Maize-rice cropping systems in Bangladesh: Status and research needs*

M. Yusuf Ali[1], *S. R. Waddington*[2], *J. Timsina*[3], *D. Hodson*[4], *J. Dixon*[4]

(1. On-Farm Research Division, Bangladesh Agricultural Research Institute, Gazipur 1701, Bangladesh;

2. CIMMYT, Dhaka 1212, Bangladesh; 3. IRRI-Bangladesh Office, Dhaka 1212, Bangladesh;

4. CIMMYT, Apdo Postal 6-641, 06600 México DF, México)

Abstract: Maize-rice cropping systems are expanding in Bangladesh. Hybrid maize has increasing demand and value, particularly for poultry feed, while rice remains the traditional dominant starch staple food. Bangladesh maize yields (with average farm yields around 5.7 $t\cdot ha^{-1}$) are among the highest found in Asia. Cool winter (*Rabi*) season maize followed by *T. Aman* (monsoon) rice is the major cropping system; however it is now becoming diversified with many other crops including potato. Financially, hybrid maize is far more profitable than *boro* (irrigated) rice, wheat, or most other competing winter season *Rabi* crops. 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. Continued sustainability of hybrid maize production in Bangladesh depends on optimization of planting time, quality seed of appropriate hybrids, balanced use of nutrient inputs along with soil fertility conservation and other management, for which further research would be high priority.

Key words: maize-rice; Bangladesh; problems and risks; promising technologies; research needs

1. Introduction

In Bangladesh, very large numbers of people depend on intensifying cereal crop production systems for most of their food and a large part of their livelihoods. Traditionally rice has provided almost all of the cereal carbohydrate. During the 1980s to 2000s, rice-wheat (R-W) cropping systems became important and wheat chapatti an important part of human diets. Recently wheat has been declining largely due to climatic adaptability problems and the availability of more lucrative crop alternatives for farmers during the cool season. During the 2000s, maize has expanded rapidly, mainly for poultry feed, but increasingly directly as human food. During 2007-2008 Rabi season, wheat area was the lowest (approx. 400,000.00 ha) and during 2007-2008 Rabi and 2008 kharif-1 season, maize area was the highest (approx. 380,000 ha) in Bangladesh. Anecdotal evidences and recent informal visits and interactions with farmers, however, reveal that wheat area has decreased while maize area increased during the current Rabi season (2008-2009) in Bangladesh. Both wheat and maize are mostly (approx. 95%) grown in crop systems dominated by rice. In this paper we examine the expansion of maize in Bangladesh, the emerging maize-rice (M-R) cropping systems in which it is grown, crop production and sustainability problems associated with intensification of these systems, existing crop technologies that can help to address these issues and the research needed to ensure their future.

2. Maize production in Bangladesh

* **Acknowledgements:** This work was supported by World Bank IFAR and was conducted at CIMMYT, Mexico. The authors thank G. M. Panaullah and A. Dobermann for helpful technical contributions to this paper. Researchers, farmers, maize businessmen and extension staff in Rangpur, Dinajpur, Bogra, Kushtia and Jessore provided their expertise and information, as did several BARI and BLRI scientists.

M. Yusuf Ali, Ph.D., principal scientific officer; research fields: farming systems, on-farm adaptive research, Livelihood adaptations, rice-maize/legumes systems.

Corresponding author: J. Timsina, Ph.D.; research fields: cropping/farming system research, cereal and legume systems, conservation agriculture, nutrient management, crop simulation modelling. E-mail: j.timsina@cgiar.org.

Its widespread fertile alluvial soils and sub-tropical monsoonal climate make much of Bangladesh suitable for maize cultivation (Fig. 1). Maize is a relatively new crop in Bangladesh. Before independence in 1971, maize was rarely cultivated except in tribal areas of the southeastern Chittagong Hill Tracts. During the 1970s and 1980s, maize was grown on just a few thousand ha of land in Bangladesh but farmers were becoming more interested in the crop[1]. By 2001-2002 the maize area had reached around 30,000 ha with a production of 0.17 million t grain (Fig. 2). The demand for poultry feed was already high and growing fast at that time. Hossain, et al[2] reported an emerging impact from previous maize research and extension in Bangladesh and suggested additional investments in promoting the crop.

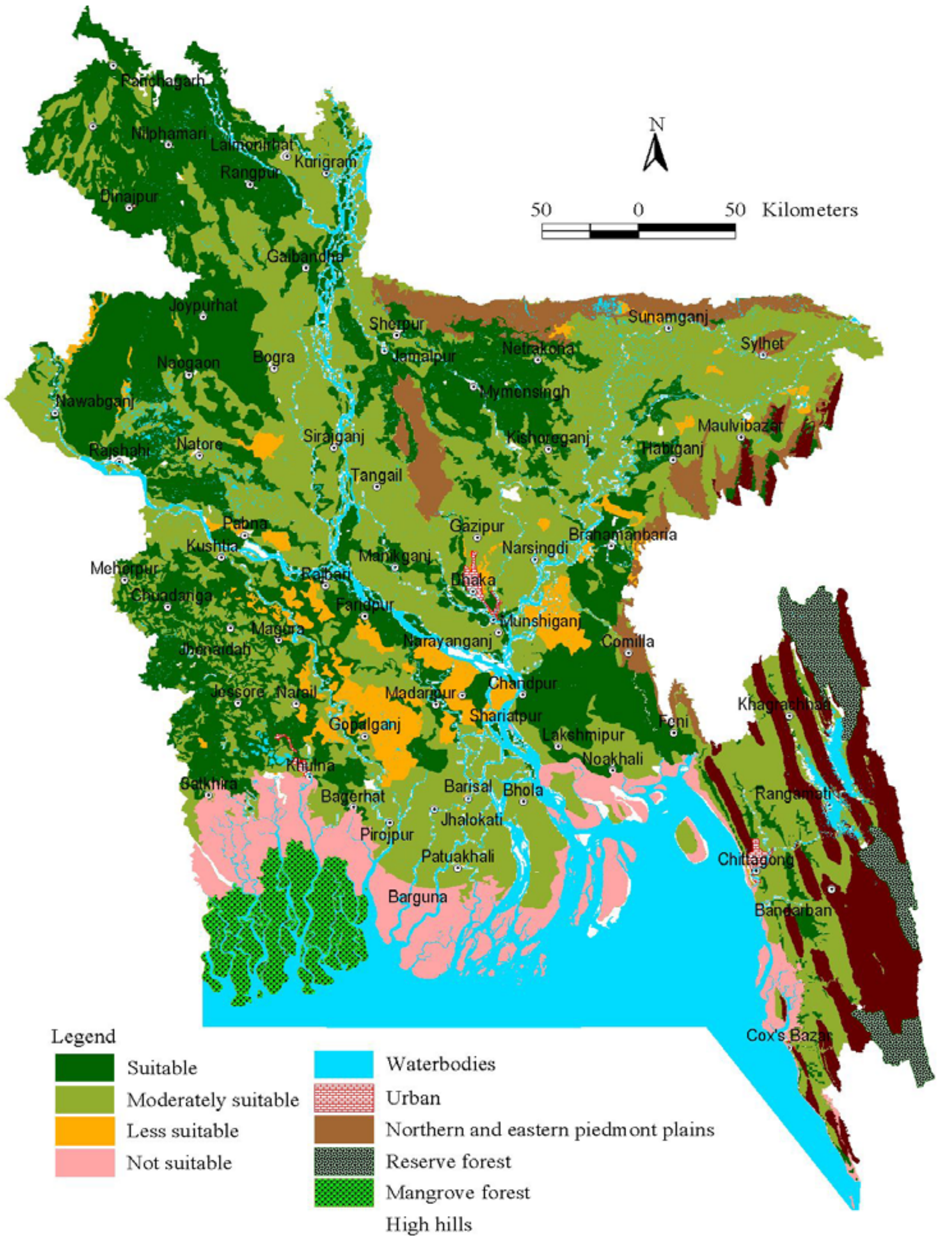

Fig. 1 Maize suitability map of Bangladesh. Most of the country is moderately or very suitable for maize cultivation, based on soil and climate

Source: Waddington, et al. *Bangladesh Country Almanac*.[3-4]

Responding to expanding attractive poultry feed markets in the early 2000s, the maize area quickly rose to 137,000 ha in 2005-2006 (Fig. 2)[5-6] and reached 179,000 ha in 2006-2007[3-4]. By the 2007-2008 cropping season, it was planted on about 380,000 ha of land in Bangladesh, with national average grain yields of around 5.7 t/ha (Fig. 3), producing well over a million t of maize grain annually. Most area and production expanded in northwestern and central western districts.

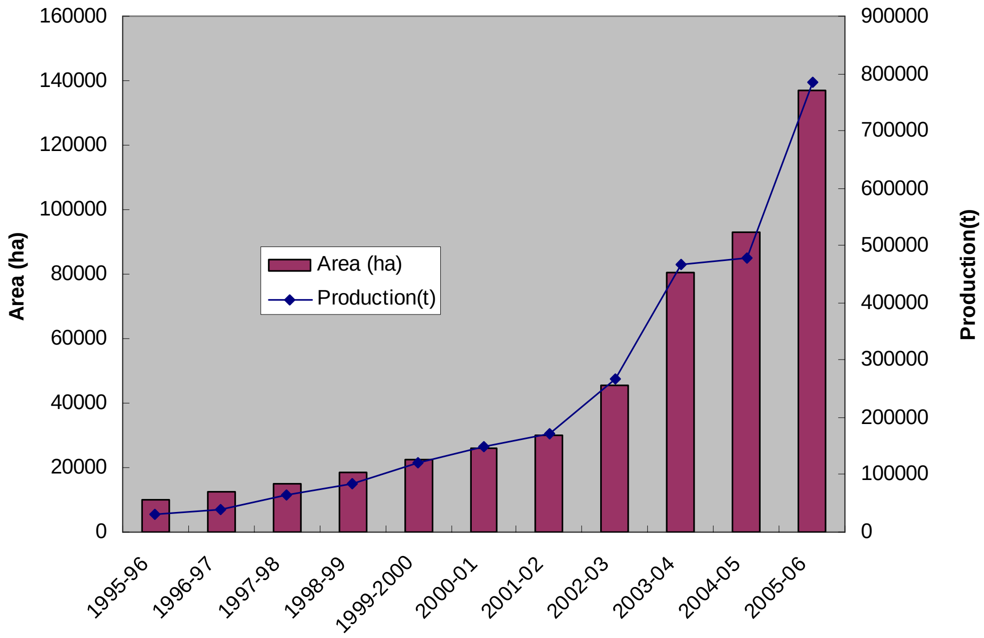

Fig. 2 The rapid increase in hybrid maize area planted and grain production in Bangladesh, 1995 to 2006
Data source: Bangladesh Department of Agriculture Extension.

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. Maize crop production training – in the form of whole-family training with about 13,000 farm families – and the distribution of good hybrid seed among the trained farmers have increased maize production in Bangladesh[5-7]. More area was planted with maize, farmers employed new production practices and attained higher yields in areas that had received whole-family maize training in comparison to farmers in areas without training[5-7].

Thus 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. Maize grain consumption (currently about 1.2 million t/year) in Bangladesh is mainly by the poultry industry. With the rapid expansion of the poultry industry in the 1990s and 2000s, the demand for maize grain as poultry feed increased many fold. Besides poultry, maize grain 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. Still, as recently as 2005-2007, the local production of maize in Bangladesh could meet only 55%-60% of national maize demand for poultry and other feeds. The expanding poultry industry suggests that future demand for maize is likely to rise, although recent outbreaks of bird flu during 2007 and 2008 may temper demand somewhat.

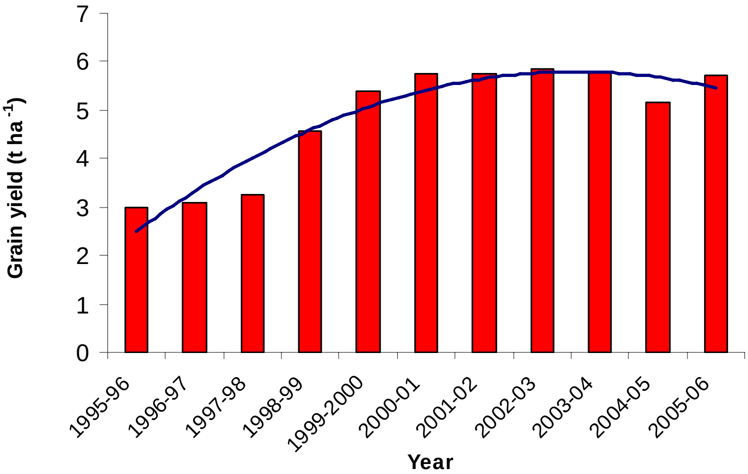

Fig. 3 Average grain yield of hybrid maize in Bangladesh from 1995 to 2006

3. Rice production in Bangladesh

Rice is the traditional staple cereal crop in Bangladesh. It is grown throughout the country all year round, with often 2-3 crops per year on the same land. 11.25 million ha of rice were planted in 2005-2006, with a production of 29.75 million t at an average grain yield of 2.6 t/ha. The country was just self sufficient during 2000-2005 and had a surplus of 3-4 million t in 2005-2006. The rice area for 2015-2020 is projected to decline to 7.8 m ha. Since the 1980's, 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 1995-1996, 7.2 million t of *boro* rice were produced on 2.75 million ha. In 2005-2006, 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 *Aus* and deepwater rice areas have been declining and farmers have been switching to *Boro*. The area of monsoon *Aman* rice has remained static since the 1970s but yields have nearly doubled[3-4].

4. Maize-rice cropping systems and management practices

4.1 Existing cropping patterns

In Bangladesh, hybrid maize is grown mostly in the dry and cool winter (*Rabi*) season (during November-April). Winter *Rabi* season maize is grown in rotation after the traditional transplanted monsoon *Aman* rice crop. Additionally, the area of warmer season *Kharif-I* (March-June) maize, mainly after the harvest of potato, is increasing. *Rabi* maize is grown as a high input –hybrid seed, large rates of fertilizer, irrigated– crop especially in Northwest and West central Bangladesh where it is replacing mostly wheat, chilli, mustard or vegetables, or *Boro* (irrigated) rice in some areas[3-4]. Maize is also expanding into new areas such as the High Barind Tract in Rajshahi in western Bangladesh and into eastern districts. *Rabi* season maize has higher grain yield, yield stability and profitability compared with the two other principal winter cereal crops; *Boro* (irrigated) rice and wheat. 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 2005-2007 national mean grain yield of around 5.7 t·ha^{-1}.

Maize is most commonly grown in maize-fallow-transplanted monsoon (*T. Aman*) rice, potato-maize/relay maize-*T. Aman* rice, maize-relay jute/jute-*T. Aman* rice, maize-pre monsoon (*Aus*) rice-*T. Aman* rice, or maize-vegetables-vegetables, cropping patterns[5-6]. Small amounts are planted during the pre-monsoon *Kharif-1* season and on hill slopes in eastern Bangladesh during *Kharif-2* (monsoon) season. 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 during *Kharif-2* on hillsides in the Chittagong Hill Tract areas. There are problems with alternative *Rabi/Kharif-1* cereal crops; particularly power and water shortages for irrigated (*Boro*) rice and low yields of wheat due to its marginal adaptation to the Bangladesh climate.

4.2 Emerging cropping patterns

As indicated earlier, hybrid maize was promoted as a winter crop and is generally cultivated in Bangladesh after the harvest of traditional *T. Aman* rice. But now increasingly farmers are fitting maize with a widening range of other traditional crops, such as potato, jute and various vegetables. Unlike in adjacent West Bengal, India[8] crop systems involving maize with grain legumes/pulses are relatively unimportant. This all indicates that hybrid maize cultivation in Bangladesh is becoming increasingly integrated by farmers into their cropping systems. In Bogra –one of the first areas where maize expanded–for example, 20 different maize-based cropping patterns were found (Table 1). 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%). In most of the areas except Rangpur Sadar and Pirjang in Rangpur district, Maize-Fallow-*T. Aman* is the major cropping pattern[9]. 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. Maize-potato based systems also reported to be financially highly rewarding elsewhere on the Indo-Gangetic Plains in India[10]. 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 Main maize-based cropping patterns of Bogra district, Bangladesh, 2005-2006

Cropping pattern	Land area (ha)	% maize area	Maize cultivar
Maize-Fallow-*T. Aman*	4415	40.6	Agroso-900M and 900M Gold
Maize-Maize-Fallow	3098	28.5	Agroso-827 and Agroso717
Maize-*T. Aman* seedling-Fallow	1158	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
-	10869	100	-

4.3 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 per ha are common[5-7]. Maize is flat-planted in rows at approximately 53,000-66,000 plants per ha on conventionally tilled land (often with a power tiller). Soil ridges are made after hand weeding.

Almost 100% of the maize area is planted using hybrid maize seed each year, mainly single cross and double cross hybrids. Maize has a wide planting window relative to some other crops like wheat and lentil, and up to 57% of farmers plant within the optimal planting period of 1 November-15 December for high maize grain yield[5-7], 83% 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 very 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[7]. 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.

4.4 Maize production in *Kharif-I* season

Currently *Kharif-I* (pre-monsoon) maize –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 flat 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 reach maturity and produces 3-6 t·ha^{-1} grain yield (estimated mean of 4 t·ha^{-1}). For *Kharif-I* plantings, farmers prefer a double cross hybrid like Pacific-11 and non-hybrid cultivars. After harvest of potato, farmers level their land and then manually plant their maize seed. They do not use PKS fertilizer because they believe that residual PKS from fertilizer applied to potato is sufficient for maize. They do apply 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 1733 ha of *Kharif-I* maize (personal communication Nure-E-Alam, Scientific Officer, OFRD, BARI, Rajshahi). In Bagmara (and in whole of 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. Research issues identified with *Kharif-1* 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 since 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 (about 373,000 ha) for *Kharif-I* maize.

4.5 Financial and environmental 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^{-1} grain) that makes it more than two times more economic per unit land area than wheat or

Boro rice alternatives. From hybrid maize, Tk. 49,000/ha could be earned, compared with Tk. 20532/ha from *boro* rice or Tk. 20680/ha from wheat (Table 2). 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 fewer pest and disease problems in Bangladesh than *boro* rice and wheat.

Table 2 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)*	38468	24320	35000
Gross return (Tk/ha)	59000	45000	84000
Gross margin (Tk/ha)	20532	20680	49000
Benefit cost ratio	1.53	1.85	2.4

Note: * Only variable cost is considered.
Source: *Field Survey and OFRD Annual Report*, 2007.

Maize may be less detrimental to the environment than *boro* rice. With increasing concern about arsenic contamination in *boro* rice[13], maize offers an attractive alternative cereal crop that has 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 As 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 an 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 3,000L/kg rice grain (with 20-35 irrigations) for *boro* rice.

5. Emerging production problems in the maize-rice system

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, there is recent evidence and increasing concern that productivity of maize is stagnating (Fig. 3[12]) in traditional areas and may be in decline. For example, farmers and Department of Agriculture Extension (DAE) staff in Rangpur and Dinajpur report decreasing grain yields where maize has been grown on the same land for the last 5-10 years. This is very alarming because the land area of Bangladesh is small (around 144,000 km^2) and arable land is being lost at around 1% per year, while feed demand is increasing at about 15% per year. Thus it is crucial to achieve and maintain high grain yield. Experienced farmers and concerned researchers have 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.

5.1 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* rice. Thus the planting of maize depends on the harvest time of *Aman* rice, the speed of drying of the soil just after rice harvest, and farmer priorities on planting other *Rabi* season crops. Farmers cultivate *T. Aman* rice varieties that have a long development cycle (145-150 days, seed to seed) and are harvested mid November to early

December. This means that most maize farmers plant 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 23 ℃ max, 11 ℃ min). Late planted maize takes around two weeks to germinate due to cold winter weather and grows slowly. Late planting –from 20 December onwards– may cause yield losses of 12%-22% (Fig. 4). The 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 a low market price. Late planted maize has also an increased danger of lodging and waterlogging later in crop development because of pre-monsoon storms during March and April.

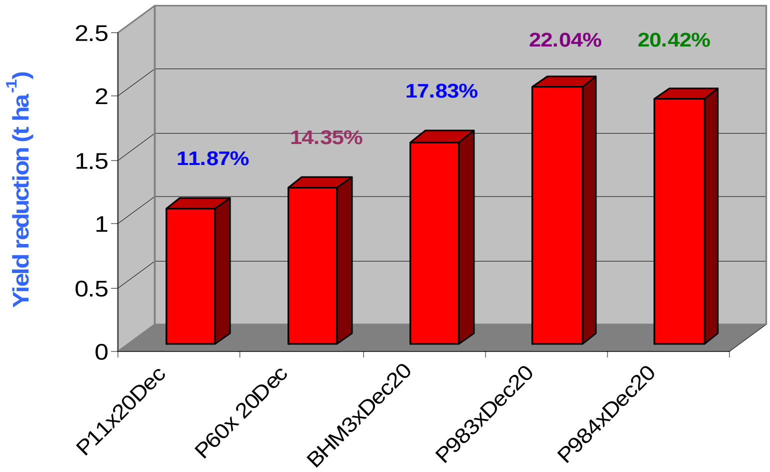

Fig. 4 Grain yield reduction in maize from planting on 20 December compared with a 20 November planting at Rangpur, Bangladesh, 2004-2005 season

Source: Ali, M. Y., 2006.

5.2 Unsustainable soil management

To grow maize and rice, opposite soil environments are required. Maize prefers loamy soils with good tilth and aeration, whereas rice needs well-puddled wet clay soils with high water holding capacity. After the harvest of *T. Aman* rice, to make the soil suitable for maize good and deep tillage is usually needed, along with adequate (but not excessive) soil moisture for germination of maize seed. This is 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 in the crop sequence– while excessive tillage for maize contributes to the loss of soil organic matter and nutrient depletion. There are major doubts about whether such soil management practices, especially those for maize, are sustainable long term.

5.3 Soil fertility depletion

Continuous production of high yield maize will lead to the depletion of mineral nutrients from soil unless appropriate nutrient inputs are given and management followed. Soil nutrient depletion is often accelerated with maize because of the greater nutrient uptake and off take from maize than either rice or wheat. Maize planted in the *Rabi* season can produce about 10 t·ha^{-1} of grain and 12 t·ha^{-1} non-grain biomass. To produce such high yields, maize plants take up around 200 kg N, 30 kg P, 167 kg K and 42 kg S ha^{-1}[14]. However, farmers mostly apply unbalanced fertilizers, with low amounts of PKS and micro-nutrients. In Maize-*T. Aman* cropping pattern, the apparent nutrient balance was highly negative for N and K (-120 kg·ha^{-1} to -134 kg·ha^{-1} and -80 kg·ha^{-1} to -109 kg·ha^{-1}, respectively), while the P balance was positive (15kg·ha^{-1} to 33 kg·ha^{-1})[12]. Results for rice-wheat-maize/mungbean cropping systems in central and northwest districts reveal negative to positive balances for N (-64 kg·ha^{-1} to＋62kg·ha^{-1}), a negative balance for K (-25 kg·ha^{-1} to -212kg·ha^{-1}), and a positive balance for P (9 kg·ha^{-1}-50 kg·ha^{-1}) for treatments ranging from zero N, to farmers' management N, to soil-test based N[15-17]. Positive N balances occurred in treatments where large amounts of N were applied to *Kharif-1* maize following wheat. Additionally, as the cattle population decreases on many farms and much dung is used for fuel, the use of organic manure on fields is going down. These developments are detrimental for soil nutrition and continued maize crop productivity.

5.4 Water logging

Water logging risks are significant later in crop development for late-planted winter *Rabi* maize on the heavy clay soils that are widely used for rice-maize. Water logging and flooding currently prevent farmers from investing in high input/high output maize grain production into the *Kharif-1* season in Bangladesh. In *Kharif-1*, farmers can only safely plant maize on top fields and lighter soils. Water logging of well established crops in later stages of development is an increasing risk in the *Kharif-1* cropping season in April and May with increasingly frequent heavy rainstorms into the pre-monsoon. Initial crop establishment on wet soils after *T. Aman* rice can also be difficult.

5.5 Irrigation difficulties and drought

In many parts of Bangladesh in the dry *Rabi* and early *Kharif-I* 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 is not possible. Grain filling of the maize crop can be reduced, producing low yields of poor quality grain. Irrigation is becoming costlier and more uncertain because of high prices and acute shortages of electricity and rapidly increasing prices of diesel, used to power pumps for shallow tube wells. 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 in Bangladesh. Also in some central, southern and eastern parts of the country, farmers depend 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.

5.6 High production costs

Hybrid maize is a high value crop. Its cultivation cost –about 35,000-40,000 Taka/ha, i.e. US$ 500-571/ha– is also higher than most other *Rabi* crops. It needs a large amount of N and other fertilizers to approach its high potential yield. The production of high yield maize and rice in Bangladesh is increasingly dependent on the availability of cheap N and other fertilizers. 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. Most N fertilizer is currently available as synthetic urea made from natural gas extracted inside Bangladesh. Proven reserves of natural gas are sufficient for little more than 10 years of current consumption. Fertilizer shortages are encouraging unscrupulous fertilizer traders to adulterate fertilizers with inert ingredients. In this situation, most resource poor farmers apply N fertilizer at rates near the optimum on maize, but under-dose other essential nutrients. This is one reason farmers give for the stagnating yield of hybrid maize in parts of the country. Hybrid maize seed is also costly. For resource poor farmers, it is difficult to bear all those costs and this can mean that poorer farmers afford only small areas of hybrid maize.

5.7 Lack of information and training for farmers

The very high potential productivity of maize in Bangladesh has yet to be fully achieved. There are considerable gaps between potential and achievable and between achievable and farmers' yields[18]. Farmers indicated a large part of the gaps is due to inadequacies in farmer knowledge about maize production, along with socio-economic factors. To cultivate a new crop like hybrid maize, information and technology needs to flow to and among farmers. Farmers lack information on suitable crop management practices such as time of planting, optimum doses of different fertilizers, the application of micronutrients such as boron, and weeding and irrigation at critical stages of crop development. Farmers usually receive advice from input retailers, DAE extension workers and lead farmers. Retailers are not always able to provide good advice due to their 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, many farmers depend on their own experience. Some hands-on and audio-visual aided training, such as "Maize Whole family Training (WFT)"[7], has been provided, with important benefits. Between 2001 and 2006, nationally around 13000 farm families (or 36000 maize growers) from 35 of the 64 districts in Bangladesh were trained on modern maize production practices through the WFT program. This resulted in higher production of maize by trained farmers and increased the demand for quality hybrid seed for planting[7]. However, many more farmers have not received training.

6. Available maize-rice technologies

Although there has been relatively little research to develop maize technologies in Bangladesh, several maize and rice technologies are available that can help to alleviate the M-R system problems described.

6.1 High yield maize hybrids

An increasingly wide range of well adapted, high yielding full season maize hybrids are available in Bangladesh. These provide stable high yields that farmers seek. Good hybrids have been available from the private sector for the last 10 years. Additionally, largely based on germplasm from CIMMYT, and often direct crosses of CIMMYT maize inbred lines (CMLs), BARI has now developed and released seven maize hybrids. Grain yields of 8-9.5 t/ha can be regularly obtained with these hybrids[9]. Among them, BARI Hybrid Maize 3 has the potential to produce 11 $t{\cdot}ha^{-1}$ grain while BARI Hybrid Maize 5 is a high yield quality protein maize (QPM) with a similar yield potential. These two BARI-developed hybrids consistently produce high grain yields on Bangladesh farms that are comparable with or better than other commercial hybrids[5-6], and they are proving popular in Bangladesh.

6.2 Early maturity, high yielding *T. Aman* rice varieties

A wide range of rice varieties are available for the different rice seasons in Bangladesh. Early maturing high yielding *T. Aman* rice varieties are an immensely important option that will allow the earlier planting of maize after the harvest of rice. 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 $t{\cdot}ha^{-1}$) compared to popular long duration varieties like BR-10 or BR-11 or Swarna (4-5 $t{\cdot}ha^{-1}$). Most farmers remain reluctant to sacrifice rice yield because that is their main staple food, preferring to first ensure food security, then profit. However, some farmers are adopting short duration rice varieties to ensure better profit from high value *Rabi* maize. Bangladesh Rice Research Institute (BRRI) is trying to develop shorter duration *T. Aman* rice varieties that have better yield and quality comparable with traditional varieties (personal communication Dr M Anser Uddin, BRRI, Rajshahi).

6.3 Profitable intercrop/relay crop options with hybrid maize

Rabi season hybrid maize is a long duration (145 days) crop, but resource poor farmers want quick returns from their investment. Maize is spaced on rows 75 cm apart and canopy closure happens only after 45-50 days. Through intercropping/relay cropping of maize, the productivity per unit of 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 feasible and very economic; providing early additional income without reducing maize grain yield[5-6] (Fig. 5). Relay cropping of maize 20-35 days after the planting of potato can also bring very high profit, providing 20-21 t·ha^{-1} maize equivalent yield within five months (Fig. 5 and Table 3)[5-6, 9]. Such diversified and highly profitable crop patterns should be promoted widely.

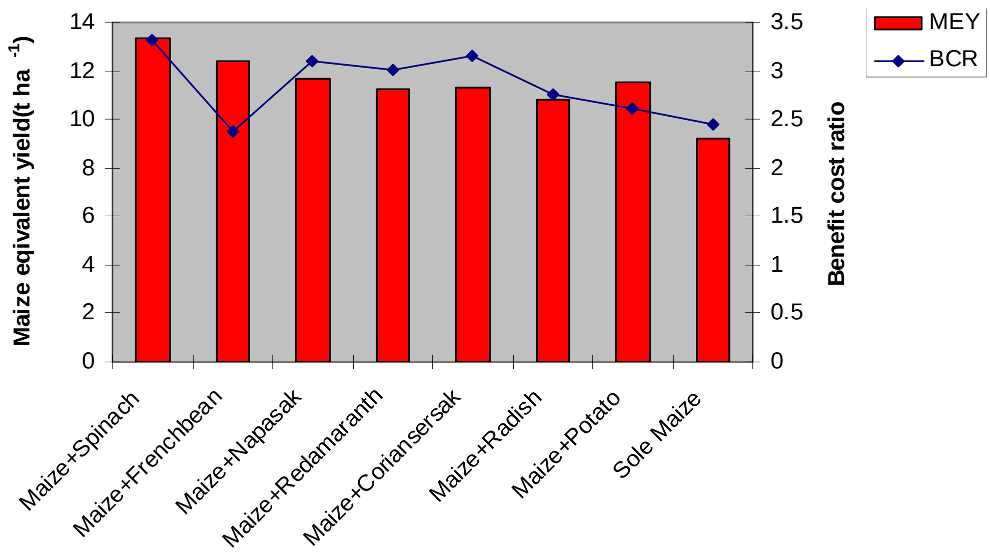

Fig. 5 Maize equivalent yield and benefit-cost ratio of maize-vegetable intercrops and sole-crop hybrid maize in Bangladesh

Table 3 Yield of potato and maize, and maize equivalent yield (MEY) as relay crops in Bangladesh

Treatment	Potato yield (t/ha)		Maize yield (t/ha)		MEY (t/ha)		
	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, M. Y, 2006.

6.4 Nitrogen management options

As elsewhere, a large amount of N (>250 kg·ha^{-1}) is required to achieve the very high (10＋t/ha) grain yields possible with hybrid maize in Bangladesh. Rice crops also require large amounts of N. Most N fertilizer in Bangladesh is in the form of urea made from natural gas which is projected to last no more than 10 further years. Thus N fertilizer prices are likely to increase as supplies fall. New more sustainable sources of N are needed, along with its efficient use. Maize farmers in Bangladesh generally try to follow the current recommendation[14] which is to apply one third N as a basal dressing during land preparation, one third at the 8-leaf stage and the remaining one third at tasseling. But because the crop is tall and dense, the last application is hazardous to the skin and eyes of farmers. In this situation many farmers avoid the last application, which then reduces yield. New research[11] found that

N could be applied half as a basal dressing and the remaining half at the eight leaf stage or 30% as a basal and the rest 70% at eight leaves. 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 without losing rice or maize yield[12]. USG is prepared by applying pressure on prilled urea in a mini brickette making machine. Such machines are now widely available and the resulting 'Guti' urea is increasingly used for rice[19-20]. Research data benefits from the application of USG to hybrid maize is 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.

Some integrated mineral-organic fertilizer combinations can help maintain soil health and sustainability of the farm system. Various opportunities to better use crop residues and animal waste products through composting exist in Bangladesh. While cattle manure is becoming scarce, poultry manures are now common. Bangladesh produces about 1.63 million t of poultry manure per year, containing large amounts of N and other essential elements, but still it is rarely used. Mineral fertilizers combined with 25 % of poultry manure gave good results with maize in a preliminary study[12] (Table 4). However, more research work is needed to develop recommendations.

Table 4 Effect of fertilizer combinations on maize and *T. Aman* rice grain yield in a Maize-*T. Aman* cropping pattern at Pushpapara, Pabna, Bangladesh, 2003-2006

Treatments	2003-2004		2004-2005		2005-2006		Mean	
	Maize	*T. Aman*	Maize	*T. Aman*	Maize	*T. Aman*	Maize	*T. Aman*
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	-	-

Note: PM = Poultry Manure.

6.5 Minor nutrient application

Boron (B) is an important micronutrient needed in small amounts for grain formation. In B deficient soil, it must be applied to raise the efficiency of use of macro nutrients (NPKS) and realize higher maize yields. 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 areas with B deficiency are unaware about the importance of B for their light soils. There, by applying 2 kg B ha^{-1}, grain yields of maize can be doubled from 5.2 to 10.1 t/ha[12]. Zinc can also raise the yields and N use efficiency in maize-mungbean-rice crop systems in Bangladesh[21].

6.6 Plant population density optimization for hybrid maize

Research on maize plant population densities with open pollinated varieties and synthetics during the 1980s and 1990s in Bangladesh, concluded that plant densities of around 66000-80000 plants/ha were optimal[2]. Recent results with varying plant population densities of hybrid maize (using BHM 2 and 5) in the long duration-145 days *Rabi* season indicated no marked difference in grain yields between 44444 plants/ha (75 cm×30 cm) to 133333 plants/ha (75 cm ×10 cm). 53333 plants/ha (75 cm×25 cm) gave a slightly higher yield[5-6]. Elsewhere, the yield response to plant density is often greater for shorter season hybrids and least for long duration maize[23-24]. In Bangladesh all currently available *Rabi* season maize hybrids are long duration (145 days), and possibly that is the reason for little response to a higher plant density. Farmer plant densities with the current hybrids are often around 66000 plants/ha[7]. Farmers may save expensive hybrid seed if a recommendation of 53333 maize plants/ha (75 cm×25 cm) was promoted.

6.7 Use of mechanized planters

Early planting within the optimum time period is important to achieve high yield with *Rabi* season hybrid maize. Also the turnaround period between the harvest of *T. Aman* rice and planting of maize is very narrow in Bangladesh. Here, mechanized planters which can be used to sow the maize seed rapidly on large areas of flat land, are very helpful. Wheat Research Centre (WRC) of BARI has developed a multiple power-tiller-operated seeder (PTOS)[25]. Originally for wheat, the PTOS now has a cup seed mechanism for maize and other big seeded crops, and has been used successfully to plant maize on farmer's fields[5-6]. Additional units of the maize PTOS need to be fabricated, tested, marketed and promoted with farmer planting service providers, in cooperation with interested private farm implement companies such as Green Machinery Stores.

6.8 Bed planting for *Kharif* maize

Soil beds or ridges are an important management option for maize growing into increasingly wet conditions in the *Kharif*-1 season[26-27]. Work has been done on the development of hand-tractor-mounted ridging equipment for R-W systems[25,28] and now increasingly M-R systems in Bangladesh. The suitability of soil beds for rice is less clear. They may not work well unless rainfall is very high and the beds are essentially saturated throughout the season. Making soil beds for maize followed by destruction of the beds for rice may not be practicable, being labor and equipment intensive, and may negate benefits to be had.

Significant improvements to and testing of soil bed formers and bed planters have been made in Bangladesh in recent years[3]. A power-tiller-operated bed former and planter is available that simultaneously creates a trapezoidal raised bed and performs seeding and fertilizing operations on top of the bed in one operation behind the two-wheel tractor. 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 several crops, including maize and rice. Maize yields can be raised by 2 t/ha compared to conventional planting. However, on farm tests of this equipment suggests crop growth on beds may be more variable than in conventional systems. This equipment needs to be more widely tested on farm in Bangladesh before widely promoted.

7. Research to optimize Bangladesh maize-rice systems

Given the increasing importance of M-R systems in Bangladesh and the relatively little emphasis to date, considerable research is necessary to ensure these systems remain highly productive. In this last section, we discuss some of these needs. Among these, the development of sustainable alternative cropping patterns, tillage management options and integrated plant nutrient systems (IPNS) are important for intensifying M-R systems.

7.1 Maize-rice crop system optimization strategies

In Bangladesh there has been limited research on opportunities to sustainably intensify and optimize the emerging M-R systems. These systems have only become important during the 2000s and concerns over their sustainability are just beginning. Sets of appropriate technologies for M-R cropping should be developed for key parts of Bangladesh where the system is important, considering major factors such as variety × planting time × nutrient management × weeding plus other management × irrigation, along with their post-harvest management. These should be developed both for *Rabi* and *Kharif* season maize separately.

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 viewpoint. 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 highly profitable, but their sustainability implications require investigation. Computer-based crop system simulation modeling can help with some aspects of intensification including the construction of optimal crop sequence calendars. As technology options emerge, dissemination of key information should be ensured through training events and field-days, in picture-oriented posters and on compact discs. The target would be to ensure profitable, high yield potential and sustainable M-R systems for Bangladesh. Some of these options are likely to be applicable to similar irrigated systems in parts of eastern India such as West Bengal and Bihar.

7.2 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 over coming decades the productivity of M-R cropping systems through integrated soil fertility management strategies. These are needed for diverse situations in the countries' different agro-ecological regions. 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;[12]) appear related to soil fertility problems including deficiencies of NPK arising from improper N management and inadequate P and K use. Nutrient depletion-replenishment studies have shown negative balances for N and K in such systems[11, 15, 17]. 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. One recent estimate shows that about 200 kg/ha/yr N+P+K applied as fertilizer remain unutilized by the crops in these systems, mainly due to improper management practices that include imbalanced fertilizer doses, inappropriate time of fertilizer application and irrigation[14].

We need to understand more about the extent and rate of nutrient depletion and soil physical degradation in these intensifying M-R systems and formulate amelioration strategies. Further work to sustain the cropping system by addressing soil mineral and organic fertility and maintenance of soil structure is required. To push the achieved grain yields even higher up the yield potential curve will require larger amounts of nutrients, their better management and overall soil stewardship. There is need to conduct nutrient series experiments on very high input and yield maize crops on farm to find out which nutrients are limiting so that ways to manage these can be incorporated into recommendations and training to achieve the higher yields necessary to feed the animals and people in Bangladesh from a fixed soil resource.

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 M-R production systems, particularly those involving newly released BARI maize hybrids. The widespread important *T. Aman* rice-maize system brings special issues. This system is complicated because the component crops are grown in sharply contrasting physical, chemical and biological environments –rice under flooded conditions where soil structure is destroyed by puddling and strong reducing conditions tend to create S and Zn deficiency problems; and then maize under aerobic conditions requiring good soil structure and macro-porosity. Here 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 more important given that most soils of Bangladesh currently have low organic matter contents, seldom exceeding 1.5%. Residue management systems with zero tillage will have a key role.

Integrated plant nutrition system (IPNS) packages for intensive M-R 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:

(1) Understanding soil fertility constraints in representative maize growing areas across the country.

(2) Assessing crop nutrient requirements for optimum yield targets for both maize and rice in the intensifying systems in the prevailing biophysical environments.

(3) 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.

(4) Maximum use of residual fertilizer by the cropping sequence to reduce the cost of fertilizers for farmers.

(5) Field testing the IPNS packages in comparison with farmers' existing practices.

(6) Financial analysis of the IPNS packages to evaluate farmers' profit margins.

(7) Combination of IPNS with water management and soil physical management, and with water-efficient maize that may be developed.

(8) 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 grain. Large amounts of cow dung are produced in Bangladesh but during the dry season most (67%) is used as household fuel for cooking. About 1.6 million t of poultry manure is currently produced in Bangladesh each year but currently little of it is used on crop fields. Therefore, within the IPNS nutrient packages, the management of poultry manure (as an important organic component of such inputs) should be a high priority.

(9) Widespread B deficiency is a concern in the northern region. 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 yield. Hybrid maize seems to be sensitive to B. Many farmers are not aware of B, and much of the imported B fertilizer is adulterated. It is worthwhile to seek B tolerant maize genotypes and refine the management of B fertilizer.

(10) To conserve soil fertility, crop residue retention is gaining popularity globally. In intensive maize production areas in Bangladesh, maize stover is either used as fuel or thrown outside the plot to clear land for succeeding *T. Aman* rice. If this residue could be composted quickly and mixed with soil, it would recycle nutrients and organic matter into degrading soil. Quick and cheap composting mechanisms should be developed for maize straw.

7.3 Development and testing of water logging-, drought- and lodging-tolerant maize

The development of short-duration, water logging- 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 important for future M-R systems in South Asia.

If water logging-tolerant maize was available for use in Bangladesh it would greatly expand opportunities for the low risk production of maize for grain into the *Kharif-1* pre-monsoon season on additional upper and some mid toposequence fields. However, the elite high yielding tropical and subtropical maize germplasm developed specifically with a high degree of water logging tolerance that would be needed has yet to be developed. Breeding such materials may be a slow process since relatively little is known about the physiology and genetics of water logging 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 tolerance to waterlogged conditions[28]. Promisingly, Zaidi, et al[28] report considerable variability for such traits among genotypes studied.

The development of such high yield potential water logging-tolerant maize hybrids should be undertaken cooperatively by plant breeders at CIMMYT in Mexico and BARI in Bangladesh. In Bangladesh, BARI and CIMMYT can screen adapted high yield potential maize germplasm already available in Bangladesh for tolerance to water logging during crop establishment and for terminal flooding, form hybrids and test them in the research stations first under warm waterlogged conditions in the *Kharif-1* season. Promising materials can then be tested by smallholder farmers using their current cropping management and in combination with bed planting systems, to develop effective and low risk production management systems that farmers can use to grow maize into the *Kharif-1* season.

During the *Rabi* season, maize irrigation can 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 yield potential 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 water logging tolerance, CIMMYT and its partners have a long successful history of developing and deploying drought tolerant maize in Mexico and Central America, in sub-Saharan Africa, and most recently in SE Asia. CIMMYT can facilitate the entry of candidate drought tolerant inbreds into Bangladesh. These materials can be tested on farm with current irrigation schedules and on dryer upper toposeuence fields and those with sandier soils with reduced irrigations.

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

7.4 Faster turn round between *T. Aman* rice and *Rabi* maize

There are several opportunities to facilitate earlier planting of monsoon rice, its faster harvest and the faster planting of winter *Rabi* maize to shorten turn-around-time between crops and better synchrony of cropping patterns to climate. 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 PTOS has been modified by 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 successful. Yields were similar to transplanted rice with 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 these are often reported 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 cold weather in December. 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. To address mineral nutrient depletion and declining crop productivity in these intensifying M-R 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* rice.

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

(1) Management briefs for extension staff and farmers that synthesize best current information about the transition from the harvest of *Aman* rice to the establishment of maize. These should be widely publicized and used in farmer whole-family-training and field school initiatives underway by BARI, DAE, Winrock, and others.

(2) Modification and testing of power-tiller-operated wheat reaper and wheat thresher for faster harvest and processing of *Aman* rice on dry fields, freeing labor resources more quickly for planting maize.

(3) Development and testing of manual methods for very early zero till planting and fertilizing of maize on drying fields with rice stubble. Small jab-type planters can be tested for soft soil conditions.

(4) Modification and testing of 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 the soil in one pass[29-30]. This should reduce turn-around time by 10 to 20 days, and reduce maize establishment costs by up to 60%.

(5) Farmer participatory on-farm research and development on integration of new early maturing and abiotic-stress-tolerant maize, along with efficient planting and establishment technologies into existing and improved M-R systems in Bangladesh.

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

Crop management options have a big role in controlling water logging. For example, planting maize on raised soil beds or ridges is worth further study.

Evidence of longer-term productivity, intensification and sustainability benefits of permanent soil beds with crop residue management is emerging in Bangladesh. Results are available from WRC-Cornell University-CIMMYT studies conducted over four years at the WRC in Nashipur-Dinajpur and at Rajshahi, 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[26-27]. The combination of permanent beds and straw retention at Nashipur produced the maximum grain yield of 11 to 21 t ha^{-1} per year compared with 7 to 15 t ha^{-1} for conventional tillage without straw retention[26], with 14%-38% less irrigation water[27]. 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 centralwest Bangladesh[27]. Yields were mixed in the short term as farmers learn how best to space beds and crop rows. More participatory on farm research and extension is needed.

7.6 Farm economics of maize vs. alternative enterprises

The dominant drivers for the increased adoption and production of maize in Bangladesh are economic. The grain market is strong and recent (2000-2006) 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 35000, with a profit of Taka 49000 per ha, compared with Taka 20680 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 is established in recent years 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 2008-2009 that may undermine the financial dominance of maize. These include rises in fertilizer price raising input costs, increasingly serious bird flu outbreaks reducing maize grain demand by poultry industries, decreasing the price of maize grain, and wheat grain prices rising internationally and locally. Local market prices of wheat grain rose strongly in the second half of 2007 throughout 2008, reflecting international increases.

Thus there is need for more work on the economics of maize. Surveys of farmers are needed 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 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 important for policy decision making on crop support and assessments of the impact 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 policy issues on imports and support to local maize and rice production.

8. Conclusion

Hybrid maize is an emerging high value cereal crop in Bangladesh, grown in intensive M-R cropping systems, and having among the highest average farm yields (5.7 $t{\cdot}ha^{-1}$) found in Asia. Economically, hybrid maize is far more profitable than *boro* rice, and wheat, or most other competing winter season *Rabi* crops. It is predicted that over the near future its expansion would continue to increase at about 15% per year. A booming poultry industry is the key driver behind the expansion of maize for the supply of feed, albeit with temporary setbacks from Avian flu. In future, alternative uses of maize may increase. Maize-*T. Aman* rice is the major cropping system; however it is now becoming diversified with many other crops, including potato. Maize is relatively problem-free in Bangladesh, but some constraints are intensifying with increased concern over input supply and soil related environmental sustainability. An array of new technologies for sustainable intensive M-R production system is emerging in Bangladesh and some are being promoted and adopted. However, the sustainability of M-R production system in Bangladesh depends on optimization of planting time, quality seed of appropriate hybrids, balanced nutrient management along with soil fertility conservation and other management, for which further research would be a high priority.

References:

[1] Ahmed, J. and S. M. Elias. Socio-economic study of winter maize in some selected areas of Bangladesh. *Journal of Rural Development (Bangladesh)*, 1988, *18*: 60-68.

[2] Alam, M. M., M. M. Basher, A. Karim, et al. Effect of rate of nitrogen fertilizer and population density on the yield and yield attributes of maize (*Zea mays*) (in Bangladesh). *Pakistan Journal of Biological Sciences*, 2003, *6*: 1770-1773.

[3] Waddington, S. R., N. E-Elahi and F. Khatun. *The Expansion of Rice-maize Systems in Bangladesh. Invited Oral Presentation in the Symposium on Emerging*

Rice-Maize Systems in Asia. ASA-CSSA-SSSA 2006 International Annual Meetings, 12-16 November 2006, Indianapolis, Indiana, USA.

[4] Waddington, S. R., F. Khatun, N. E-Elahi, et al. Maize in Bangladesh. Presentation at the *Rice-Wheat Consortium for the Indo-Gangetic Plains 14th Regional Technical Coordination Committee Meeting*, February 14-15, 2007, Kathmandu, Nepal.

[5] CIMMYT Office in Bangladesh. Maize whole family training. In: *Food Security in Bangladesh: Improving Wheat, Maize and Papaya Production and Impacts of Arsenic Contamination*. Project Annual Report for 2004-2005: 45-66.

[6] CIMMYT Office in Bangladesh. Maize whole family training. In: *Food Security in Bangladesh: Improving Wheat, Maize and Papaya Production and Impacts of Arsenic Contamination*. Project Annual Report for 2005-2006: 31-44.

[7] Hasan, M. M., S. R. Waddington, M. E. Haque, et al. Contribution of whole family training to increased production of maize in Bangladesh. *Progressive Agriculture (Bangladesh),* 2007, *18*(1): 267-281.

[8] Sarkar, R. K., A. Chakraborty and B. Bala. Effect of alternative cropping systems on yield and advantage in direct seeded upland rice areas in Indian sub-tropics. *Journal of Agronomy and Crop Science*, 1998, *180*(1): 1-6.

[9] Ali, M. Y. Rice-maize systems in Bangladesh. *Invited Oral Presentation in the Workshop on Assessing the Potential of Rice-Maize Systems in Asia*. IRRI-CIMMYT Alliance Program for Intensive Production Systems in Asia, held December 4-8, 2006, IRRI, Los Baños, Philippines.

[10] Pal, M. S. Alternative crop production strategies for rice-wheat cropping systems in the Indo-Gangetic plains of India. *Australian Journal of Experimental Agriculture*. 2003, *43*(6): 605-615.

[11] OFRD (On-Farm Research Division) of BARI. *Annual Report for 2005-2006.*

[12] OFRD (On-Farm Research Division) of BARI. *Annual Report for 2006-2007*.

[13] Heikens, A., G. M. Panaullah and A. A. Meharg. Arsenic behaviour from groundwater and soil to crops: Impacts on agriculture and food safety. *Rev Environ Contam Toxicol,* 2007, *189*: 43-87.

[14] BARC (Bangladesh Agricultural Research Council). *Fertilizer Recommendation Guide*. Dhaka, Bangladesh, 2005.

[15] Panaullah, G. M., J. Timsina, M. A., Saleque, M. Ishaque, et al. Nutrient uptake and apparent balances for rice-wheat sequences: III. Potassium. *Journal of Plant Nutrition,* 2006, *29*(1): 173-187.

[16] Saleque, M. A., J. Timsina, G. M. Panaullah, M. Ishaque, et al. Nutrient uptake and apparent balances for rice-wheat sequences: II. Phosphorus. *Journal of Plant Nutrition,* 2006, *29*(1): 157-172.

[17] Timsina, J., G. M. Panaullah, M. A. Saleque, et al. Nutrient uptake and apparent balances for rice-wheat sequences: I. Nitrogen. *Journal of Plant Nutrition,* 2006, *29*(1): 137-156.

[18] Timsina, J., R. J. Buresh, A. Dobermann, et al. *Strategic Assessment of Rice-maize Systems in Asia.* IRRI-CIMMYT IPSA Publication. IRRI, Philippines, 2008. (unpublished report)

[19] Setty, R. A., K. M. Devaraju and S. Lingaraju. Response of paddy to different sources and levels of nitrogen under transplanted condition. *Oryza,* 1987, *24*(4): 381-382.

[20] Singh, B. K. and R. P. Singh. Effect of modified urea materials on rainfed and lowland transplanted rice and their residual effect on succeeding wheat crop. *Indian Journal of Agronomy*, 1986, *31*(2): 198-200.

[21] Hossain, M. A., Jahiruddin M., Islam M. R., et al. The requirement of zinc for improvement of crop yield and mineral nutrition in the maize-mungbean-rice system. *Plant and Soil,* 2008, *306*(1-2): 13-22.

[22] Sarlangue, T., F. H. Andrade, P. A. Calvino, et al. Why do maize hybrids respond differently to variations in plant density? *Agronomy Journal,* 2007, *99*: 984-991.

[23] Ewards, J. T., L. C. Purcell and E. D. Vories. Light interception and yield of short-season maize hybrids. I. the Midsouth. *Agronomy Journal,* 2005, *97*: 225-234.

[24] Hossain, M. I., C. A. Meisner, M. A. Sufian, et al. Performance of power tiller operated seeder for wheat cultivation. *Bangladesh Journal of Agricultural Research,* 2002a, *27*(3): 393-400.

[25] Talukder, A. S. M. H. M., C. A. Meisner, M. E. Baksh, et al. Wheat-maize-rice cropping on permanent raised beds in Bangladesh. In: Humphreys, E. and Roth C.H. (Eds.). *Permanent Beds and Rice-residue Management for Rice-wheat Systems in the Indo-Gangetic Plain*. *Proceedings of a Workshop Held in Ludhiana*, India, September 7-9, 2006. ACIAR Proceedings No. 127, 2008: 111-123.

[26] Lauren, J. G., G. Shah, M. I. Hossain, et al. Research station and on-farm experiences with permanent raised beds through the soil management collaborative research support program. In: Humphreys, E. and Roth C. H. (Eds.). *Permanent Beds and Rice-residue Management for Rice-wheat Systems in the Indo-Gangetic Plain*. *Proceedings of a Workshop Held in Ludhiana*, India, September 7-9, 2006. ACIAR Proceedings No. 127, 2008: 124-132.

[27] Zaidi, P. H., S. Rafique, P. K. Rai, et al. Tolerance to excess moisture in maize (*Zea mays* L.): Susceptible crop stages and identification of tolerant genotypes. *Field Crops Research,* 2004, *90*: 189-202.

[28] Hossain, M. I., C. A. Meisner, M. H. Rashid, et al. Development and testing of power tiller operated bed planter for upland crop establishment. *Bangladesh Journal of Agricultural Research,* 2004, *29*(1): 29-36.

[29] Hossain, M. I., M. A. Sufian, M. A. Z. Sarker, et al. Power tiller operated bed planter for improved crop establishment. *Journal of Science and Technology,* 2004, *2*: 17-23.

(Edited by August, Hellen and Pann)