that farmers will use it because they have to find the money at planting time, usually before they have money available from selling their rice crop.

One indication that farmers were convinced of the practicability of the methodology used in the trials was in the area immediately surrounding the co-operating farmer blocks in Jamalpur. There land sown to wheat increased from 36 ha in 2004 to 181 ha in 2005. Assuming average field size of 0.15 ha, up to 1000 farmers were interested in reaping the benefits demonstrated in the research project. There are no data from other sites or on the methods actually used by the adopting Jamalpur farmers.

Hopefully they learnt from the co-operating farmers that high yields generally do not come from changing just one component of a farming system, but also of matching and readjusting inputs to satisfy the changed and changing requirements of the crop.

Limitations of the results and future research issues

While the project showed profitable yields can be produced over two seasons there is no certainty that the climate will allow this to continue. Sunshine hour data over the past decades (Figure 3) show a downward trend setting ceiling yields progressively lower, and predicted changes in global temperatures are likely to further limit yields. However, there was no indication that the two seasons of the study were unusually good in terms of long-term weather records, so the results should be reproducible in future. Currently, the Agricultural Production Systems Simulator (APSIM) model is being used in an Australian Centre for International Agricultural Research project to assess the long term economic feasibility of growing wheat and other crops in the zone using historic weather and soil data. Whether crops can expand through the fallow zones will depend in each region on the amount of stored moisture in the profile, access to surface water for at least one early irrigation and attention to reducing the input of fertilizers without significant yield loss to reduce on-farm costs. These are the issues under study.

CONCLUSIONS

By identifying the environmental, plant and human constraints to yield and then comparing systems to address them, this small project demonstrated that profitable wheat crops could be produced by farmers on their farms in villages representing a large area, previously considered to be mainly of low cropping potential. The zone is considered to have 1 million t production potential which can be realized by using the approaches outlined of research-extension teams working closely with farmers and of on-farm teaching and demonstration cells scattered throughout the region. In the traditional zones, 800 000 t more wheat can be produced by following the general management practices based around optimum times and amounts of inputs and activities as described. A first step will be to replace the old variety Kanchan with new varieties such as Shatabdi, something already happening in the neighbourhood of collaborating sites of this study.

Acknowledgements. FAO Rome is thanked for funding the project and FAO Bangladesh for administering the funds. Dr M. Hossain, M. E. Haque, Dr K. Sayre and S. Justice were mechanization experts. I. Hossain, H. Hossain, M. Rahman, Rokshana and A. Farooque gave research support. Dr C. A. Meisner of CIMMYT Bangladesh provided emergency support in many ways. Dr J. Comas provided advice on statistical analysis and D. Sarker of CIMMYT, the elements of the Bangladesh maps in Figure 1. The many farmers are thanked for their key role, as are the many other participants in the project. Finally, BARI and DAE are thanked for a continuing commitment to the project.

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