Maize-Rice Cropping Systems in Bangladesh: Status and Research Opportunities




M. Yusuf Ali, S.R. Waddington,
D. Hodson, J. Timsina, and J. Dixon

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M. Yusuf Ali, On-Farm Research Division, BARI, Gazipur 1701, Bangladesh
S.R. Waddington, CIMMYT, PO Box 6057, Gulshan, Dhaka 1212, Bangladesh
D. Hodson, CIMMYT, Apdo Postal 6-641, 06600 Mexico DF, Mexico
J. Timsina, IRRI and CIMMYT, DAPO Box 7777, Metro Manila, Philippines
J. Dixon, CIMMYT, Apdo Postal 6-641, 06600 Mexico DF, Mexico

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International Rice Research Institute

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International Maize and Wheat Improvement Center

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Abstract: Responding to demand from expanding poultry feed markets, maize area in Bangladesh rose from only a few thousand hectares in the 1980s to more than 200,000 hectares in 2007-08. This publication describes the rise of maize in Bangladesh, emerging problems or risks, technology options for rice-maize systems, and future research and development needs. It also outlines the role of CIMMYT, through its Bangladesh office, in the establishment and promotion of maize, as well as the provision of germplasm and capacity building for researchers and farmers, in collaboration with the Bangladesh Agricultural Research Institute (BARI), the Department of Agricultural Extension (DAE), and diverse non-governmental organizations.

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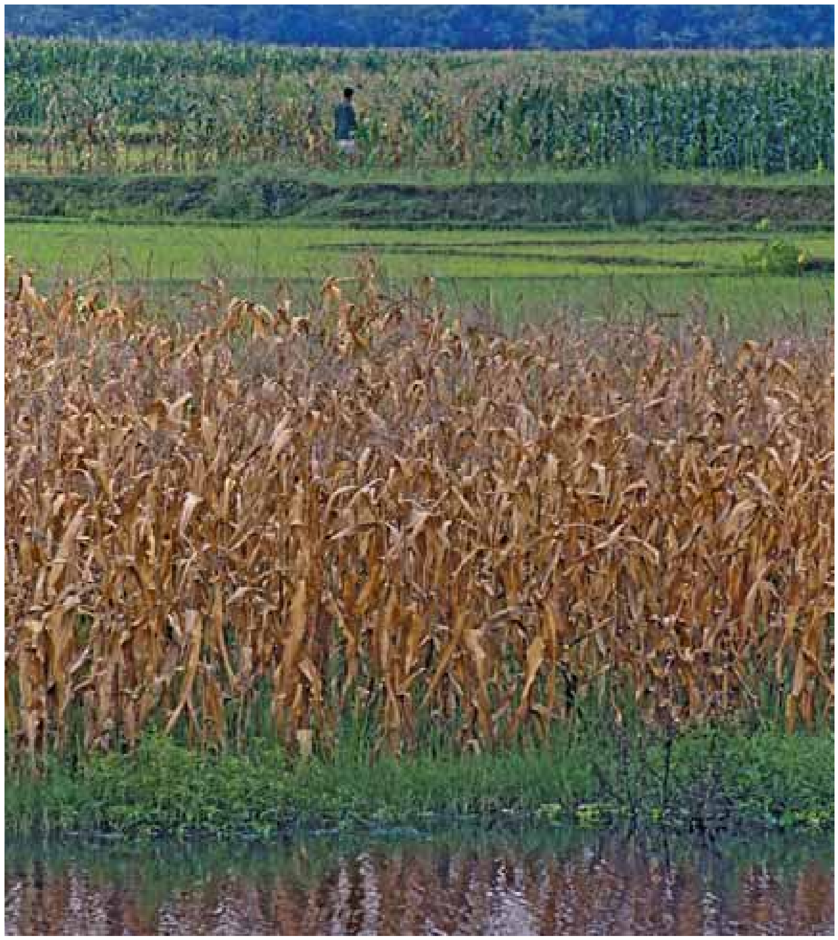
Contents

A. Maize: An Increasingly Important Cereal in Bangladesh



1. Brief history of maize in Bangladesh

The widespread fertile alluvial soils and subtropical monsoonal climate make much of Bangladesh suitable for maize cultivation (Figure 1), but maize is a new crop there. Before independence in 1971, maize was rarely cultivated across Bangladesh except in a few tribal areas of the southeastern Chittagong Hill Tracts. By the 2007-08 cropping season, we estimate it was planted on about 220,000 ha of land in Bangladesh, with national average grain yields of around 5.7 t/ha, producing well over a million tons of maize grain annually.

After the creation of the Bangladesh Agricultural Research Institute (BARI) in 1976, BARI felt there was potential to develop maize as an important high-yielding cereal crop. Maize became an emerging key mandate crop of BARI and programs were developed for crop improvement, crop management, and subsequent area expansion. Within a few years, BARI had collected maize germplasm from home and abroad, including from CIMMYT, released its first high-yielding open pollinated variety (OPV) in 1986, and followed that with a further seven OPV releases. The Department of Agricultural Extension (DAE) mounted maize demonstration plots in farmers' fields to increase awareness about maize and expand its cultivation. However, progress was slow and by the early 1990s still only a few farmers had adopted this crop, largely because at that time there was no market for maize and people were not accustomed to mixing maize flour with wheat for local consumption in chapatti flat bread.

With the rapid expansion of the Bangladesh poultry industry in the 1990s and 2000s, the demand for maize grain as poultry feed increased many fold. This was initially mostly met by grain imports from Thailand, the USA, and other countries. Observing the expanding demand for maize, a small amount of hybrid maize seed (mainly Pacific 11) was imported by two private seed companies called Kushtia Seed Store and ICI Seed International, and by IFDC in the early 1990s (OFRD, 1993). Excellent high yield crops grown from this seed showed the potential and profitability of hybrid maize in Bangladesh. During the 2000s, other seed companies, including BRAC, have imported and marketed hybrid maize seed, especially from Pacific Seeds in Thailand. BARI began a program in the mid 1990 to develop its own

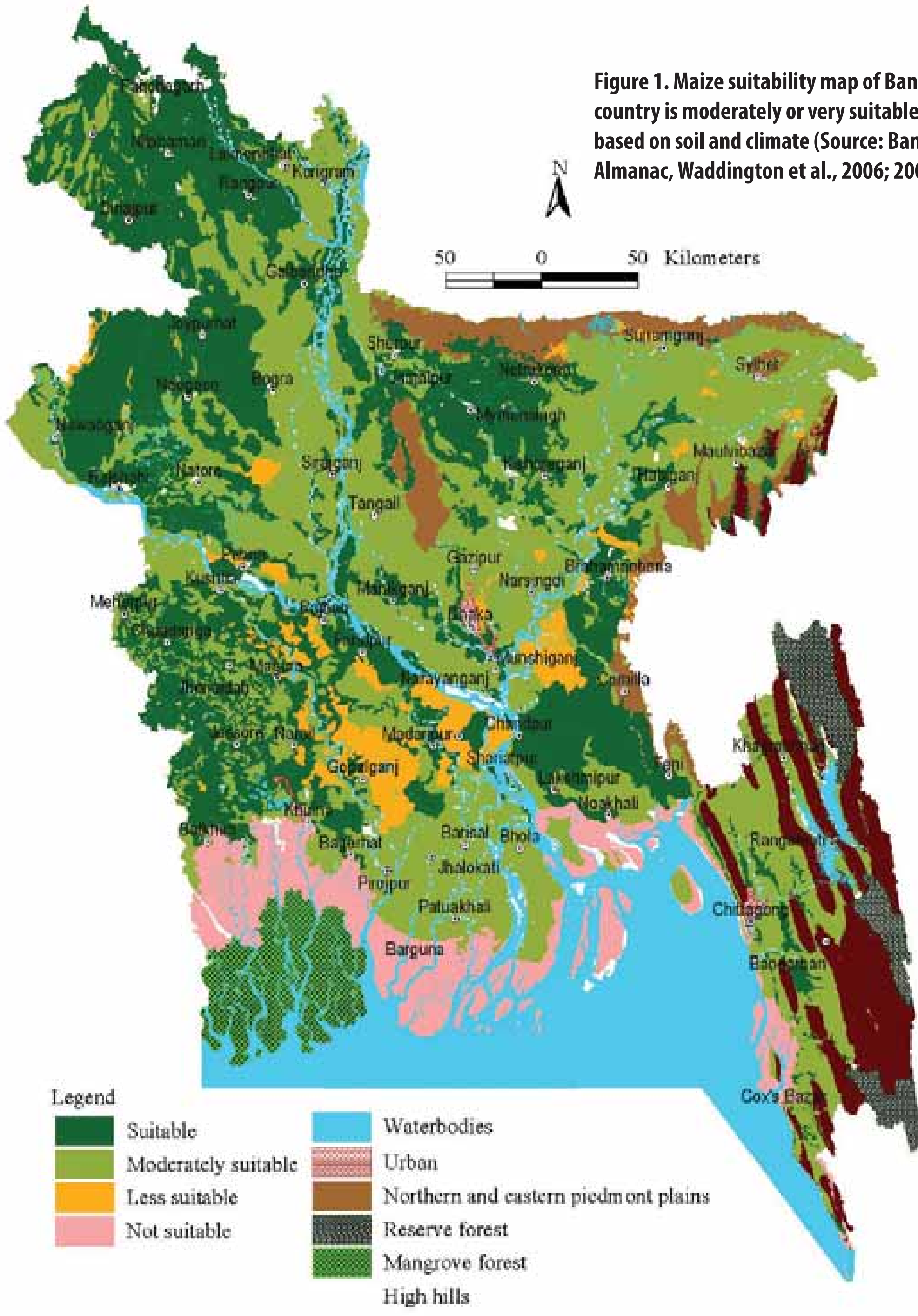


Figure 1. Maize suitability map of Bangladesh. Most of the country is moderately or very suitable for maize cultivation, based on soil and climate (Source: Bangladesh Country Almanac, Waddington et al., 2006; 2007).

maize hybrids in collaboration with international partners, particularly CIMMYT, and it released its first maize hybrid (BARI hybrid *Bhutta* 1) in 2001. Two further maize hybrids, BARI hybrid *Bhutta* 3 (released in 2002) and BARI hybrid *Bhutta* 5 (a quality-protein maize (QPM), released in 2004) have become very popular since they can produce up to 10-11 t / ha of grain under optimum conditions. This was comparable with or better than exotic commercial hybrids such as Pacific 11. BARI has recently released two other maize hybrids called BARI hybrid *Bhutta* 6 and BARI hybrid *Bhutta* 7 (Plant Breeding Division, 2007).

From 2000 onwards, maize became a lucrative cash crop with a huge and expanding market demand, particularly to the farmers of northern and western Bangladesh. The crop has higher grain yield, yield stability, and profitability compared with the two other principal winter cereal crops: *Boro* (irrigated) rice and wheat. In Bangladesh, hybrid maize is grown mostly in the dry winter (*Rabi*) season (during November-April) after the harvest of *T. aman* rice (transplanted monsoon rice). At that time, because of prevailing cool temperatures during early phases of crop development, the field duration of winter hybrid maize is long; around 145 days. This and the widespread use of high rates of fertilizer along with irrigation help ensure high grain yields (with a current 2005-07 national mean grain yield of around 5.7 t / ha). Additionally, increasing area is coming under *Kharif-I* (March-June) maize, mainly after the harvest of potato.

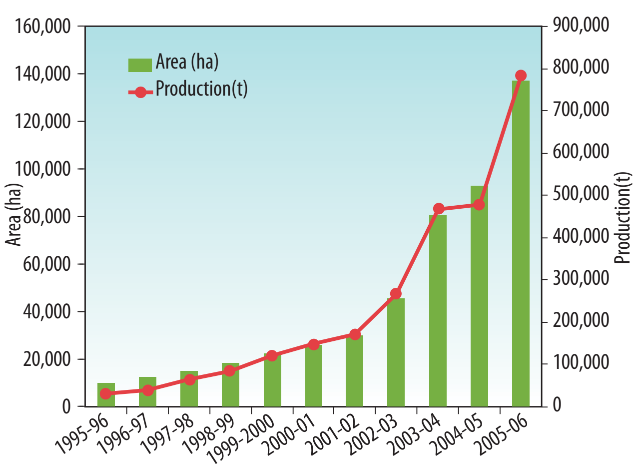


Figure 2. The rapid increase in hybrid maize area planted and grain production in Bangladesh over the period 1995 to 2006 (Source: Bangladesh Department of Agriculture Extension).

Still, as recently as 2005-07, the local production of maize in Bangladesh could meet only 55-60% of national maize demand for poultry and other feeds. The continually expanding poultry industry indicates that future demand for maize is likely to rise for some time, although recent outbreaks of bird flu during 2007 and 2008 may temper demand somewhat.

2. Expansion of maize area and production

During the 1970s and 1980s, maize was grown on just a few thousand ha of land in Bangladesh, although farmers were becoming more interested in the crop (Ahmed and Elias, 1988). In the early 1990s, shortly after the introduction of hybrid maize in some selected areas of central, northern, and southwestern Bangladesh, its adoption remained slow. By 2001-02 the maize area had reached no more than around 30,000 ha with a production of 0.17 million t grain (Figure 2), though the demand for poultry feed was already high and growing fast at that time. Hossain et al. (2002a) reported an emerging impact from previous maize research and extension in Bangladesh and suggested additional investments in promoting the crop. However, because maize was new to most farmers in Bangladesh, they needed time to learn how best to fit it into their existing complex intensive cropping patterns involving 2-3 different crops per year, manage it using the best production practices, and handle its post-harvest processing. Also, the domestic marketing and use of maize in local villages was minimal. However, the poultry industry continued to look for competitively priced poultry feeds. Responding to demand from expanding poultry feed markets in the early 2000s, the maize area quickly rose to 137,000 ha in 2005-06 (Figure 2) (CIMMYT Office in Bangladesh, 2006), reached 179,000 ha in 2006-07 (Waddington et al., 2007; Hasan et al., 2007), and we now estimate 220,000 ha in 2007-08. Most area and production expanded in northwestern and West-Central districts.

CIMMYT, through its Office in Bangladesh, has played a key role in the establishment and promotion of maize in Bangladesh by providing hands-on training to about 11,000 farm families on maize production (in the form of whole family training; CIMMYT Office in Bangladesh, 2006; Hasan et al., 2007) and distributing good hybrid seed among the trained farmers (Hasan et al., 2007) with collaboration from its principal partners, BARI, various NGOs and DAE. It was observed that in the areas where more training was arranged (such as Dinajpur, Lalmonirhat, and Bogra) more area came under maize (Figure 3). In some areas, private entrepreneurs and seed companies also played an important role in bringing more land area under hybrid maize. In areas that had received whole family maize training, maize production was also higher (Figure 4) in comparison to farmers in areas without training (CIMMYT Office in Bangladesh, 2006; Hasan et al., 2007). More area expansion occurred in northern and western Bangladesh, perhaps because of more suitable soils and climate for *Rabi* maize, cheap availability of labor, and greater land resources in comparison to central parts, even though major poultry farms and feed industries surround Dhaka city (Gazipur, Savar, Sreepur, Narshingdi, Kishorejang, Valuka, and Tangail) in central Bangladesh, targeting a market of over 12 million urban dwellers with expanding purchasing capacity. Even with fairly high road transport costs for carrying maize from northern and western parts to feed industries adjoining Dhaka, the domestic grain price seems to be competitive with imported maize.

Although the area of maize has continued to increase dramatically over the last few years, there is recent evidence and increasing concern that grain yield per unit land area has leveled and may be in decline (Figure 5). This is very alarming because the land area of Bangladesh is small (around 144,000 km^2) and arable land is being lost at up to 1% per year, while feed demand is increasing at about 15% per year. Thus it is crucial to achieve and maintain a high potential grain yield and high achieved yield. Personal communication with experienced farmers and concerned researchers suggested that degrading soil fertility (as hybrid maize is an exhaustive crop), emerging micro-nutrient problems, imbalanced use of fertilizers, improper and low use of irrigation, and late planting in the winter season are the main reasons for yield stagnation (however more studies are needed to confirm and quantify those constraints). These problems will have to be addressed properly to maintain and increase maize yield.

3. Maize-rice systems

Winter *Rabi* season maize is grown in rotation after the traditional monsoon *Aman* rice crop in Bangladesh. Rice is the traditional staple cereal crop in Bangladesh. It is grown throughout the country year round, with often 2-3 crops per year on the same land. In 2005-06 11.25 million ha of rice were planted, with a production of 29.75 million t at an average grain yield of 2.6 t/ha. The country was just

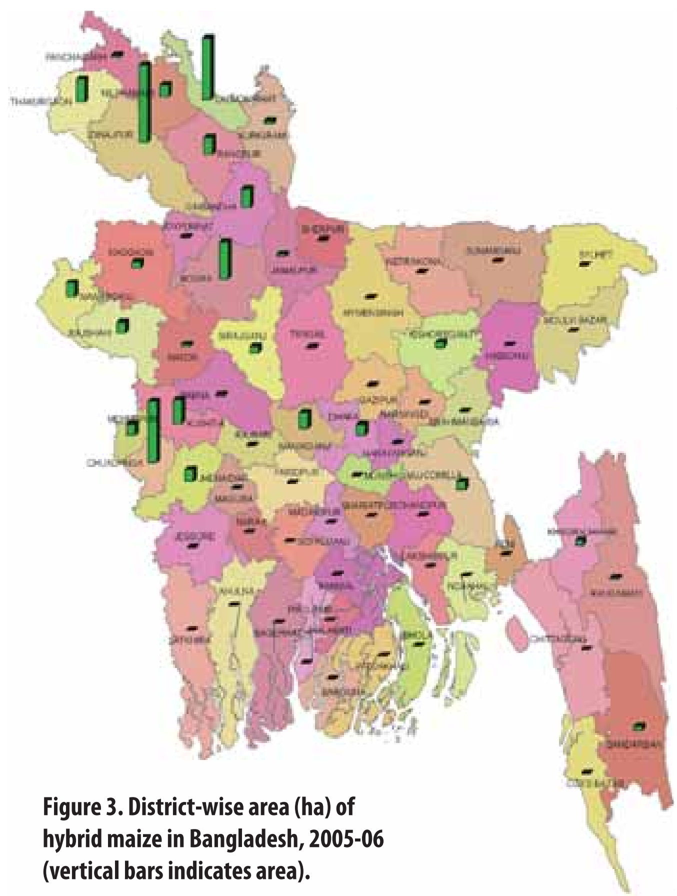


Figure 3. District-wise area (ha) of hybrid maize in Bangladesh, 2005-06 (vertical bars indicates area).

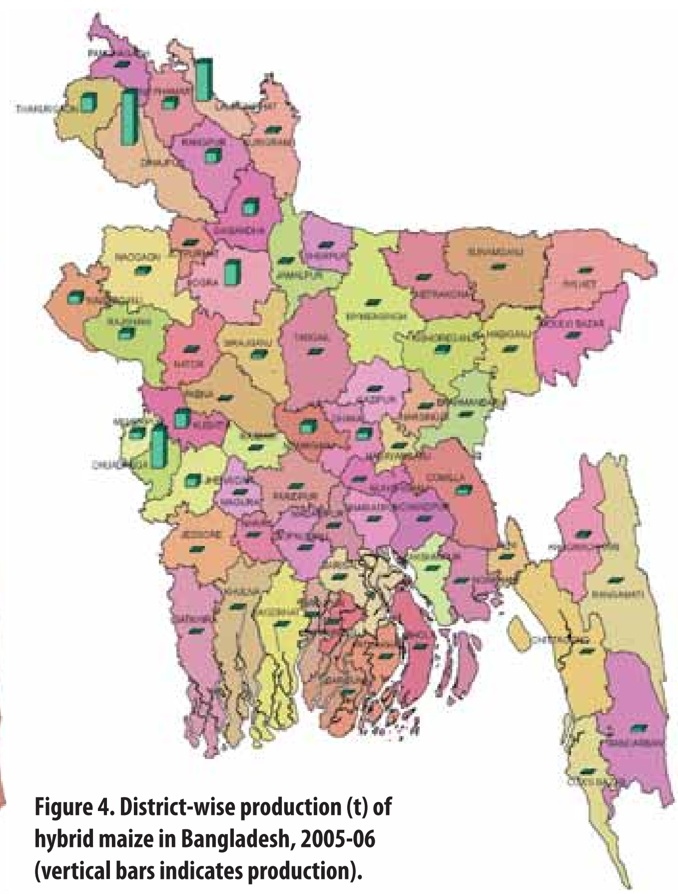


Figure 4. District-wise production (t) of hybrid maize in Bangladesh, 2005-06 (vertical bars indicates production).

self sufficient during 2000-05 and had a surplus of 3-4 million t in 2005-06. The rice area for 2015-20 is projected to decline to 7.8 m ha. Since the 1980s, the great success with rice in Bangladesh has come from winter *Rabi* season *Boro* (irrigated) rice, where both area planted and yields have been increasing. In 1995-06, 7.2 million t of *Boro* rice were produced on 2.75 million ha. In 2005-06, 15.5 million t came from 4.34 million ha. Average grain yields have risen from around 2 t / ha in the 1970s to around 3.6 t / ha now. The pre-monsoon *T. aus* and deepwater rice areas have been declining and farmers have been switching to *Boro*. The area of monsoon rice has remained static since the 1970s but yields have nearly doubled (Waddington et al., 2006).

Almost all the maize is grown as a high-input (hybrid seed, large rates of fertilizer, irrigated) crop during the dry and cool winter *Rabi* season, especially in Northwest and West central Bangladesh, where it is replacing mostly wheat, chili, mustard, or vegetables, or *Boro* rice in some areas (Waddington et al., 2006; 2007). Maize continues to expand into new areas such as the High Barind Tract in Rajshahi. Maize is most commonly grown in maize-fallow-transplanted monsoon (*T. aman*) rice, potato-maize / relay maize-*T. aman*, maize-relay jute / jute-transplanted monsoon rice, maize-pre monsoon (*Aus*) rice-transplanted monsoon rice, or maize-vegetables-vegetables, cropping patterns (CIMMYT Office in Bangladesh, 2005 and 2006). Small amounts are planted during the pre-monsoon *Kharif-1* season and on hill slopes in eastern Bangladesh during *Kharif-2* (monsoon). While best adapted to cropping during the *Rabi* season, there is potential for it to be grown more widely in many parts of the country during the *Kharif-1* and even during the monsoon (*Kharif-2*) season on

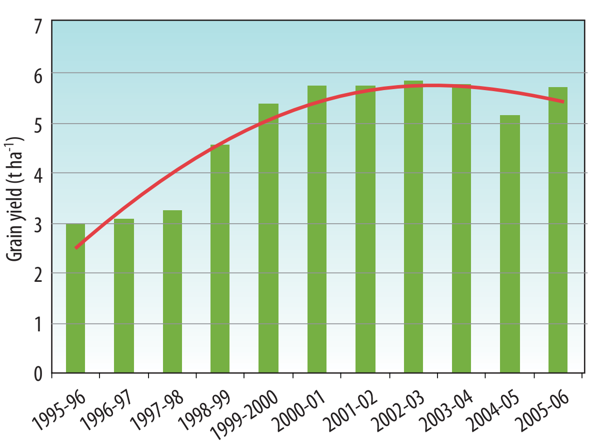


Figure 5. Average grain yield of hybrid maize in Bangladesh from 1995 to 2006.

hillsides in the Chittagong Hill Tract areas. There are problems with alternative *Rabi/Kharif-1* cereal crops; particularly power and water shortages for *Boro* rice and low yields of wheat due to its marginal adaptation to Bangladesh.

Additionally, maize may be less detrimental to the environment than *Boro* rice. With increasing concerns about arsenic contamination in *Boro* rice (Heikens et al., 2007), maize offers an attractive alternative cereal crop that has already been shown to contain lower concentrations of arsenic. Maize may be environmentally safer because it requires much less water for irrigation than *Boro* rice so the risk of arsenic accumulation in the soil and ultimately in the crops is lower with maize than *Boro* rice. In areas where soils are already contaminated with As, maize can be grown instead of *Boro* rice as an As management option. Additionally, the high financial and environmental costs of irrigating *Boro* rice with large amounts of water from electric or diesel pumps is of increasing concern. Maize needs only around 850 l water per kg grain production (with 2-4 irrigations) compared with 1,000 l / kg wheat grain (1-3 irrigations) and over 3,000 l / kg rice grain (with 20-35 irrigations) for *Boro* rice.

4. Maize-based cropping patterns

As indicated in the previous sections, hybrid maize was promoted as a winter crop and is generally cultivated in Bangladesh after the harvest of traditional *T. aman* rice. But now farmers are increasingly fitting maize with a widening range of other traditional crops, such as potato, jute, and various vegetables. This indicates that hybrid maize cultivation in Bangladesh is becoming increasingly integrated by farmers into their cropping systems. In Bogra (Table 1) for example—one of the first areas where maize expanded—20 different maize-based cropping patterns were found. In some cases two maize crops (both *Rabi* and *Kharif-I* season) were grown on the same piece of land in a large proportion of the maize area (about 28.5%). Table 1 also shows that most of the maize hybrids cultivated were imported. More seed of BARI-released hybrids are to be produced and marketed to save foreign currency. In most of the areas except Rangpur Sadar and Pirjang, Rangpur, Maize-Fallow-*T. aman* is the major cropping pattern (Tables 2, 3, 4, and 5). In Rangpur Sadar, 80% of the maize was grown after potato. Maize was sown as a relay crop 20-35 days after planting potato or it was grown after the early harvest of potato in late February / early March. These high value potato-maize systems are expanding fast in some districts. Thus hybrid maize cultivation is becoming diversified from the initial "traditional" systems (in which it was first promoted), and new systems are emerging, which suggests the increasing acceptability of maize cultivation by different types of farmers in Bangladesh.

Table 1. Maize-based cropping patterns of Bogra district, Bangladesh, 2005-06.

Cropping pattern	Land area (ha)	% of maize area	Maize cultivar
Maize-Fallow-*T. aman*	4,415	40.6	Agroso-900M and 900M Gold
Maize-Maize-Fallow	3,098	28.5	Agroso-827 Agroso717
Maize-*T. aman* seedling-Fallow	1,158	10.7	Pacific 11 and 60
Maize-Jute-*T. aman*	551	5.1	Pacific 984 and 3334
Maize-Vegetables-fallow	530	4.9	Pacific 983M and 740
Maize-*T. aman* seedling-*T. aman*	250	2.3	Pacific 884 and 759
Potato-Maize-*T. aman*	234	2.2	Pacific 747 and 948
Maize—*T.aus-T. aman*	110	1.0	Pacific 988
Maize-Jute-Fallow	109	1.0	AMK 40 and Hira 405
Maize-Vegetables-*T. aman*	86	0.8	Hira 11
Vegetables-Maize-Fallow	70	0.6	Kanok, NK-40
Vegetables-Maize-*T. aman*	63	0.6	NK48, NK6621
Maize-Vegetables-Vegetables	50	0.5	NK46
Potato-Maize-Vegetables	45	0.4	Uttaran, Badsha
Potato-Maize-Fallow	30	0.3	NT6323
Blackgram-Maize-Fallow	22	0.2	Samrat, Highton
Wheat-Maize-Fallow	20	0.2	Sufala, Puja
Maize-*T. aus*-Fallow	20	0.2	Joykishan
Vegetables-Maize-*T. aman* seedling	5	0.04	BARI hybrid Bhutta2, Monisha
Maize-Vegetables-*T. aman* seedling	3	0.03	HP100, CP918
-	**10,869**	**100**	-

Table 2. Maize-based cropping patterns of Mithapukur, Rangpur, Bangladesh, 2005-06.

Cropping pattern	Land area (ha)	% of maize area
Maize-Fallow-*T. aman*	1,587	71.8
Maize-*T. aman* seedling-*T. aman*	211	9.6
Maize-*T.aus-T. aman*	183	8.3
Potato-Maize-*T. aman*	180	8.2
Maize-Maize-*T. aman*	20	0.9
Mustard-Maize-*T. aman*	10	0.5
Onion-Maize-*T. aman*	6	0.3
Garlic-Maize-*T. aman*	4	0.2
Total	**2,201**	**100**

Table 3. Maize based cropping patterns of Pirjang, Rangpur, Bangladesh, 2005-06.

Cropping pattern	Land area (ha)	% of maize area
Maize-Vegetables-Vegetables	500	35.7
Maize-Fallow-*T. aman*	400	28.6
Potato-Maize-Fallow	200	14.3
Potato-Maize-*T. aman*	200	14.3
Maize-Jute-*T. aman*	100	7.1
Total	**1,400**	**100**

5. Current and projected maize grain demand, supply, and production prospects

Maize grain consumption (currently about 1.2 million t / year) in Bangladesh is directly related to the poultry industry. Bangladesh now has a very large poultry industry producing about 220 million chickens, 37 million ducks, and around six billion eggs annually. Five million people are directly employed by the poultry industry and millions of households rely on poultry production for income generation and nutrition. Poultry production has shown tremendous growth rates in the 1990s and 2000s and is expected to continue to grow as a result of human population growth and an increasing per capita consumption of chicken meat and eggs as incomes rise. For example in 1995 one-day broiler chick production was less than one million chicks per week. In 2007 it had increased to 6 million per week (personal communication Dr. Rostom Ali, poultry farm owner). Poultry has proven itself as the major source of cheap animal protein able to fulfill this demand. Besides poultry, maize is also used for cattle feed and fish feed and increasingly in rural communities and some urban ones it is mixed with wheat flour for human consumption primarily in chapatti flat bread. However, the present main use of maize remains the booming poultry industry. A lack of domestic investment and land constraints has meant that feed production has not kept pace with the 15%-per-year rise of the poultry sector nationally since 1991. Even more feed will be needed soon, as poultry meat consumption among Bangladeshi

Table 4. Maize-based cropping patterns of Rangpur Sadar, Rangpur, Bangladesh, 2005-06.

Cropping pattern	Land area (ha)	% of maize area
Potato-Maize-*T. aman*	800	80
Wheat-Maize-*T. aman*	100	10
Maize-Fallow-*T. aman*	50	5
Maize-Jute-*T. aman*	50	5
Total	**1,000**	**100**

Table 5. Maize-based cropping patterns of Kushtia Sadar, Kushtia, Bangladesh, 2005-06.

Cropping pattern	Land area (ha)	% of Maize area
Maize-Fallow-*T. aman*	4,500	64.1
Maize-Jute-*T. aman*	1,500	21.4
Maize-Jute-Fallow	390	5.6
Maize+ relay Vegetables-*T. aman*	350	5.0
Maize-relay Vegetables-Fallow	200	2.9
Maize-Mungbean (chance crop)-*T. aman*	85	1.2
Total	**7,025**	**100**

people continues to rise. The present consumption of poultry in Bangladesh remains very low by comparison with many neighboring countries. The current average annual consumption of poultry meat per person in Bangladesh is less than 2 kg per year, compared with almost 4 kg in Pakistan, 14 kg in Thailand, and 33 kg in Malaysia. Thus it is quite possible that the consumption of poultry and maize grain in Bangladesh could easily double or possibly even triple in the next 10 years, although bird flu presents some uncertainty to this. Reports from Bangladesh suggest that 32 mills operated by 17 enterprises are the main producers of poultry feed, while up to 30 companies sell feed to poultry farms (Feed E-News, Vol 6, No7, July 11, 2007). Official data show 160,000 poultry farms, along with about 136 breeder sites and hatcheries, now in operation. Nearly half of the chickens, however, are raised in very small "backyard" enterprises on millions of farms. Current poultry feed demand is about 2 million t per year of which 60% is maize grain (Feed E-News, Vol 6, No7, July 11, 2007, http://www.wattnet.com/newsletters/feed/pdf/jul06feednews.pdf). Another source, Salaque (2005), pointed out that in 2005 the actual demand for poultry feed was 1.8 million t of which maize demand was about 1.08 million t, which was very close to our present estimated production of 1.2 million t per year.

From Table 6 (prepared in consultation with stakeholders that included large-scale poultry businessmen, agricultural researchers, and maize farmers) we estimated that the demand of maize for poultry feed is increasing at about 15% per year and in 2030 Bangladesh might require 1.6 million t of maize. However, from the projection in Table 6, the maize area and production are currently increasing at a faster rate of 20% per year (Figure 2). The projection also hypothesized that the rise of alternative uses of maize grain other than poultry feed is 10% in 2006; it could increase at a 5% rate per year for cattle feed / fish feed / mixing with flour and for other human food along with industrial use. At the same time the price of wheat flour is increasing rapidly in the international market and locally. Domestic production of wheat has been decreasing—with only 0.97 million t of wheat produced in 2005 compared with 1.9 million t in 1999 (FAOSTAT)—due to adaptation problems and many more lucrative alternative crops that farmers can grow during the *Rabi* season; whereas it seems that the consumption of wheat flour, bakery products, and fast foods is increasing dramatically with the rapid urbanization of the country and increasing per capita income. Additionally, the food habits of urban people are changing due to chronic diseases like diabetes. The price of maize grain is around 40% lower than wheat. Thus the use of maize as an alternative human food should increase.

Even though arable land is scarce in Bangladesh, land on which to plant the extra maize should be available. Some of the arable land that traditionally has been planted to wheat in northwest and western Bangladesh has been switched to maize and this trend may continue. Additionally, many other areas of Bangladesh have land suitable for maize production (Figure 1). Thus the prediction (prepared in consultation with different stakeholders including big poultry businessmen, researchers and maize farmers) suggests that in 2030 Bangladesh would produce about 1.95 million t of maize grain against the poultry feed demand of 1.63 million t with about 35% of the maize for alternative use, including probable industrial use. Thus the available maize for poultry feed will be 1.26 million t and the deficit would be about 0.363 million t; approximately 22%. The projection indicates that maize production and its related value addition industries have a bright future in Bangladesh, if other conditions remain favorable.

Table 6. Present demand and future projected demand of maize grain as poultry feed and use of maize other than poultry feed in Bangladesh.****

Year	Demand (t)*	Maize area (ha)	Own production (t)**	Use of maize other than poultry feed (t)	Available maize for poultry feed (t)***	Apparent deficit (-)/surplus (+) for poultry feed (t)
2006	1,200,000	137,177	784,137	78,414	705,723	-494,277 (41%)
2010	1,272,000	164,612	940,964	141,145	799,819	-472,181 (37%)
2015	1,362,000	197,534	1,129,157	225,831	903,326	-458,674 (34%)
2020	1,452,000	237,041	1,354,988	338,747	1,016,241	-435,759 (30%)
2025	1,542,000	284,449	1,625,986	487,796	1,138,190	-403,810 (26%)
2030	1,632,000	341,339	1,951,183	682,914	1,268,269	-363,731 (22%)

* increase of poultry feed demand at 15% per year

** increase of maize grain production at 20% per year

*** considering per year 5% increase of maize grain use other than that for poultry feed, starting from 10% in 2006.

**** prepared in consultation with big poultry farm businessmen, maize growers and researchers

6. Availability of hybrid maize seed

For the current maize area in Bangladesh about 3000 t of hybrid seed is required per year. In 2006-07 the expected seed production was about 200 t by government agencies, principally Bangladesh Agricultural Development Corporation (BADC) and BARI. Bangladesh Rural Advancement Committee (BRAC) expected to produce 900 t, while private companies (principally Supreme Seed and East-West Seed) were to produce another 100 t. The remainder (around 60%) is met from imports, mainly from Thailand, India, Vietnam, and a few other countries. Therefore maize production in Bangladesh currently relies heavily on imported seed. However, in coming years private companies would be able be produce more seed of BARI-released hybrids, as they have signed an MOU with BARI, and have been provided with technology and training.

7. Farmer management practices for maize

Winter *Rabi* season maize is grown in Bangladesh with an intensive inputs and management package under irrigation on small fields with fertile alluvial soils, targeting high grain yields of > 6 t / ha. During the winter (November-March) season, temperatures and radiation are generally excellent for maize development and growth, although cold and foggy spells in December can delay crop establishment. Most maize is grown on deep fertile alluvial soils supplemented by large applications of NPK fertilizer. N fertilizer rates of around 200 kg N per ha are common (CIMMYT Office in Bangladesh, 2005 and 2006; Hasan et al., 2007). Maize is flat-planted in rows at approximately 53,000-66,000 plants per ha on conventionally tilled (often with a power tiller) land. Soil ridges are made after hand weeding.

Almost 100% of the maize area is planted with hybrid maize seed each year, mainly with single cross and double cross hybrids. Although maize has a wide planting window relative to some other crops like wheat and lentil, up to 57% of farmers plant within the period 1 November to 15 December, which is considered the optimal planting period for high maize grain yield in Bangladesh (CIMMYT Office in Bangladesh, 2005 and 2006; Hasan et al., 2007). Eighty-three percent of farmers weeded their crop within the recommended period of 30 days after crop emergence. Almost all the maize is sole cropped but farmers are interested to intercrop maize with early harvested vegetables, including potato, red-amaranth, spinach, radish, coriander, and French bean. Irrigation scheduling is well developed, with around 85% of farmers providing the optimal 2-4 irrigations at appropriate stages of crop development (Hasan et al., 2007). Increasing use of mechanical maize shellers and grain dryers make large-scale maize production more attractive.

While maize production practices and inputs are relatively well developed for the main *Rabi* season cropping, crop management practices for maize grown during the *Kharif-1* season on flatland and the *Kharif-1* and *-2* seasons on hill slopes in the Chittagong Hill Tracts are more variable and traditional. Mechanization opportunities with maize and rice need further exploring, as do possibilities of planting maize on raised soil beds and with zero tillage.

8. Prospects of maize production in *Kharif-I* season

Currently *Kharif-I* (pre-monsoon) maize, that is grown from March / early June, is cultivated only on 15,000 ha of hill slopes in the Chittagong Hill tracts and in Bogra, Rangpur, Comilla, Dhaka, and Rajshahi districts. On the main land (except in Bogra) most of the *Kharif-I* maize is grown after the harvest of potato in February / early March. *Kharif-I* maize requires only 100-110 days to maturity and produces 3-6 t / ha grain yield (with an estimated mean around 4 t / ha). For *Kharif-I* plantings, farmers prefer a double cross hybrid like Pacific-11 and non-hybrid cultivars. After potato harvest, farmers level their land and then manually plant the maize seed. They do not use PKS fertilizer because they believe that residual PKS from fertilizer applied to potato is sufficient for the maize. They do apply nitrogen (N) fertilizer as required. Thus the production cost of *Kharif-I* maize is less than for winter *Rabi* maize. Well resourced farmers and businessmen are anxious to cultivate maize after potato on a large area. As Potato-Maize is a highly productive and profitable cropping pattern, it seems that the area of *Kharif-I* maize could increase dramatically in coming years, as did winter maize. However, the risk of waterlogging, lodging, and post-harvest drying problems are significant. In 2007 the farmers of Paba in Rajshahi planted 5,000 ha of potato and then they planted 1,733 ha of *Kharif-I* maize (personal communication Nure-E-Alam, Scientific Officer, OFRD, BARI, Rajshahi). In

Bagmara (also in Rajshahi), farmers planted 8,000 ha of *Kharif-I* maize after the harvest of potato. Similar information is also emerging from other areas such as Comilla and Rangpur districts. Thus the research issues identified with *Kharif-I* maize need to be addressed in this area along with winter maize. In the *Kharif-I* season, competition with other crops is also less intense as vast potato lands and those planted to other early *Rabi* crops remain fallow. Potato growing areas of Rangpur, Dinajpur, Bogra, Rajshahi, Comilla, Jessore, and Mushijang could be the potential area (amounting to about 373,000 ha) for *Kharif-I* maize.

9. Comparative productivity, financial, and other benefits of maize

Among the three competitive crops in the *Rabi* season, hybrid maize has clear superiority over irrigated winter *Boro* rice and wheat. While maize is a high input crop, it has a very high output in Bangladesh (averaging 5.7 t / ha grain) that makes it more than two times as economic per unit land area as that of wheat or *Boro* rice alternatives. From hybrid maize, Tk. 49,000 / ha could be earned, whereas less than half of that is earned from *Boro* rice (Tk. 20532 / ha) or wheat (Tk. 20680 / ha) (Table 7). The benefit cost ratio of hybrid maize production is also higher (2.4) over *Boro* rice (1.53) and wheat (1.85). Maize requires far less water than *Boro* rice. Maize produces consistently higher output yields than *Boro* rice and wheat. In particular wheat is often vulnerable to temperature fluctuation resulting in shriveled grains and poor yield. Also, at present, maize has few pest and disease problems in Bangladesh in comparison with *Boro* rice and wheat.

Table 7. Comparative grain yield and economic benefit from Boro rice, wheat, and hybrid maize in Bangladesh.

Item	Boro rice	Wheat	Hybrid maize
Grain yield (t/ha)	5.9	2.5	8.4
Production cost (Tk/ha)*	38,468	24,320	35,000
Gross return (Tk/ha)	59,000	45,000	84,000
Gross margin (Tk/ha)	20,532	20,680	49,000
Benefit cost ratio	1.53	1.85	2.4

Source: Field survey and OFRD annual report (2007)
* Only variable cost is considered

10. Value addition from including maize in the cropping system

Maize provides several opportunities for Bangladesh farmers to increase their income from its use in poultry feed, fish feed, or cattle feed, and its mixture with wheat flour for chapatti. Additionally, extra value is obtained by some farmers in Bangladesh by feeding green maize leaves and stems to dairy cattle. One kg of maize grain, which costs the farmer Tk 4.11 to produce, is ultimately sold to a poultry farm owner at Tk. 16.5 / kg, with a value addition of more that four fold (Table 8). There could be variability in value addition within different regions of the country, but this has not been studied. Through this change of ownership and processing, a very large amount of money is circulated and tremendous amounts of employment are generated. It is estimated that at the present production level per year, maize grain of Tk. 3.22 billion becomes Tk. 12.92 billion by value addition (i.e. Tk. 9.7 billion is added, equivalent to 138.57 million USD). For the cultivation of 137,000 ha of land, 11,508,000 man-days (84 man-days labor per ha) employment is generated. An additional 1,568,000 man-days of jobs are created in drying, processing, packaging, and loading of maize for the present level of production in Bangladesh (200 labor-days for 100 t maize grain). Besides these, a large amount of employment is generated for feed processing and selling. Thus a job market of more than Tk. 1.5 billion (21.43 million USD) is created per year through maize production for the animal feed business in the country.

Table 8. Value addition of maize grain as poultry feed from the farmer to poultry farm owner in Bangladesh.

Farmer production cost per kg maize	Farmer selling rate to local market	Retailer selling price	Wholesale purchaser selling price	Miller selling price to feed businessmen	Poultry farm owner purchasing price
	(Tk/kg)				
4.11	10	12	13.5	15	16.5

- Only variable cost for production is considered
- Based on recent field survey
- 1US$ = 70 Bangladesh Taka (Tk)

B. Emerging Problems or Risks with Maize in the Maize-Rice Systems

1. Late planting of maize in *Rabi* (winter) season

In Bangladesh most of the winter *Rabi* season maize is planted after the harvest of *T. aman* (transplanted monsoon season) rice. Thus the planting of maize depends on the harvest time of rice, the speed of drying of the soil just after rice harvest, and farmer priorities on planting other *Rabi* season crops. Currently farmers cultivate *T. aman* rice cultivars that have a long development cycle (145-150 days, seed to seed) and farmers mostly harvest in mid-November to early December. There are some shorter duration varieties with a slightly lower yield potential, but few farmers adopt those rice varieties. Since rice is their food security, they do not want to sacrifice rice yield. This means that most maize farmers plant their maize in the second or third week of December, after other *Rabi* crops (including wheat and various pulses) that must be planted earlier because of adaptation needs. Temperatures in mid-December are often low (average 23º C max. 11º C min.) and this late planted maize takes around two weeks to germinate due to cold winter weather and grows slowly, which leads to comparatively low yield. Late planting (20 December onwards) may cause yield losses of 22% or more when further delayed (Figure 6). The necessary later harvesting of the late planted crop makes it vulnerable to early monsoon rain, when post-harvest processing becomes difficult. This raises the moisture content of maize and the incidence of cob rot diseases resulting in poor quality grain and ultimately a low market price. Late planted maize also has an increasing danger of lodging and waterlogging later in crop development because of pre-monsoonal storms called *Kalboisaki* that increase in frequency during March and April. These storms can cause immense damage to maize crops by inducing plant lodging at later stages of crop development.

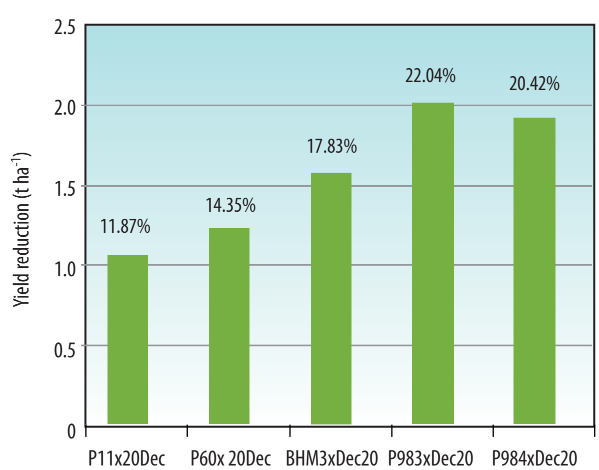


Figure 6. Grain yield reduction in maize from planting on 20 December compared with a 20 November planting at Rangpur, Bangladesh, 2004-05 season (Source: Ali, 2006).

2. Use of recycled hybrid maize seed by farmers

Uncertain availability of hybrid maize seed in nearby markets at a fair price can sometimes cause resource-poor farmers in Bangladesh to use recycled seed harvested the previous year from maize crops planted with F_1 hybrid seed. In 2007-08, hybrid maize seed prices were at least Tk 300-400 (USD4.5-5.8)/kg. Unavailability of hybrid seed is an issue in more remote or non-traditional maize growing areas. It is estimated that around 20-25% of maize farmers are using seed recycled from hybrids across the country (personal communication OFRD, Kushtia and Rajshahi offices). This results in 20-40% lower yield (personal communications with farmers and CIMMYT Office in Bangladesh, 2005; 2006). This does not seem to be a very common issue, but a survey may be needed to confirm its extent. Thus the timely and local availability of hybrid maize seed at a fair price is important. To keep the price reasonable there needs to be competition among public and private seed producers and dealers. Farmers need motivation and training so that they can understand the importance of F_1 hybrid seed and the benefits expected with using F_1 seed compared with recycled seed.

Picture: Hybrid maize seed being kept on the cob for planting next year by a farmer in Daulatpur, Kushtia, Bangladesh. (Photo by M Yusuf Ali)

3. Unsustainable soil management in maize-rice systems

To grow maize and rice, almost opposite soil environments are required. Maize needs loamy soils of good tilth and aeration whereas rice needs well puddled wet clay soils with high water holding capacity. Thus after the harvest of *T. aman* rice, to make the soil suitable to plant maize, good and deep tillage is usually needed, along with adequate (but not excessive) soil moisture for germination of maize seed. This is often difficult to achieve due to lack of proper tillage equipment, shortage of time and unavailability of irrigation. Puddling in the rice phase leads to loss of soil structure (which may be sustainable for continuous rice but can increase soil structural problems for aerobic crops) while excessive tillage for maize contributes to the loss of organic soil matter and nutrient depletion. There are major doubts about whether such soil management practices, especially those for maize, are sustainable long term. Thus the development of sustainable alternative cropping patterns, tillage management options, and integrated plant nutrient systems (IPNS) are important for intensifying maize-rice systems.

4. Productivity stagnation of maize in traditional areas and soil fertility depletion

Maize-rice systems in Bangladesh are dominated by long duration exhaustive cereal crops. Although Bangladeshi maize yields are currently among the highest in the tropics, over the last three or four years signs of stagnation and possibly decline in maize yields have started to emerge. This has led to concern that continuous production of high yield maize will lead to depletion of mineral nutrients from the soils unless appropriate nutrient inputs are given and management followed. Soil nutrient depletion is often accelerated with maize versus rice or wheat because of the higher biomass production, greater nutrient requirements, and increased nutrient removal. As a C_4 crop, maize planted in the *Rabi* season can produce about 10 t/ha of grain and 12 t/ha non-grain biomass. To produce such high yields, maize plants must take up about 200 kg N, 30 Kg P, 167 Kg K, and 42 Kg S ha^{-1} (BARC, 2005). Such high uptake of nutrients makes the land less fertile for the succeeding crop unless excellent soil nutrient management practices are followed. However, farmers mostly apply unbalanced fertilizers, particularly with low amounts of PKS and other micro-nutrients. Experimental results (OFRD, 2006) have shown that in Maize-*T. aman* cropping patterns, the apparent nutrient balance was highly negative for N and K (-120 to -134 and -80 to -109 kg / ha, respectively), while P balance was positive (15 to 33 kg / ha). Other results for rice-wheat-maize / mungbean cropping systems in Joydebpur, Ishwardi, and Dinajpur (see Panaullah et al., 2006; Saleque et al., 2006; Timsina et al., 2006) reveal negative to positive balances for N (-64 to +62 kg / ha), a negative balance for K (-25 to -212 kg / ha), and a positive balance for P (9-50 kg / ha) for treatments ranging from zero N to farmers' management N to soil-test based N. Positive N balances occurred in treatments where large amounts of N were applied to *Kharif-1* maize following wheat (Panaullah et al., 2006; Saleque et al., 2006; Timsina et al., 2006).

Discussions with farmers and DAE staff in Rangpur and Dinajpur indicated that grain yields have been decreasing where maize has been grown on the same land for the last 5-10 years. Their experience is that by applying large amounts of cattle manure, the yields can be sustained. However, given declining cattle numbers and widespread use of cattle dung as a fuel, large amounts of cattle manure are not available and can only be applied to small land areas each year. Staff members from the DAE extension service were especially concerned and expect maize yields to decline drastically within 10 years. We need to understand more about the extent and rate of such degradation and the amelioration strategies that are possible in the intensifying of rice-maize based systems found in Bangladesh. Further work on production agronomy and on maintaining the sustainability of cropping systems by addressing soil mineral and organic fertility and maintenance of soil structure is required.

5. Waterlogging

In a recent maize traits identification and prioritization study, in part covering maize grown in the Bangladesh rice systems (see Gibbon et al., 2007), several abiotic stress traits and associated management issues were identified by panels of experienced informants to be among the most important constraints to maize production. These included flooding / waterlogging and drought.

Waterlogging risks are significant later in crop development for late planted winter *Rabi* maize on the heavy clay soils that are used in the rice-maize systems. Waterlogging and flooding currently prevent farmers from investing in high input / high output maize grain production into the *Kharif-1* season in Bangladesh. In the *Kharif-1*, farmers can only safely site on top fields and lighter soils. Initial crop establishment on wet soils after *T. aman* rice can be an issue, but waterlogging of well established crops in later stages of development is an increasing risk later in the *Kharif-1* cropping season in April and May when there are frequent heavy rainstorms leading into the pre-monsoon. Management options have a big role here; for example, planting maize on raised soil beds or ridges is an option worth further study.

6. Irrigation difficulties and drought

In many parts of Bangladesh in the dry *Rabi* and *Kharif-1* seasons during February to May, the water table can fall below the reach of traditional shallow-tube wells (that are frequently used for irrigation), and thus often irrigation fails. Grain filling of the maize crop can be reduced, producing low yields of poor quality grain. Irrigation is becoming costlier and more uncertain than before due to acute shortages and high prices of electricity and rapidly increasing prices of diesel, by which most shallow tube wells operate. Nevertheless, maize needs only 2-5 irrigations depending on soil conditions compared with 20 or more for *Boro* rice. Excessive pumping of ground water is one the main reasons for arsenic contamination problems in Bangladesh. Additionally, in some central, southern, and eastern parts of Bangladesh farmers depend initially on residual soil moisture and then rainfall for their *Rabi* and late *Rabi* season maize. Some maize is grown on lighter soils and on residual moisture in riverbed *Char* lands. Maize in these areas frequently suffers from drought, as winter rainfall is rare.

7. High price of mineral and organic fertilizers

The production of high yield maize (and rice) in Bangladesh is increasingly dependent on the availability of cheap N and other fertilizers. Most N fertilizer is currently available as synthetic urea made from natural gas extracted inside Bangladesh. However, proven reserves of natural gas are sufficient for little more than 10 years of current consumption. Application of balanced and optimum amounts of fertilizers is one of the key factors to obtain high and profitable yield of hybrid maize, particularly because hybrid maize requires more nutrients than most other crops. But the prices of imported fertilizers (N, P, K, S, Zn, B) have more than doubled in recent years and locally produced urea-N is in increasingly short supply. Shortages are encouraging unscrupulous fertilizer traders to adulterate fertilizers with inert ingredients. In this situation, most resource-poor farmers are applying N fertilizer at rates near the optimum on maize, but under-dosing other essential nutrients. This is one of the reasons for the stagnating yield of hybrid maize in some parts of the country (personal communication with farmers of Rangpur and Ghoraghat in Dinajpur). Additionally, as the cattle population is decreasing on many farms and much dung is used for fuel, so the use of organic manure on fields is going down. All of these developments are detrimental for soil health and maize crop productivity.

8. High production costs for maize and credit shortages

Hybrid maize is a high value crop. Its cultivation cost (about 35,000-40,000 Taka / ha, i.e. USD 500-571 / ha) is also higher than most other *Rabi* crops. It needs a large amount of N and other fertilizer to approach its high potential yield. However, as indicated in the previous section, urea is likely to become increasingly scarce and its costs are already rising. Hybrid maize seed is also costly. For resource-poor farmers it is difficult to bear all those costs at a time and this can mean that poorer farmers can only afford small areas of hybrid maize. Thus the ready availability of soft credit is important to maintain high average yield over large areas. The government of Bangladesh is providing loans at a low 2% interest rate for a high value crop like maize but it can be difficult for poor farmers to access such loans. In practice, public bankers have many formalities and can demand “speed money.” Alternatively, loans from NGOs, are easy to get but are very costly (with interest rates often around >30%). Other forms of financial support such as revolving funds are needed.

9. Risk of bird flu reducing the demand for poultry feed

Bird flu or avian influenza caused by the H5N1 virus is a devastating disease for poultry that can also affect humans. The disease was reported in Bangladesh during the 2007 and 2008 *Rabi* dry seasons (the period when many migratory birds come to Bangladesh) when it caused significant losses of poultry and increasing concern that it will reduce the demand for feed, including maize. To date (late March 2008), there are no reports of human infection with H5N1 virus in Bangladesh. The disease was first reported in March 2007, when 32 farms located in eight districts of Bangladesh were affected by this disease and at least 79,000 chickens were culled. Consumer confidence in poultry products declined for some weeks but demand for poultry and maize grain to feed them rebounded such that farmers again planted more land with maize in the 2007-08 season.

Expert opinion was that bird flu was likely to recur during the next dry season (i.e. November 2007-April 2008), despite various veterinary bio-security precautions being taken. A new outbreak occurred in mid-January 2008, spread very quickly, and has led to substantial losses in the industry. As of the third week of March 2008, estimates were that around 40% of the 150,000 poultry farms had been affected by bird flu. Over 1.3 million birds have been culled, and industry losses could be as high as USD 735 million. Again at the onset of the outbreak, poultry prices fell drastically, but increased during March.

Expectations had been that such large losses in the poultry sector would reduce maize grain prices, but prices have remained robust. Early maize from western districts was on the market in late March at around 7.5 taka per kg for fresh grain and 12 taka per kg for dry grain (personal communication Ittafaq, 19 / 3 / 08). Prices appear remarkably stable because demand from the poultry industry remains optimistic, prices of maize grain in international markets are high because of use to make bio-fuel, and the mixture of maize flour with wheat flour is increasingly common due to the high price of wheat. Newspaper reports in early 2008 claim that about 20-40% of maize flour is now mixed with wheat flour to reduce the price of flat breads.

While it is impossible to predict the consequences of endemic bird flu for maize grain demand in Bangladesh, it is likely that demand for poultry products will remain robust since human population and income are expected to continue to rise, few cheap alternatives are available, and because Bangladesh cooking habits are such that most poultry products are eaten well-cooked as fried eggs or in meals such as curries, making a major spread to humans unlikely. The poultry industry of Bangladesh has proved to be an extremely economic means of supplying cheap protein in highly desirable forms for many in the country. Investment in the poultry industry is 12,000 crore Taka (USD 171.43 billion) and five million Bangladeshis are directly or indirectly associated with poultry farming. From 125,000 small and large farms, around 250 million broilers and six billion eggs are produced annually (www. flutrackers.com / forum /). It seems that in the next few months to few years the likely continued outbreaks of bird flu will temper the demand for maize grain only to the small extent that it may result in a reduced growth rate in demand and supply, but will not reverse it.

10. Lack of information and training for farmers

The very high potential productivity of maize in Bangladesh has yet to be fully achieved. A recent yield-gap trial on farmers' fields showed that achieved yields of more than 3 t / ha below optimal (Table 9a and 9b) are due to gaps in farmer knowledge along with other socio-economic factors. For the cultivation of a new crop like hybrid maize, information and technology needs to flow to and among farmers. Thus hands-on and audio-visual aided training such as "Maize Whole-family Training (WFT)" (Hasan et al., 2007) is important (Figure 7). Farmers lack information on proper crop management practices such as time of planting, optimum doses of different fertilizers, the application of micronutrients like Boron, weeding, and irrigation at crucial stages of crop development. Farmers usually receive advice from input retailers, DAE extension workers, and lead farmers. Retailers, however, are not always able to provide good advice due to their own limited understanding of farming methods. DAE workers are often not available. Lead farmers generally do not have an incentive to share information and technology with other farmers. As a result, in practice, farmers often have to depend on their own experience.

Table 9a. Yield gap between farmers' own practice plot and researcher-guided farmer plot, at MLT site, Manikganj, Bangladesh during 2006-07.

Management practices/factor	Level of technology employed	
	Researcher-guided farmer plot (RGFP)	Farmers' own practice plot (FOPP)
Variety	BARI Hybrid Maize-3 and 5	Pacific-11
Plant spacing (cm)	75 x 25	75 x 20
Seed rate (kg/ha)	11.25	18
Plowing by tractor (No.)	3-4	2-3
Human labor (man-days/ha)	46	31
Sowing time	18 November	1 December
Fertilizer (kg/ha):		
Cowdung	5,000	2,000
N	256	276
P	55	56
K	144	50
S	34	26
Zn	13	-
B	1	-
Weedings (No.)	2	1
Insecticides used	Dursban, Furadan	Dursban
Irrigations (No.)	2	1
Harvesting time	17-26 April	2 May
Grain yield (t/ha):	BHM-3: 9.95 BHM-5: 11.27	Pacific-11: 7.16
Stover yield (t/ha):	BHM-3: 12.44 BHM-5: 14.09	Pacific-11: 8.93

Yield Gap: 3.45 t/ha (33%)

Table 9b. Comparative economic advantage among researcher-guided and farmer's own maize plots.

Management practices/factor	Researcher-guided farmer plot (RGFP) (Tk./ha)	Farmers' own practice plot (FOPP) (Tk./ha)	Gap between RGFP and FOPP (Tk./ha)
Total variable cost	38,391	24,678	13,659
Gross return:	BHM-3: 120645 BHM-5: 142285	Pacific-11: 76,065	58,255 (42%)
Gross margin:	BHM-3: 83052 BHM-5: 104692	Pacific-11: 51,333	44,995 (45%)
Benefit/Cost ratio:	BHM3: 3.14 BHM-5: 3.71	Pacific-11: 3.08	-

BHM-BARI Hybrid Maize (Source: OFRD, 2007)

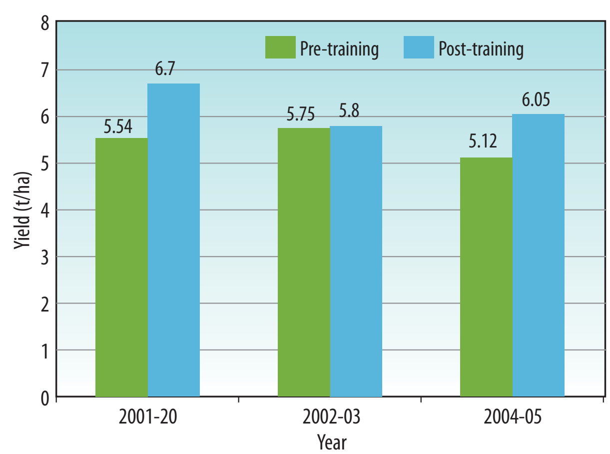


Figure 7. Comparison between pre-training and post-training grain yield of maize with farmers in Bangladesh (Source: CIMMYT Office in Bangladesh, 2006).

Where training such as WFT has taken place for maize it has had major benefits. A large USAID-CIMMYT whole-family training program, conducted for maize in Bangladesh from 2001 to 2006, had a tremendous impact on modern maize cultivation, promotion, and increased production. Over 1,100 trainers from a variety of GOs, NGOs, and private organizations were exposed to modern maize cultivation practices using the WFT concept. They are now knowledgeable on maize production and have been training other staff and farmers. Nationally, around 13,000 farm families (or 36,000 maize growers) from 35 of the 64 districts in Bangladesh were taught modern maize production practices. Of these, 11,000 received training specifically from the USAID-funded CIMMYT and partner program. Numerous training materials were prepared and distributed, including 20,000 manuals in Bangla, hundreds of large posters, and CDs on modern maize cultivation and utilization.

Maize improvement training manuals were made for and used by scientists and field level workers along with manuals on modern hybrid maize seed production for the scientists, seed producing agencies, and students.

WFT has resulted in higher production of maize through trained farmers and increased the demand for quality hybrid seed for planting. Families who participated in maize WFT obtained about 1.5 t more yield per ha compared to the non-trained farmers (Hasan et al., 2007). Trained families increased their maize area and production, which improved their livelihoods. The WFT concept has been adopted by other organizations like the DAE and Winrock International. While a total of around 20,000 farm families have been trained in maize WFT in all these programs (Hasan et al., 2007), additional farmers in other parts of the country are interested to receive training to grow maize.

C. Promising Technology Options for Maize-Rice Systems

1. Promising maize hybrids from BARI

Largely based on germplasm from CIMMYT, and often direct crosses of CIMMYT maize inbred lines (CMLs), BARI has developed and released seven maize hybrids. Among them, BARI Hybrid Maize 5 is a high yield quality protein maize (QPM), with a yield potential of 11 t / ha. The normal grain BARI Hybrid Maize 3 has also the potential to produce 11 t / ha grain. These two BARI developed hybrids consistently produce high grain yields under field conditions that are comparable with or better than other commercial hybrids (Table 10) (CIMMYT Office in Bangladesh, 2005; 2006), and they are proving very popular in Bangladesh.

Table 10. Grain yield of BARI-developed maize hybrids across 10 locations in Bangladesh, 2005-06 (Ali, 2006).

Location	BHM2	BHM3	BHM5	Pacific11
Comilla	8.1	7.3	6.3	-
Rangpur	7.3	10.1	9.5	-
Mymensingh	10.3	9.9	9.8	-
Patuakhali	9.7	11.4	10.0	-
Kushtia	8.0	7.5	8.5	7.3
Jhenidah	9.2	9.5	8.2	-
Tangail	8.7	9.3	8.7	10.1
Faridpur	12.5	11.9	11.5	11.5
Barind, Rajshahi	7.0	8.5	6.3	-
Manikganj	5.5	8.9	9.0	-
Mean	8.6	9.4	8.8	9.6
SDEV (±)	2.0	1.5	1.6	-

2. Early-maturing high-yielding *T. aman* rice varieties

Early-maturing high-yielding *T. aman* rice varieties are an immensely important option that will allow the early planting of maize. Currently, three short duration (118-130 day) rice varieties (BRRI dhan 32, 33, and 39) are available, but their grain yields are low (2.8-3.5 t / ha) compared to popular long duration varieties like BRRI dhan 10 or 11 or Swarna (4-5 t / ha). Most farmers are reluctant to sacrifice rice yield because it is their main staple food. Their culture is to first ensure food security, then profit. However, gradually some farmers are adopting short duration rice varieties to ensure better profit from high value *Rabi* crops like hybrid maize. The Bangladesh Rice Research Institute (BRRI) is trying to develop suitable short duration *T. aman* rice varieties that have yield and quality comparable with traditional varieties (personal communication Dr M Anser Uddin, BRRI, Rajshahi).

3. Profitable intercrop/relay crop options with hybrid maize

Rabi season hybrid maize is a long duration (145 day) crop, but resource-poor farmers want quick returns from their investment. The maize crop is spaced on rows 75 cm apart and canopy closure happens only after 45-50 days. Through intercropping / relay cropping of maize, the productivity of a unit of scarce land could be increased considerably. During this early period of maize crop development, the production of quick growing vegetables such as spinach and red amaranth is very feasible and economical; it provides early additional income without reducing maize grain yield (CIMMYT Office in Bangladesh, 2005; 2006) (Table 11). Relay cropping of maize 20-35 days after the planting of potato can bring very high profit, providing 20-21 t/ha maize equivalent yield within five months (Figure 8 and Table 11) (CIMMYT Office in Bangladesh, 2005; 2006). Thus intercropping and relay cropping are becoming more popular among the subsistence farmers. Such diversified and highly profitable systems can be promoted.

Picture: View of intercrop/relay crop with hybrid maize. Upper photo is maize+red amaranth and lower one is maize+potato. (Photo by M. Yusuf Ali)

4. Nitrogen management options

N is the key major element needed for the growth, development, and yield formation of the maize crop. A large amount of N (>250 kg N ha-1) is required to achieve the very high grain yields (10+ t/ha) possible with hybrid maize in Bangladesh. At the same time N fertilizer is costly and likely to become more so in Bangladesh in coming years, as natural gas and urea supplies fall. Most N fertilizer in Bangladesh is in the form of urea made from natural gas which is projected to last no more than 10 years. Thus, as well as seeking new more sustainable sources of N, the rational and timely use of N fertilizer is important. N management recommendations for maize are available (BARC, 2005). Most maize farmers in Bangladesh generally try to follow the current recommendation, which is to apply $^1/_3$ N as a basal dressing during land preparation, $^1/_3$ at the 8-leaf stage, and the remaining $^1/_3$ at tasseling. Because the crop is tall and dense, the last application is very hazardous and can injure the skin and eyes of farmers, so many farmers avoid the last application, reducing yield. Researchers of the On-Farm Research Division (OFRD) of BARI

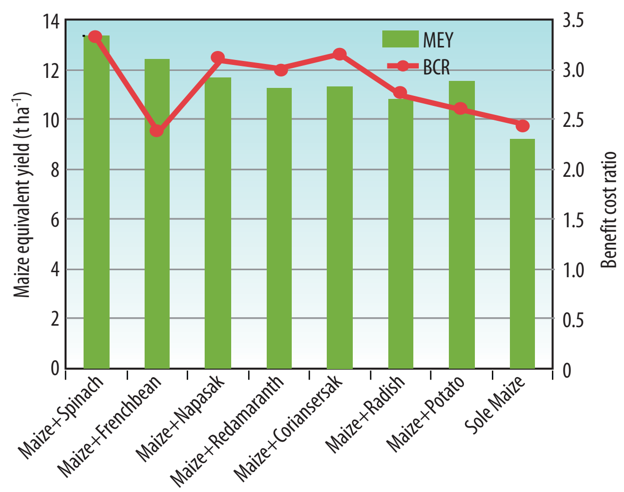


Figure 8. Comparative maize equivalent yield and benefit cost ratio of different intercrops and sole hybrid maize.

Table 11. Yield of potato, maize and equivalent yield (MEY) as relay crops in Bangladesh.

	Potato yield (t/ha)		Maize yield (t/ha)		MEY (t/ha)		
Treatment	**Rangpur**	**Pabna**	**Rangpur**	**Pabna**	**Rangpur**	**Pabna**	**Mean**
Same day potato +maize planting	15.8	10.9	8.3	8.7	17.9	18.4	18.2
Potato planting 20 days before maize	17.7	12.4	9.9	8.1	21.7	19.1	20.4
Potato planting 35 days before maize	20.1	15.4	9.4	7.3	22.6	21.0	21.2
Sole maize	-	-	10.4	9.2	10.4	9.2	9.8

Source: Ali, 2006

(OFRD, 2006) found that N could be applied at two splits: half as a basal dressing and the remaining half at the 8-leaf stage, or 30% as a basal dressing and the rest at the 8-leaf stage (Figure 9). In this way a potential health hazard could be avoided and less labor used without losing yield. Farmers are more likely to follow such a new recommendation, which should be promoted.

Additionally, by using N as urea super granules (USG; or mini brickettes) instead of traditional prilled urea, 10% N could be saved (OFRD, 2007) without losing maize yield. USG is prepared by applying pressure on prilled urea by a mini-brickette-making machine, and the product looks like a white naphthalene ball (Table 12). Such machines are now widely available because of interest for rice and the resulting 'Guti' urea is already quite widely and increasingly used for rice (Setty et al., 1987; Singh and Singh, 1986). However, research data on the application of USG to hybrid maize is still preliminary. More comparative trials across locations are needed to formulate a recommendation. Such work would form a synergy between rice and maize agronomists in Bangladesh.

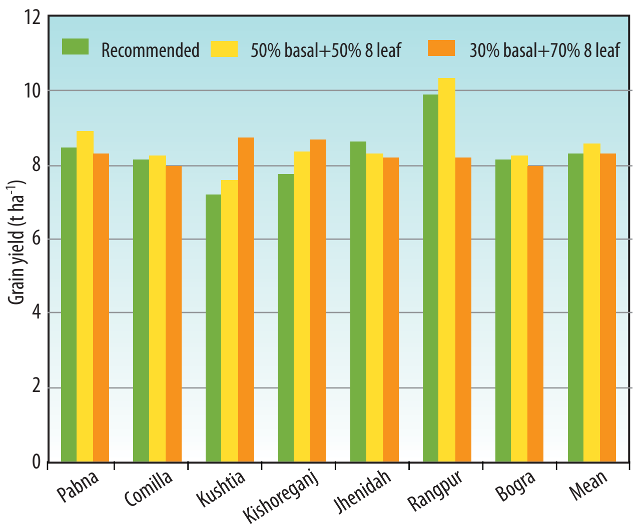


Figure 9. Grain yield of maize (BHM5) as affected by Urea-N application, 2005-06.

To reduce the possible detrimental effects of continued over-use of inorganic mineral fertilizer on the soil, integrated plant nutrient systems (IPNS) techniques are necessary. These would apply organic matter sources and manures in combination with inorganic fertilizers to maintain soil health and system sustainability. Various opportunities to better use crop residues and animal waste products exist in Bangladesh through composting. While cattle manure is becoming scarce, poultry manures are now commonplace. Currently Bangladesh produces about 1.63 million t of poultry manure per year with a good amount of N and other essential elements, but still it is rarely used. Chemical fertilizers combined with 25% of poultry manure gave good results with maize (OFRD, 2007) in a preliminary study (Table 13). However, more research work is needed to develop conclusive recommendations.

5. Boron application to maize on light soils of the northern region

Boron (B) is an important micronutrient needed in small amounts for grain formation. In B-deficient soils, it must be applied to raise the efficiency of use of traditional macro nutrients (NPKS) and obtain better yields with hybrid maize. The problem is widespread in the increasingly important maize areas of northern Bangladesh and in char (seasonally flooded river bed and floodplain) areas. Many farmers in B-deficient areas are still unaware about the importance of B for their light soils. In those conditions, by applying 2 kg B ha^{-1}, grain yields of maize can be doubled, compared to those without B (Table 14; OFRD, 2007).

Table 12. Yield and other yield parameters of hybrid maize as influenced by source and amount of nitrogen in a char land situation of Bhuyapur, Tangail, Bangladesh during 2006-07.

Amount and form of N fertilizer (kg/ha)	Plant height (cm)	Cob length (cm)	Cob breath (cm)	Grain/ cob (no.)	Grain wt/ cob (g)	1000-grain wt. of (g)	Grain yield (t/ha)	Stover yield (t/ha)
256 N as prilled urea (recommended dose)	215.2a	18.7b	15.2b	430b	182.3a	445.2a	8.9b	9.8b
256 N as USG	220.2a	19.7a	16.4a	455a	185.6a	455.3a	9.8a	10.2a
230 N as USG (10% les than recommended dose)	217.7a	20.1a	16.4a	448a	184.3a	452.5a	9.8a	10.4a
204 N as USG (20% less than recommended dose)	208.7b	18.5b	15.0b	408b	165.7b	420.4b	8.8b	9.3b
Farmer's dose	190.0c	16.4c	14.9c	368c	146.5c	390.5c	7.3c	7.4c
CV (%)	9.85	8.99	5.99	6.15	8.26	6.44	9.29	12.37

Note: Char lands are lands on river beds and near floodplains that are flooded during the monsoon but cropped during the dry season as flood waters recede.

6. Plant population density optimization for hybrid maize

Earlier research on maize plant population densities was conducted for open pollinated varieties and synthetics in Bangladesh during the 1980-90s. Much of this research concluded that plant densities of around 66,000-80,000 plants / ha were optimal (e.g. Alam et al., 2003). More recent research with hybrids is very limited. Preliminary results with varying plant population densities of hybrid maize (using BHM 2 and 5) in the long duration-145 days *Rabi* season indicate that there is no marked difference in grain yields for densities from 44,444 plants / ha (75 cm x 30 cm) to 133,333 plants / ha (75 cm x 10 cm). Apparently 53,333 plants / ha (75 cm x 25 cm) gave a slightly higher yield (CIMMYT Office in Bangladesh, 2006). More in-depth study is needed to identify the physiological basis for this. Researchers elsewhere found that the yield response to plant density was greatest for shorter-season hybrid maize and least for the long-duration hybrid maize (Sarlangue et al., 2007; Edwards et al., 2005). In Bangladesh all currently available *Rabi* season maize hybrids are long-duration (145 days), which may be the reason a response to a higher plant population density is not visible. Farmer plant densities with the current hybrids are often around 66,000 plants / ha (Hasan et al., 2007). Farmers may save costs of expensive hybrid seed if a recommendation of 53,333 maize plants / ha (75 cm x 25 cm) were promoted.

7. Use of mechanized planters

Early planting within the optimum time period is important to achieve a higher proportion of the yield potential with *Rabi* season hybrid maize. The turnaround period between the harvest of *T. aman* rice and maize planting is very narrow in Bangladesh. Mechanized planters for sowing maize seed rapidly on large areas of flat land would be helpful. Wheat Research Centre (WRC) of BARI has developed a multiple power-tiller-operated seeder (PTOS) (Hossain et al., 2002b) originally for wheat, which is suitable for maize after simple modification. The PTOS has been modified with cup seed mechanisms for maize and other big seeded crops and has been used successfully to plant maize on farmers' fields (personal communication Enamul Haque, CIMMYT office, Dhaka; CIMMYT Office in Bangladesh, 2005 and 2006). Additional units of the maize PTOS need to be built, tested, marketed, and promoted with farmer planting service providers, in cooperation with interested private farm implement companies such as Green Machinery Stores.

Table 13. Effect of different treatment on the yield of Maize and T. aman under a Maize-T. aman cropping pattern at the Pushpapara FSRD site, Pabna, Bangladesh from 2003-04 to 2005-06.

	2003-04		2004-05		2005-06		Mean	
Treatments	**Maize**	***T. aman***	**Maize**	***T. aman***	**Maize**	***T. aman***	**Maize**	***T. aman***
Grain yield (t/ha)								
100% Inorganic	7.1a	5.4a	7.5b	4.6ab	7.7b	4.4b	7.5	4.8
75% Inorganic + 25% PM	7.3a	5.5a	8.4a	4.2bc	8.3a	4.5ab	8.0	4.7
50% Inorganic + 50% PM	7.1a	5.7a	7.2b	4.8a	7.3b	4.9a	7.2	5.1
25% Inorganic + 75% PM	6.6b	5.7a	7.1b	4.1c	6.6c	4.5b	6.8	4.7
100% PM	6.0c	5.5a	6.1c	4.2bc	6.0d	4.2b	6.0	4.6
Control	3.8d	2.9b	4.3d	3.2d	4.2e	2.6c	4.1	2.9
LSD (0.05)	0.3	0.25	0.67	0.42	0.50	0.34	-	-
CV (%)	4.4	4.0	8.4	8.4	6.3	5.4	-	-

PM = Poultry manure

Table 14. Yield and yield contributing characters of maize as influenced by Boron fertilizer application at Serudanga, Rangpur, during 2006-07.

Treatment (B kg/ha)	100 grain weight(g)	Plants/m2 (no)	Plant height (cm)	Ear height (cm)	Cob length (cm)	Cob breadth (cm)	Grains/ cob (no)	Grain yield (t/ha)	Yield increase over control (%)
2.00	32.2a	5.8	250	133.3	22.8a	16.4a	570.1a	10.1a	94.2
0.75	29.9ab	5.6	251	132.4	20.2ab	15.3ab	467.6b	7.5b	44.2
0	27.5b	5.8	253	123.7	17.3b	13.5b	322.3c	5.2c	-
CV (%)	4.57	6.60	6.14	7.18	6.46	5.44	7.19	9.43	-

Source: OFRD, 2007.

8. Bed system planting for *Kharif* maize

Soil beds or ridges will be an important management option for maize growing in increasingly wet conditions in the *Kharif 1* season. This would build on the extensive work that has been done on the development of hand-tractor-mounted ridging equipment for rice-wheat systems (Hossain 2004a and b) and now increasingly rice-maize systems in Bangladesh. The suitability of soil beds for rice is less clear. Indications are they may not work unless rainfall is very high and the beds are essentially saturated throughout the season. Making the soil beds for maize followed by destruction of soil beds for rice may not be practicable, being labor- and equipment-intensive, and may negate potential benefits. Semi-permanent soil beds may not be such a good option for the light-textured upper fields that are the target for maize in the wet season.

Significant improvements to and testing of soil bed formers and bed planters have been made at Dinajpur in the WRC-BARI / CIMMYT farm machinery program in recent years (Waddington et al., 2006). A power-tiller-operated bed former and planter that simultaneously creates a trapezoidal raised bed and performs seeding and fertilizing operations on the top of the bed in one operation behind a two-wheel tractor can now handle flexible bed sizes and soil clumps. Bed formation and seeding is done by introducing a modified shaper; replacing the regular press roller of the PTOS behind the seeder. Performance of the implement was tested for wheat, maize, mungbean, and rice cultivation (Figure 10). After initially forming the bed, an additional advantage is that a reshaped bed can be used for crop cultivation without any further tillage operation. However, on-farm tests of this equipment by WRC suggest the resulting crop growth on beds may be more variable than in conventional systems. This equipment needs wider on-farm testing in Bangladesh before BARI or DAE will promote it.

Picture: Soil bed former and planter for light soil being used in Bangladesh. (Source: Enamul Haque, 2003)

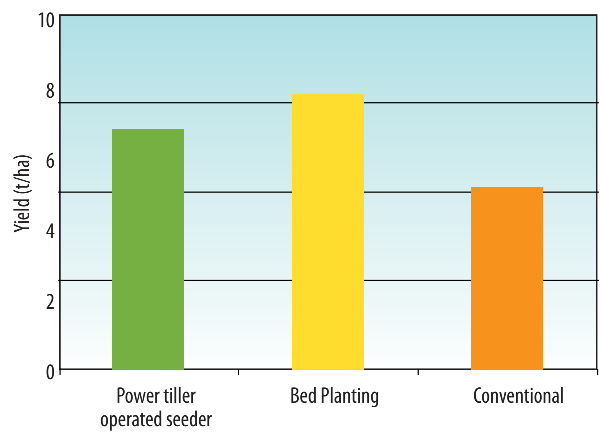


Figure 10. Comparative hybrid maize yield between planting on soil beds and other planting systems in the light soils of Dinajpur, Bangladesh, 2004-05.

D. Yield Potentials of Rice and Maize

1. Yield potential of rice and maize

Choice of varieties/hybrids and planting dates: Successful intensification of cropping systems requires selection of suitable crop varieties and hybrids of varying maturities with high yield potential. Depending on the local climate and soils, water resources and irrigation sources, and technologies available, farmers may choose varieties and hybrids of a range of maturity types and plant the crops at appropriate planting dates. Thus, it would be useful to determine theoretical yield potentials of several varieties and hybrids over the entire year so that appropriate hybrids or varieties and suitable planting dates may be chosen to fit into the local crop calendars. Rice yield potentials for four rice varieties with seed sowing on the first day of each month for Bogra and Dinajpur districts were determined using the ORYZA2000 simulation model (Bouman et al., 2000). Likewise, maize yield potentials for four hybrids with planting on the first day of each month were determined using the Hybrid Maize simulation model (Yang et al., 2004). Rice varieties of four maturities / growth durations (extra early, early, intermediate, and late) were chosen. These varieties mature in 80-90 days, 90-100 days, 105-115 days, and 125-140 days, respectively, under conditions at IRRI-Los Baños. The extra early, early, and late varieties were created by changing the development rate during the panicle development phase (DVRP) and development rate during reproductive phase (DVRR) coefficients used in the model. DVRP for those varieties at Los Baños were 0.0014, 0.0010, and 0.000999, while DVRR were 0.003, 0.0026, and 0.001, respectively. DVRP and DVRR for an intermediate maturity type (IR72) were 0.000784 and 0.001784 for Los Baños conditions, and were adapted from Bouman et al. (2000). For maize yield potential, four hybrid maturities with growing degree days (GDD) of 1,400, 1,500, 1,600, and 1,700 were selected. The growth durations for rice varieties and GDDs for maize hybrids would change for Bangladesh conditions due to cooler temperatures in the *Rabi* (winter) or *Boro* rice season.

Rice: Mean yield potentials of extra early, early, intermediate (IR72), and late rice varieties for Dinajpur ranged from 4.5 to 8.0, 5.5 to 9.0, 6.0 to 12.0, and 8.0 to 14.0 t / ha, while that for Bogra ranged from

4.5 to 8.0, 5.0 to 9.5, 6.5 to 11.0, and 8.0 to 13.2 t / ha, respectively. Yield potential was slightly higher for Dinajpur than for Bogra and was always higher for the winter (*Boro*) season (1 Dec. - 1 Feb. planting) than for the *Kharif-1* (*aus*) and *Kharif-2* (*aman*) seasons (1 April - 1 Nov. planting). The corresponding mean growth durations for those varieties ranged from 80-130 days, 90-140 days, 105-150 days, and 125-178 days, respectively, in Dinajpur, and 80-120 days, 90-130 days, 105-145 days, and 125-168 days, respectively in Bogra. The growth durations were higher for Dinajpur than Bogra, and were always higher for the *Boro* season than *aus* and *aman* season rice crops. The extra-early variety received solar radiation between 1,250 and 2,325 MJ m^{-2}, while the late variety received from 1,975 to 3,275 MJ m^{-2} during the growing season. Solar radiation incidences were higher while the mean growing season temperatures were slightly lower for Dinajpur than for Bogra. For all planting dates, the intermediate or late variety had a longer growth duration, higher incident solar radiation, and slightly cooler days. All these attributes resulted in higher yields of intermediate or late varieties compared to extra early or early varieties and higher yields for Dinajpur (Figure 12) compared to Bogra (Figure 11).

Maize: Mean yield potentials of four hybrid maturity categories (1,400, 1,500, 1,600, and 1,700 GDD) across planting dates ranged from 9.0 to 20.3 t / ha in Dinajpur (Figure 14) and from 8.5 to 19.6 t / ha in Bogra (Figure 13). Yield potentials were always higher for the *Rabi* (winter) season (1 Sept. - 1 Feb. planting; 10.0-20.3 t / ha) than for the *Kharif-1* and *Kharif 2* seasons (1 March - 1 Aug. planting; 8.5 to 14.0 t / ha). The corresponding growth durations for those hybrids across planting dates and two locations ranged from 77 to 155 days, with greater durations for Dinajpur and for Rabi season than the *Kharif-1* and *Kharif-2* seasons. Growing season incident solar radiation ranged from 1,200 to 2,600 MJ m^{-2} and was higher for *Rabi* season than for *Kharif-1* and *Kharif-2*

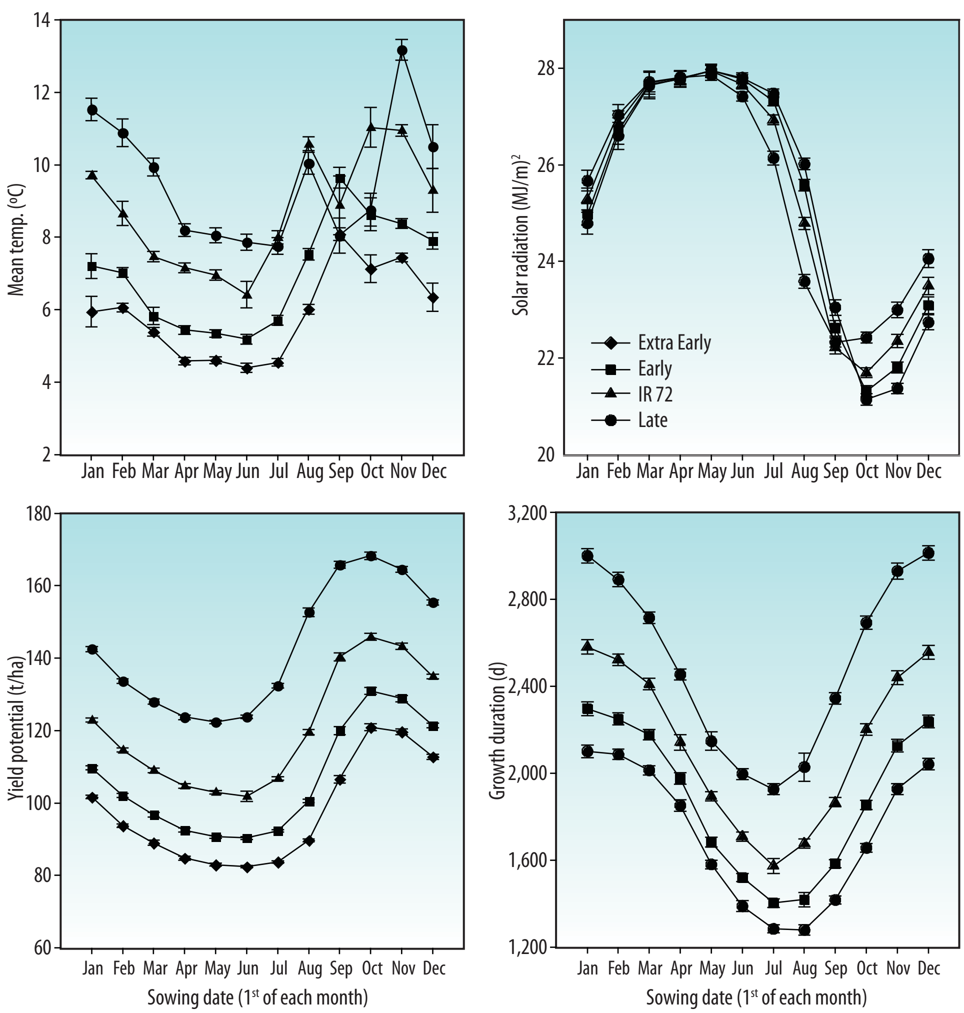


Figure 11. Simulated yield potential and growing season characteristics for four rice varieties grown at Bogra, Central North Bangladesh.

season plantings. Mean temperature from silking to maturity was lower for Dinajpur and was least for 1 September to 1 November plantings and highest for January to July plantings for both locations (Figures 13 and 14). Higher yield potential for 1 September to 1 November plantings was associated with lower temperatures during the grain-filling, which increased the growth duration and intercepted greater solar radiation. In contrast, the higher mean temperatures during grain-filling slightly reduced the growth duration for 1 January to 1 July plantings.

These yield potential estimates assume no limitations of water, nutrients, pests or diseases and no soil-related constraints, and are dictated by climatic and genetic factors only. Therefore, the predicted yield potential of maize hybrids was very high for September and October plantings. In reality, fields will be flooded and soils will be waterlogged for most of the time in September and October. Hence, those yield potentials, though possible from simply a climatic point of view, would never be achieved under field conditions in Bangladesh. Likewise, yield potentials are very high for October and November plantings due to low growing season mean temperatures, as well as low mean grain-filling temperatures, resulting in longer crop duration and large amounts of incident solar radiation. Planting maize during October and early November may not be feasible or practical, as much of the *aman* season rice crop will still be in the field and land will not be available for planting maize. Thus, planting maize from September to November would be unrealistic in Bogra or Dinajpur. For *Rabi* planting of maize after *aman* rice, late November to late December plantings would have reasonably higher yield potentials and would permit successful intensification in rice-based systems. Likewise, for *Kharif-1* planting of maize before *aman* rice, late March to early May plantings would have reasonably high yield potentials and the crops would fit easily into the existing rice-based systems.

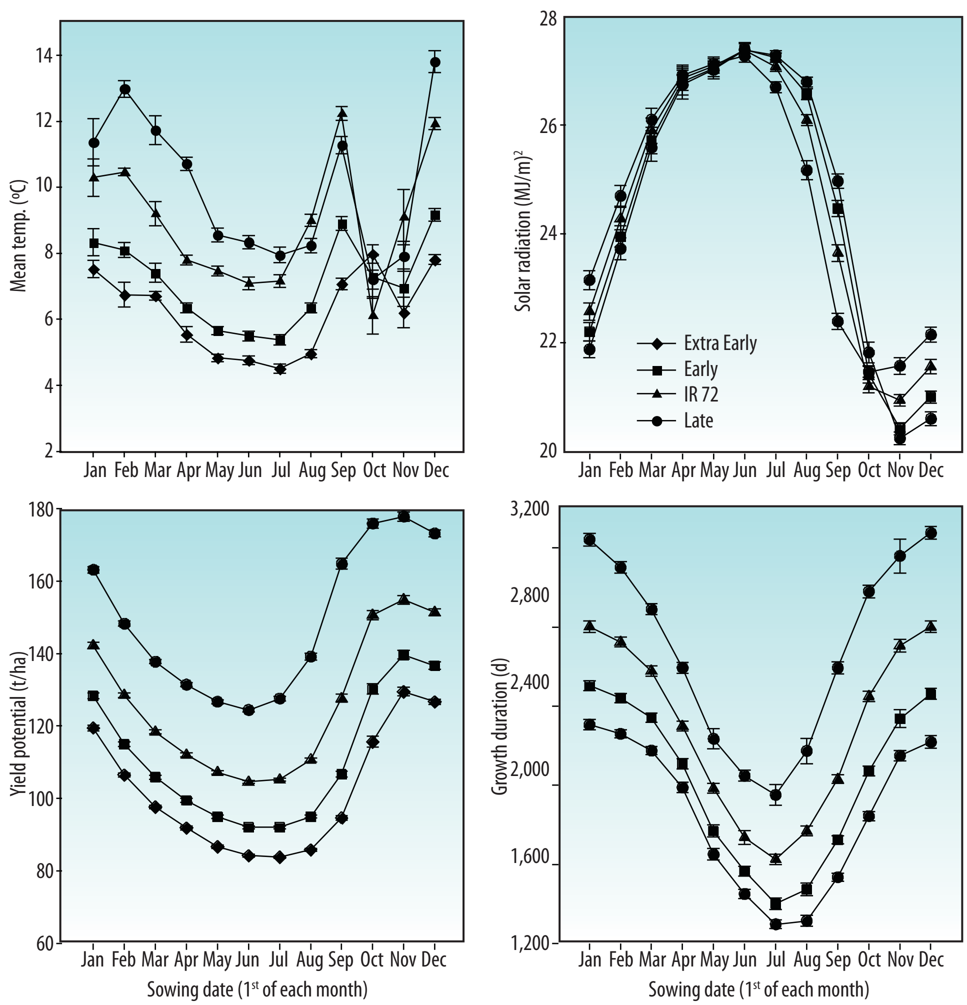


Figure 12. Simulated yield potential and growing season characteristics for four rice varieties grown at Dinajpur, NW Bangladesh.

2. Irrigation water requirements for maize for selected planting windows

The window for planting maize after *aman* rice in the *Rabi* season is from early November to late February. Based on the simulations, the optimum period for planting for maximum yield would likely be from late November to early February, when maize could utilize the residual soil water after rice. This would also minimize waterlogging during crop establishment and dry conditions during maturity. Likewise, during the *Kharif-1* season, though the window for planting maize would be from late February to late May, simulations showed that the optimum time for planting from a yield potential point of view would be from late March to early May, when maize could utilize rainfall during the early-to-mid-*aman* season. If planted too late, the crop would mature during the rainy months in July and August, when rainfall might cause disease and post-harvest processing problems. During both the *Rabi* and *Kharif-1* seasons, some supplemental irrigation for maize might be necessary.

To illustrate the effect of maize planting date, 1 December and 1 January were chosen for planting maize during the *Rabi* season in Bogra district. These dates were chosen because, as mentioned earlier, even though planting maize in November would give the highest yield potential, it might not be practical and feasible to plant in November due to late harvest of rice and soil waterlogging problems. Variability of yield potential of a hybrid of 1,700 GDD during the *Rabi* and *Kharif-1* seasons, rainfall during the growing seasons, and irrigation water requirements to achieve yield potential of that hybrid in Bogra are shown in Figure 15. Yield potential for a 1 December planting across 20 years of simulations ranged from 11.0 to 15.8 t / ha, while that for planting on 1 January ranged from 10.6 to 15.6 t / ha. Yield potential across years was less variable for a 1 December planting than for 1 January planting.

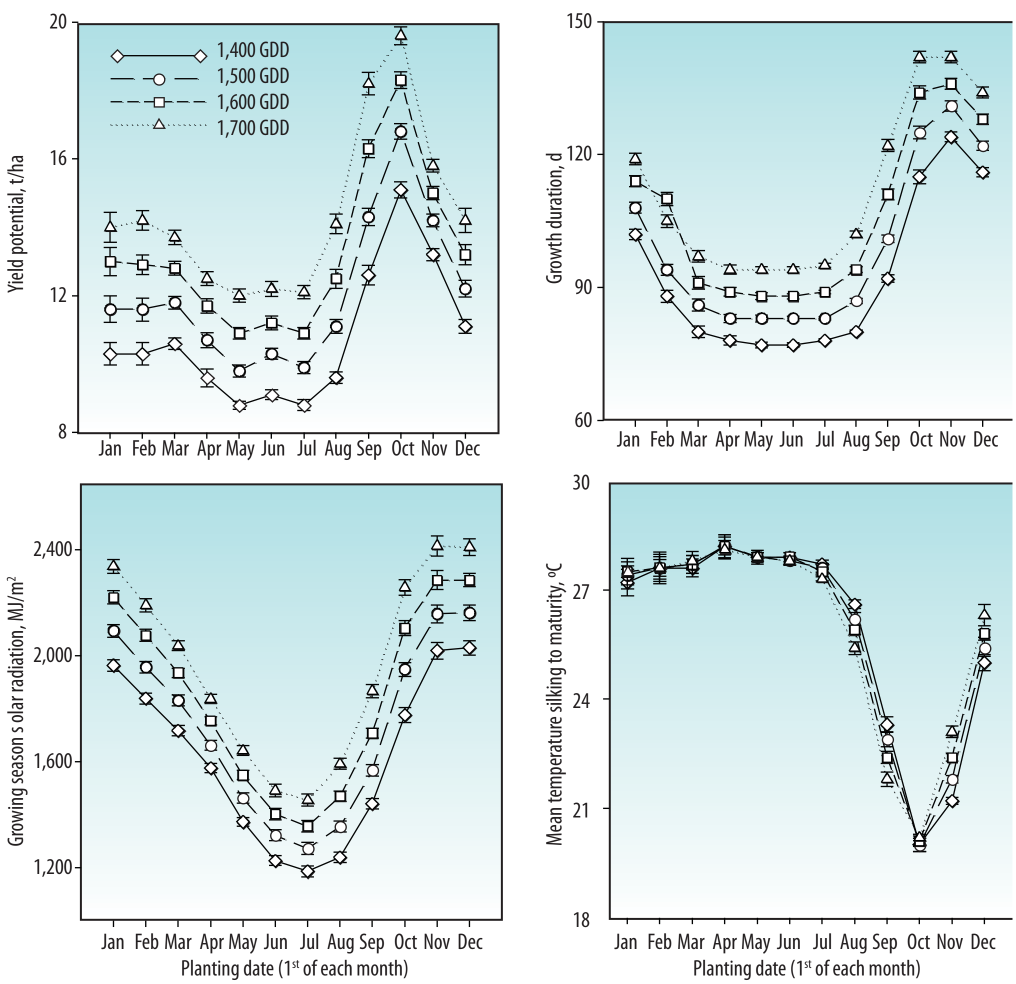


Figure 13. Simulated yield potential and factors contributing to yield potential for four maize hybrids grown at Bogra, Central North Bangladesh.

Rainfall during the season for 1 December planting ranged from 1 to 10 mm, while that for a 1 January planting ranged from 3 to 13 mm. Irrigation water requirements to achieve yield potentials across years ranged from 130 to 227 mm for the 1 December planting, or 97 to 227 mm for the 1 January planting. In all 20 years there was virtually no rainfall, so irrigation was needed.

For the pre-rice season, 1 April and 1 May were chosen for calculating irrigation water requirements of maize. These dates were chosen because planting maize in April and May would allow use of most of the growing season rainfall and would also require less irrigation water. Yield potential across years for a 1 April planting ranged from 9.7 to 13.5 t / ha; that for a 1 May planting ranged from 9.6 to 12.2 t / ha (Figures 11 and 12). Yield potential across years was more variable for the 1 April planting. Rainfall during the growing season ranged from 366 to 1,060 mm for the 1 April planting and from 531 to 1,465 mm for the 1 May planting. Since there was high rainfall during the season for the 1 May planting, the crops did not require any irrigation. For the 1 April planting, from 0 to 130 mm of irrigation was required, with crops needing irrigation in 13 out of 20 years. As mentioned earlier, if planted too late, the crops may be waterlogged and damaged by high rainfall events during the grain-filling stage and may also face post-harvesting and processing related problems. Hence, the selection of appropriate planting dates and suitable varieties and hybrids of rice and maize and optimization of cropping systems are important.

3. Optimization of cropping systems

The analysis suggests that intermediate-to-late maturing rice varieties with 110-140 days maturity and 8.0-8.5 t / ha yield potential would be suitable for *Kharif-2* (*aman*) season rice. For maize, a hybrid with a maturity of 1,500 to 1,600 GDD would be appropriate

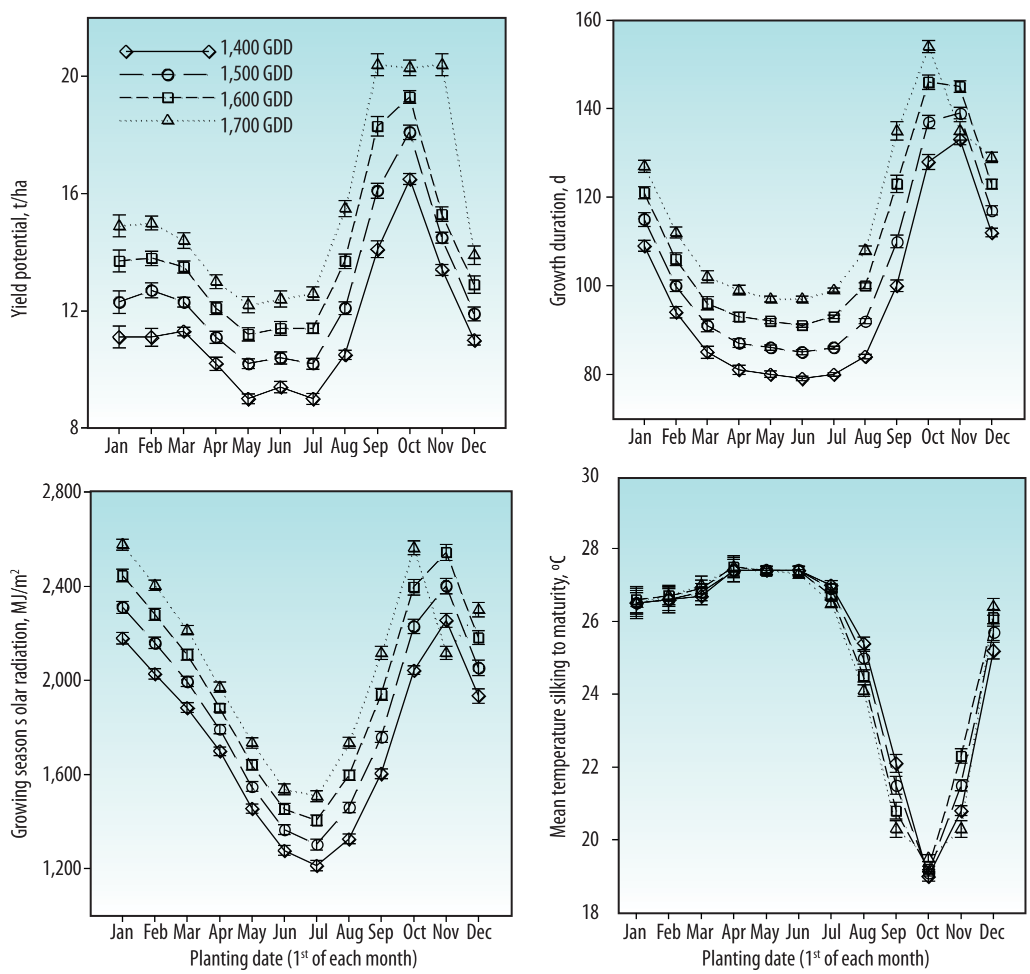
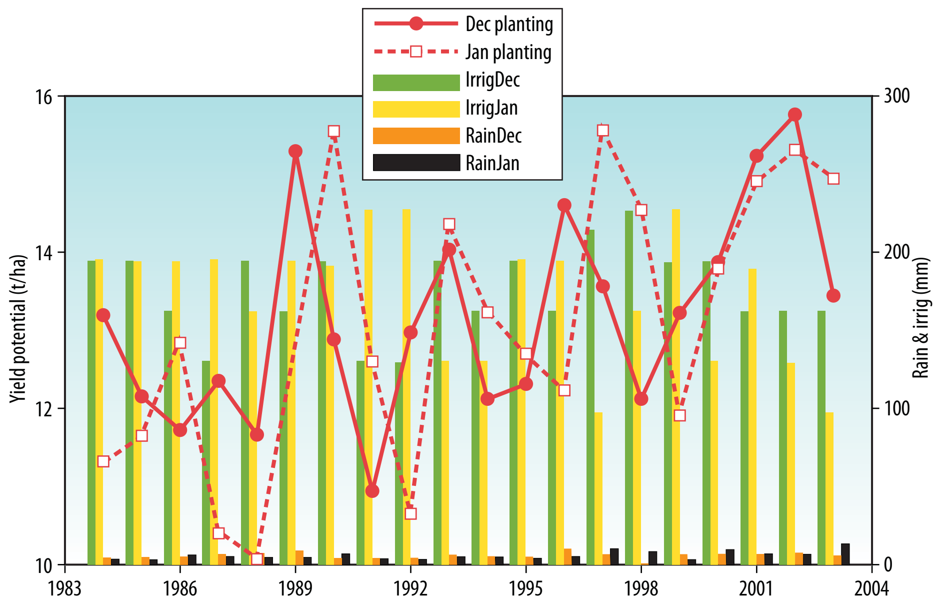


Figure 14. Simulated yield potential and factors contributing to yield potential for four maize hybrids grown at Dinajpur, NW Bangladesh.

for the *Rabi* season while 1,600 to 1,700 GDD would fit well during the pre-*Kharif* season, considering both growth durations and yield potential. Based on the yield potentials and maximum system productivity, various combinations of rice varieties and maize hybrids can be examined to optimize the rice-maize systems during both *Rabi* and *Kharif-1* seasons. Then the planting dates for those optimized high-yielding systems can be further refined and cropping calendars optimized by considering the risks due to heavy monsoons or tropical cyclones, especially during the *Kharif-1* season. For the *Rabi* season, such risk could be due either to heavy rainfall or waterlogging during planting, or drought or heat stress during the reproductive stage. Such risk analysis could help refine the planting dates and identify suitable varieties / hybrids to minimize the damage due to waterlogging or high rainfall, as well as drought and heat stress during the crop seasons. Socio-economic factors such as seasonal markets and prices for rice and maize, credit availability, costs of inputs, and the financial gains from the commodities would, however, influence the selection and adoption of optimal cropping calendars that include rice and maize.



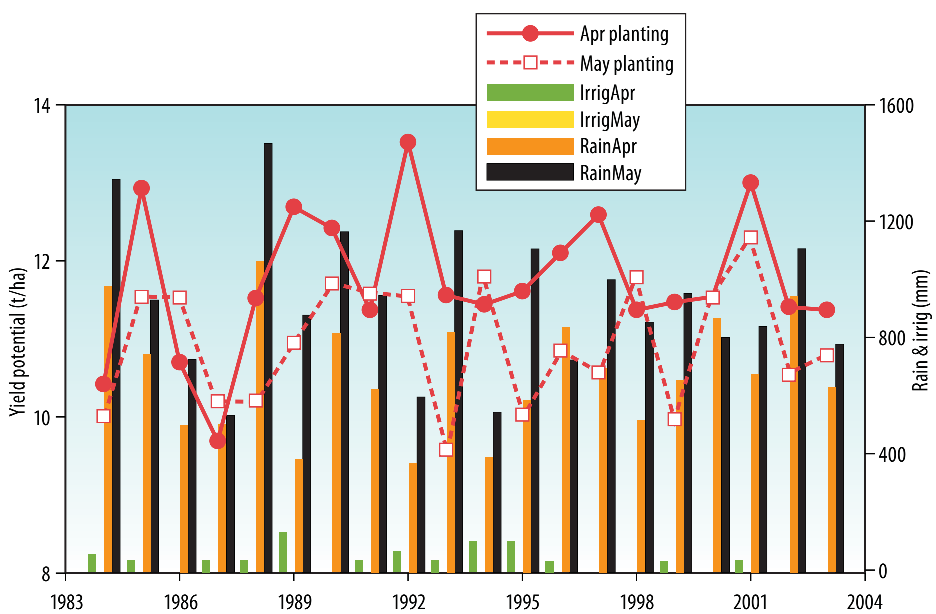


Figure 15. Variability of simulated yield potential and irrigation water requirements for growing *Kharif-1* season (April - May planting) or *Rabi* season (Dec. - Jan. planting) maize (hybrid maturity: 1600 GDD) at Bogra, Central North Bangladesh.

E. Future Research and Development Needs

1. Feasible maize-rice crop systems

There has been limited research in Bangladesh on opportunities to sustainably intensify and optimize the emerging maize-rice systems in the country. As described earlier, these systems have only become important during the 2000s and concerns over their sustainability are just beginning. Maize-rice cropping system-based packages of appropriate technologies should be developed for key parts of Bangladesh where such systems have become important, considering major factors such as variety x planting time x nutrient management x weeding plus other management x irrigation, along with their post-harvest management. These should be developed both for *Rabi* season maize and *Kharif* season maize separately. Computer-based crop system simulation modeling can help with some aspects of this, such as the construction of optimal crop sequence calendars. As the technology options emerge, dissemination of key information should be ensured through training events, field-days, picture oriented posters, compact discs, and through possible other means. The target would be to ensure profitable, high yield potential and sustainable maize-rice systems for Bangladesh. Some of these options are likely to be applicable to similar systems in parts of eastern India such as West Bengal and Bihar.

There is a need to examine more optimal and more intensified crop sequences from short-term productivity and profitability perspectives and a longer-term soil nutrient sustainability perspective. For example, there are opportunities for more intensification and greater sustainability by planting a legume like mungbean after *Rabi* maize and before long duration monsoon rice in that common crop sequence. *Rabi* potato-*Kharif-1* maize-*T.Aman* rice systems are expanding in some areas such as Rangpur, because they are such highly profitable crop sequences, but their sustainability implications require investigation.

2. Sustainable soil fertility management interventions for maize-rice systems

As maize cropping becomes more widespread and intensive in Bangladesh, an emerging issue of great importance is how to sustain long-term productivity of maize-rice cropping systems using integrated soil fertility management strategies. These are needed for diverse situations in the different agro-ecological regions of Bangladesh. Recent reports of stagnation and declines in maize grain yield in Bangladesh (personal communication with farmers of Rangpur and Dinajpur, and reports from extension staff and some researchers; OFRD, 2007) appear related to soil fertility problems like deficiencies of N, P, K arising from improper N management and inadequate P and K fertilizer use. Nutrient depletion-replenishment balances have shown negative balances for N and K in such systems (OFRD, 2006; Panaullah et al., 2006; Timsina et al., 2006). Declining soil organic C, acid leaching of soils through CO_2-charged rainwater and consequent base (Ca, Mg) deficiencies, and micronutrient deficiencies (e.g. Zn and B in calcareous and coarse-textured soils) are associated with this. A recent estimate, for example, shows that about 200 kg / ha / yr N+P+K applied as fertilizers remain unutilized by the crops in these systems (BARC, 2005), mainly due to improper management practices that include imbalanced fertilizer doses, inappropriate time of fertilizer application and irrigation.

To push the achieved grain yields even higher up the yield potential curve will require higher levels of nutrients and their management and overall better soil stewardship. There is need to do nutrient series experiments on very high input / very high yield maize crops on-farm to find out which nutrients are limiting. Ways to manage these can then be incorporated into recommendations and training to achieve the ever higher yields necessary to feed the animals and the people in Bangladesh from the declining soil resources.

Nutrient management for the rice-rice system has been widely researched and fertilizer recommendations for this system are readily available, but not much is known about soil and fertilizer nutrient management for the emerging intensive maize-rice production systems, particularly those involving newly-released BARI maize hybrids. Consider the widespread important transplanted monsoon (*T. aman)* rice (June-July to Nov.-Dec.) maize system. This system is complicated in that the component crops are grown in sharply contrasting physical, chemical, and biological environments such as rice under flooded conditions where soil structure is destroyed by puddling and where strong reducing conditions tend to create S and Zn deficiency problems, and maize under aerobic conditions which requires good soil structure and macro-porosity. This is where the role of soil organic matter becomes crucial, as a supplier of secondary and micro-nutrients, and also, especially for maize and wheat, as a natural "soil amendment" that creates a congenial soil physical environment for these crops. Organic matter becomes all the more important, given that most soils of Bangladesh currently have low organic matter contents, seldom exceeding 1.5%, which is inadequate. Residue management systems with zero tillage will have a key role.

Integrated plant nutrition system (IPNS) packages for intensive maize-rice cropping systems can be developed and management guides drafted for use in possible follow-up technology dissemination initiatives for farmers in Bangladesh. This IPNS research should involve:

- Understanding soil fertility constraints in representative maize growing areas across the country.
- Assessing crop nutrient requirements for optimum maize and rice yield targets in the intensifying systems in the prevailing biophysical environments.
- Multi-location research on mineral fertilizer use, possibilities of adding quick growing legumes such as mungbean into the system, making use of BNF in rice, use of appropriate bio-fertilizers for legumes and crop residue retention, and recycling techniques (soil surface retention, composting techniques, use of zero till machinery).
- Maximum use of residual fertilizer by the cropping sequence to economize on the cost of fertilizers for the farmers.
- Field testing the IPNS packages in comparison with farmers' existing practices.
- Financial analysis of IPNS packages to evaluate farmers' profit margins.
- Combination of IPNS with water management and soil physical management, and with water efficient maize that may be developed in future.
- Increased use of poultry manure in the maize field. Preliminary research suggests that increasingly abundant poultry manure could be a good source of organic matter for Bangladeshi maize fields, recycling some of the nutrients provided to poultry through maize. Large amounts of cow dung are produced in Bangladesh, but during the dry season most (about 67%) is used as household fuel for cooking. About 1.6 million t of poultry is currently produced in Bangladesh but little of it is used on crop fields; rather it is creating health hazards. Therefore, within the IPNS nutrient packages, the management of poultry manure as an important organic component of such inputs should be a high priority.

3. Development and testing of waterlogging tolerant, drought tolerant, and lodging tolerant maize

The development of short-duration, waterlogging tolerant, and drought tolerant maize varieties with high grain yield potential and high-quality grain protein for rainfed and inadequately irrigated environments in Bangladesh and neighboring areas of India is an important thrust for future research for maize-rice systems in south Asia.

Waterlogging tolerant maize would greatly expand opportunities for low-risk production of maize for grain into the *Kharif-1* pre-monsoon season on additional upper and even some mid-toposequence fields. However, elite high-yielding tropical and subtropical maize germplasm with good waterlogging tolerance is not available. Breeding such materials may be slow, since relatively little is known about the physiology and genetics of waterlogging tolerance in maize. Work in India has shown that genotypes with good carbohydrate accumulation in stem tissues, moderate stomatal conductance, <5 days ASI, high root porosity, and early brace root development may have good waterlogging tolerance (Zaidi et al., 2004). Promisingly, Zaidi et al. (2004) report considerable variability for such traits among the genotypes studied.

The development of high-yielding, waterlogging tolerant maize hybrids should be undertaken cooperatively by plant breeders in the CIMMYT Global Maize Program (particularly at its main campus in Mexico), IAR in India, and BARI in Bangladesh. A project that includes some of this work is starting up in 2008 with funds from BMZ. As part of this effort, at a local level in Bangladesh, the PBD, OFRD and Agronomy Divisions of BARI and CIMMYT Global Maize Program can screen available adapted high-yielding maize for tolerance to waterlogging during crop establishment and for terminal flooding. Hybrids can be formed and tested under warm waterlogged conditions in the *Kharif-1* season on-station. Afterwards, promising materials can be tested on smallholder farms with farmers, using their current cropping management and in combination with bed planting systems, with a view to developing effective and low risk production management systems that farmers can use to grow maize into the *Kharif-1* season.

During the *Rabi* season, irrigation for maize can sometimes be problematic, especially where shallow-tube-well irrigation is not available, as in the southern coastal belt and on char (seasonally dry river bed) lands. Deployment of high-yielding, drought tolerant maize will allow far greater flexibility for farmers to grow *Rabi* maize in areas with very limited prospects for irrigation. In contrast to the situation with waterlogging tolerance, CIMMYT and its partners have a successful history of developing and deploying drought tolerant maize in Mexico and Central America, in sub-Saharan Africa, and most recently in SE Asia through an on-going project funded by the Asian Development Bank. CIMMYT can facilitate the entry of candidate drought tolerant inbreds from these projects into Bangladesh. These materials can be tested on-farm with current irrigation scheduling and on dryer upper toposequence fields and those with sandier soils and reduced irrigations.

Both *Rabi* and *Kharif-I* maize is often affected by seasonal storms that produce lodging resulting in poor yield. Thus maize cultivars with a stiff culm and strong brace roots are important for Bangladesh. Currently many maize plants do not produce brace / prop roots under Bangladesh conditions. An assessment of causes for this—both genetic and environmental—is needed.

4. Boron-efficient genotype development

Widespread B deficiency is causing concern in the northern region of Bangladesh. If B is not applied to the light textured soils of Rangpur-Dinajpur (where maize is now a very important crop) and other similar regions, hybrid maize gives poor yields. Hybrid maize seems to be a B-sensitive crop. Many farmers are not aware about B deficiencies, and most of the imported B fertilizers are adulterated. In this situation it would be worthwhile to seek low B-tolerant maize genotypes either by selection or breeding, as well as refining the management of B fertilizers so farmers can get the most from them.

5. Development of QPM and vitamin A and mineral rich maize varieties

Quality protein maize (QPM) is a good option for the supply of higher quality protein to poultry and cattle, as well as to humans. It ensures somewhat faster growth of poultry and animals in comparison to non-QPM maize cultivars. Thus it would be worthwhile to release more QPM maize varieties in Bangladesh and maybe move to a situation where most of the maize grown is of QPM types. Additionally pro-vitamin A, Fe, and Zn rich cultivars are now available at the CIMMYT main campus in Mexico. If those cultivars could be adapted in Bangladesh, it would be a very good source of Vitamin A, Fe, and Zn for humans and others. Children in rural areas and slum dwellers often suffer from deficiency of those elements. It is reported that 30,000 children a year become blind due to Vitamin A deficiency.

6. Faster turnaround between *T. aman* rice and *Rabi* maize

There are various opportunities to facilitate earlier planting of pre-monsoon rice. Its faster harvest and the faster planting of winter *Rabi* maize allow shorter turn-around-time between crops and better synchrony of cropping patterns to climate. Many of these opportunities come from use of appropriate farm machinery. Additionally, possible introduction of high yield potential but earlier maturing rice and maize will allow flexibility in the system.

The power-tiller-operated seeder (PTOS) has already been modified by Wheat Research Centre (WRC) and CIMMYT for direct dry seeding of late *Boro* / early *Aman* rice and mungbean in Bangladesh. Initial testing on-farm around Dinajpur in NW Bangladesh was a success. Yields were similar to those with transplanted rice but there were savings in irrigation water and labor, and the crop was approximately two weeks earlier to harvest. Weeds were not a major issue at the testing sites, but are often reported as a problem with dry-seeded and non-flooded rice and their management needs further assessment. This equipment should be tested in farmers' fields in other parts of the country and then promoted.

Currently almost all of the *Rabi* season maize is hand planted after farmers have sown crops that must be planted in November (including lentil and wheat). While hand planting of maize is relatively fast, this delay can take farmers into December's cold weather. In that case, farmers often wait further until warmer weather in January to plant maize. The combination of earlier maturing maize with management methods for faster crop turnaround is required, including modification and testing of seeding equipment. As a way to address mineral nutrient depletion and declining crop productivity in these intensifying rice-maize systems, earlier maturing maize would allow farmers greater surety in cropping already proven legumes, especially mungbean after maize in the *Kharif-1* season, that would mature in time to plant direct seeded or transplanted *Aman* (monsoon season) rice.

Management activities / outputs for faster planting of *Rabi* maize would include:

- Management briefs for extension staff and farmers synthesizing the best current information about the transition from the harvest of *Aman* rice to the establishment of maize crops. These should be widely publicized and used in whole-family training and field school initiatives underway by BARI, DAE, and Winrock, among others.
- Modification and testing of power-tiller-operated wheat reapers and threshers for faster harvest and processing of *Aman* rice on dry fields, freeing labor resources more quickly for planting maize.
- Development and testing of manual methods for very early planting and fertilizing of maize on drying fields with rice stubble (zero till). Small jab-type planters can be tested in such conditions.
- Modification and testing of power-tiller-operated seeders (PTOS) and soil bed formers and planters for maize. This will involve modification of seed metering devices in the PTOS for row planting maize and fertilizer placement, including cup seed delivery mechanisms. The modified PTOS will prepare land, place maize seed and basal fertilizer, and press soil in one pass. This should reduce turnaround time by 10 to 20 days and reduce maize establishment costs by up to 60%.
- Farmer participatory on-farm research and development concerning integration of new early-maturing and abiotic stress tolerant maize, along with efficient planting and an establishment of technologies into existing and improved maize-rice systems in Bangladesh.

7. Improved water management for *Rabi* season and *Kharif-1* season maize

Evidence of longer-term productivity, intensification, and sustainability benefits of permanent soil beds with crop residue management is now emerging in Bangladesh. Results are available from a four-year WRC-Cornell University-CIMMYT study conducted by ASM HM Talukder at the WRC, Nashipur, Dinajpur, to compare the effects of permanent raised soil beds vs. conventional till on the flat in combination with straw retention and N fertilizer, in a wheat-maize-monsoon (*Aman*) rice cropping system (Talukder et al., 2008). The combination of permanent beds and straw retention produced the maximum grain yield of 11 to 21 t / ha per year compared with 7 to 15 t / ha for conventional tillage without straw retention. Straw retention was confirmed as an important component of soil restorative management, helping reduce soil moisture depletion and weed pressure and increasing N uptake. These bed planting systems have been tried by farmers in Rajshahi in western Bangladesh during 2006 and 2007. Yield performance was mixed in the short term as farmers learned how best to space beds and crop rows. Much more participatory on-farm research and extension is needed.

8. Post-harvest management for maize

In Bangladesh a large portion of maize is harvested during rainy days, which often makes the cobs and grains wet (containing 20-25% moisture). In this situation wet grains are affected by rots and molds, and aflatoxin is a concern. These reduce the market price for grain, and the grains that are affected with aflatoxin could be harmful for chickens and humans. Hence, an easy and cheap technology package would need to be developed for managing aflatoxin.

9. Maize residue management and composting

For the conservation of soil fertility, crop residue management is gaining global popularity. In intensive maize production areas in Bangladesh, maize stover is either used as fuel or just thrown outside the plot to clear the land for succeeding *T. aman* rice. If this residue could be composted quickly and mixed with soil, it would recycle some important nutrients and organic matter into degrading soils. Hence, quick and cheap composting mechanisms should be developed for maize straw in this country.

10. Farm economics of maize vs. alternative enterprises

It is clear that the dominant drivers for the increased adoption and production of maize in Bangladesh are economic. The market is strong and recent financial comparisons with *Boro* rice and with wheat show maize to be by far the most profitable crop. Investments per ha in maize are approximately Taka 35,000 with a profit of Taka 49,000 per ha, compared with Taka 20,680 for wheat. These detailed comparisons have been limited to Rangpur and Dinajpur, where wheat performs well, but initial estimates for other areas are similar.

Although it has been established in recent years (2000-06) that returns for maize are higher than other cereals like wheat and *Boro* rice, input cost and output dynamics can change quickly. For example, shifts are underway in 2007-08 that may undermine the financial dominance of maize. These include urea price rises raising input costs, increasingly serious bird flu outbreaks possibly reducing maize grain demand, and wheat grain prices rising internationally and locally, among others. Local market prices of wheat grain have been rising strongly in the second half of 2007 through early 2008, reflecting rises internationally.

Thus there is need for more work on the economics of maize. There is need to conduct surveys of farmers to identify the costs of production and returns to scarce resources under a variety of production systems, assess relative financial returns from maize systems, and to identify interventions that improve further the profitability of maize. There is need for more widespread and up-to-date financial assessments with other cereals and other competing crops, factoring in price trends and risks such as those posed by bird flu. Results from these will be an important component of policy decision making on crop support and assessments of the impacts that maize is having on livelihood improvement in the country. Flexible responsive financial analysis models should be developed and maintained to better inform farm decision making and central government policies on imports and local production support.

11. Marketing systems of maize, value-addition maize, and agri-business development

For diversity of value-added products and end uses, maize is the most versatile multi-use cereal. The whole plant can be grazed by ruminant animals, or selected plant parts such as leaves or tassels removed from the growing plant and fed to animals. Crop residues can also be fed or retained to help soil structure. Stems and bare cobs are a high energy fuel. The grain can be fed to poultry, fish, or other animals, including humans. Whole cobs can be roasted or specialty types of corn consumed as popcorn, baby corn, etc. Improved grain quality types with higher quality protein are available and those with high vitamin A are under development to further increase the food and nutritional value of maize and its food products. Maize can be made into corn flakes or employed in several industrial uses including oil extraction, corn starch and syrup, and as a feedstock for bio-ethanol. Current major uses of maize in Bangladesh are few; primarily as a grain for poultry and fish feed. Future work should look at the prospects and benefits, and raise awareness about some of these other uses in Bangladesh. Through improving the efficiency of the value chain, industry profits and employment can grow, demand can expand, and farmers can receive better prices. Since there is such a big demand for maize and it is so profitable, we already see interest from private entrepreneurs.

Efforts are needed to help small farmers to diversify and upgrade maize production, strengthening competitiveness in the enterprises and to compete more effectively in markets where they have advantages. Tools such as market mapping and participatory value chain analysis are useful in analyzing these opportunities. These will help to understand the structure, functioning, and linkages within the sectors and value chains that poor people depend on, and the social and institutional environment that governs how markets operate.

What is initially needed is a mapping of the different value chains within the maize sector, while carrying out a market analysis to identify potential chains for other maize products. Work can then carry out a participatory value chain analysis within those value chains identified as having the potential to benefit small-scale producers. The analysis will bring together the value chain actors to jointly identify bottlenecks and inefficiencies that prevent producers from benefiting as much as they could from their participation in these chains. The participatory value chain analysis should also identify those best able to provide producers with the business services they need. Small producers and rural entrepreneurs need sustainable and affordable access to a diverse range of business and extension services to mitigate inefficiencies and bottlenecks. These critical services may include credit, technical training, market information, enhanced co-ordination and organization among small producers, and upgrading production and processing to meet buyers' standards.

Researchers should conduct surveys of markets, agribusiness concerns, service providers, and farmers to identify and quantify emerging opportunities for a range of maize products. This will help to highlight opportunities and recommend priorities for maize research and development investment in Bangladesh. Additionally, local organizations can undertake awareness orientation meetings and publicity with agri-business processing and marketing organizations on value-added business opportunities with maize, with emphasis on market niches for small farmers.

The challenge is then to develop, test, and make accessible the analytical tools that enable small producers and those organizations working with them to acquire such market intelligence capabilities themselves. With these capabilities small producers—often working collaboratively with other actors in the value chain—will be better able to identify and implement responses to market opportunities.

12. Building scientists' capacity

Quality output from working scientists is of immense importance. As an emerging area, maize-rice systems scientists should get opportunities for education, research, and training facilities home and abroad. Suggestions include:

- Arrange and manage a program of maize scientist expert visits between south and southeast Asia, Mexico, and the Philippines along with BARI and BRAC in Bangladesh to raise the research capacity of government institutes, universities, and private partners.
- Support and provide participants for regional training events on maize breeding, seed production, management options, and technology transfer.

- Provide maize germplasm and technical guidance to upgrade maize breeding programs in Bangladesh through a strong partnership with PBD-BARI, universities, BRAC, Supreme Seed, and East-West Seed.

13. Training of farmers and related stakeholders on hybrid maize

The maize whole-family training (WFT) initiative in Bangladesh proved the importance of training for the farmers and other stakeholders. For quick dissemination of technology it is one of the best tools and all programs should include direct communication with farmers and other stakeholders. Having benefited by the USAID-funded maize WFT program from 2001 to 2006, government agricultural policy makers, government organizations / NGOs / private entrepreneurs, and farmers continued to urge an expanded WFT program for maize promotion involving more farmers, local NGOs and government partners. These should target at least 3,000 additional farm families, with emphasis on parts of the country that received little or no previous training, such as char areas and the Chittagong Hill Tracts. More maize WFT will contribute greatly to meeting national maize requirements, and reducing maize grain imports and massive foreign exchange costs. There is also a need to update WFT materials, improve methods, and modify approaches as new information and technologies become available. The approach has been very successful and efforts are needed to further institutionalize the WFT approach in extension and with NGOs.

F. Conclusion

Hybrid maize is an emerging high-value cereal crop in Bangladesh, having among the highest average farm yields (5.7 t / ha) found in Asia. Economically, hybrid maize is far more profitable than *Boro* rice, wheat, or most other competing winter season *Rabi* crops. Maize cropping is expected to expand at about 15% per year, driven by a booming poultry industry, and with temporary setbacks from avian flu. Alternative uses of maize may increase in the future. Maize-*T. aman* (monsoon) rice is the major cropping system; however it is now becoming diversified with many other crops including potato. Although maize is relatively problem-free in Bangladesh, some constraints are intensifying with increased concern over input supply and soil-related environmental sustainability. An array of new technologies for sustainable intensive maize production systems is emerging in Bangladesh and some are being promoted and adopted. However, the sustainability of hybrid maize production in Bangladesh depends on optimization of planting time, quality seed of appropriate hybrids, and balanced nutrient management along with soil fertility conservation, and other management, for which further research would be a high priority.

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