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Environmental and Natural Resource Degradation in Intensive Agriculture in Bangladesh

Stefano Pagiola

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Foreword

This report is part of a series of studies being undertaken on Bangladesh's agricultural sector to take stock of the current situation, identify problems that need to be resolved, and establish priorities for future action. It focuses on an issue which has been the source of considerable concern in recent years: environmental problems that might arise from the growth of intensive agriculture. These are issues that are critical for the future development of Bangladesh: intensification has been one of the driving forces in recent growth and will continue to play an important role in growth and poverty alleviation.

We are pleased that this report is being issued in the Environment Department Working Paper Series since the issues it discusses are of much broader interest than to Bangladesh alone. It is now widely recognized that sustainable development is closely linked to a healthy environment. The nature and magnitude of those linkages, however, are often unclear. Studies such as this one are necessary to establish whether, and in what way, economic activity might be affecting the environment and to establish priorities for action. As this report shows, agricultural growth need not be as harmful to the environment as some fear; but neither is it always without adverse consequences. The challenge is to identify the ways in which growth can harm the environment, so that appropriate actions can be taken to minimize damage.

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Acronyms, Abbreviations, and Glossary

BADC	Bangladesh Agricultural Development Corporation
BARI	Bangladesh Agricultural Research Institute
BBS	Bangladesh Bureau of Statistics
BPH	Brown Plant Hopper
BRRI	Bangladesh Rice Research Institute
CIMMYT	International Maize and Wheat Improvement Center
DAE	Department of Agricultural Extension
FAO	Food and Agriculture Organization
FCD	Flood Control and Drainage
GDP	Gross Domestic Product
IFDC	International Fertilizer Development Center
IPM	Integrated Pest Management
IRRI	International Rice Research Institute
NEMAP	National Environmental Management Action Plan
NGO	Non-Governmental Organization
NMIDP	National Minor Irrigation Development Project
TFP	Total Factor Productivity
UNDP	United Nations Development Programme

ai	Active ingredient (of a pesticide)
Aman	Rice planted during the wet season and harvested in the dry season
Aus	Rice planted during the dry season and harvested in the wet season
b. *Aman*	Broadcast *Aman*
Boro	Rice planted in the dry season
t. *Aman*	Transplanted *Aman*
Rabi	Dry season

ha	hectare
mt	metric tonne
µg	microgram (one millionth of a gram)
kg	kilogram
l	Litre

Executive Summary

Bangladesh has made substantial progress towards achieving its goal of foodgrain self-sufficiency. This achievement has been based on a substantial intensification of agriculture: modern rice varieties now account for almost half of the rice area; an increasing proportion of land is double- or triple-cropped; and use of chemical fertilizers has doubled since the early 1980s. Continued and accelerated agricultural growth will require intensification to continue. There has been rising concern, however, that intensive agriculture may not be sustainable and that it may be damaging to the environment or to other productive sectors—such as fisheries—particularly through water pollution. This report examines these concerns.

Sustainability of intensive agriculture

Evidence of declining productivity. The overall picture of rising average yields and rising production in Bangladesh has tended to camouflage evidence of declining productivity. Farmers often claim that yields have been declining and that higher fertilizer applications are necessary to maintain yields. Analysis of data on yield trends at the district level shows that, despite rising input levels, yields have been declining or stagnant on about two-thirds of the area planted to modern varieties in the *boro* season in the last decade, and stagnant throughout the country in the *aman* season. Yield declines are strongly associated with the length of time that intensive production practices have been employed in each district. The results of long-term trials by the Bangladesh Rice Research Institute (BRRI) also indicate that intensive rice cultivation can result in declining yields, even under good management and with full recommended doses of all nutrients being applied. Stagnant or declining yields in the context of rising inputs indicate that land degradation is reducing productivity; if increases in input use had not counteracted the effects of degradation, yields might have fallen even further. This evidence is consistent with patterns of yield change in other Green Revolution countries, many of which have also experienced a slowdown in the rate of growth of production and yield.

Causes of declining productivity. There is considerable debate over the exact causes of declining productivity. In Bangladesh, the most likely cause is nutrient imbalances. High-yielding modern varieties are far more demanding of soil nutrients than local varieties had been, a problem worsened by the increasing prevalence of multiple cropping. Chemical fertilizer use has increased, but not sufficiently to compensate for the higher rates of offtake and has been offset by reductions in applications of farmyard manure, which is in increasing demand for use as fuel. In general, applications of nitrogen are adequate but those of other nutrients often are not. Changes in soil physical and chemical properties, such as changing quality and quantity of organic matter and formation of a plowpan, also play a role in declining yields. Because of its particular characteristics, on the other hand, Bangladesh has not experienced the irrigation-related problems, such as declining availability of water, salinization, and waterlogging, which have been an important reason for decreasing productivity in areas such as the Pakistani Punjab. There is some evidence of a build-up of insects and diseases, but this problem does not appear to be a major factor in current yield declines.

Consequences of declining productivity. The switch from traditional to modern varieties is essentially complete in the dry season and well underway in the wet season. While further expansion of irrigation is possible, it will become progressively more difficult. If current trends continue, the scope for production growth arising from intensification alone will be exhausted in about the year 2000. Further growth will then depend on improvements in productivity. Since the yield gap between farmer yields and potential yields remains high, even in districts which have not experienced yield declines (farmer rice yields in the dry season, for example, range from about 3 to 4 mt/ha while experiment station yields are generally in the 6 to 7 mt/ha range), the potential for such growth remains substantial.

Farmer responses. Because yield declines affect them directly, farmers have incentives to respond to them and are in fact doing so. Farmers are using higher and more balanced fertilizer applications. In particular, many have recently begun using fertilizers supplying micro-nutrients such as sulphur and zinc. They are also undertaking other activities, such as fuelwood planting, which will in the long run help to relax some of causes of declining productivity. There is considerable scope for the research and extension service to assist farmers in developing appropriate responses. This will require a re-orientation of research efforts towards an increased focus on site-specific conditions, on long-term research, and on cropping systems and practices used by farmers. The days of "blanket" messages which are equally applicable to all farmers are over; what farmers need is assistance in fine-tuning their cropping practices to improve yields and avoid degradation, not fundamental qualitative changes. This effort will also require a much improved extension system, which must not only deliver information to farmers but also convey information back to the research system on farmers' needs and constraints. Efforts are already underway to achieve these aims, but much remains to be done. Farmers will also need reliable and timely access to inputs, including irrigation, fertilizers, and credit. The liberalization of irrigation in the late 1980s was largely responsible for the sharp increase in growth in that period, and liberalization of the fertilizer distribution system during the 1980s has resulted in substantial improvements in fertilizer availability at the farm level. Problems persist, however, in the supply of urea, for which a government parastatal is the only source. The problems in urea supply need to be addressed and must be prevented from resulting in back-tracking on liberalization efforts.

Environmental problems

In addition to sustainability problems, concern has been expressed that intensive agriculture harms the environment more generally. In particular, the rapid increase in the use of pesticides is thought to (i) adversely affect the health of farm workers and others exposed to pesticides; and (ii) contaminate ground- and surface water, harming downstream users of that water and damaging inland fisheries. Pesticide use fell in the late 1970s, when subsidies were removed, but has since increased again; sales of pesticides doubled in the second half of the 1980s. About 70 percent of pesticides are used on rice. Usage is heaviest on *boro*, which received over 50 percent of pesticide applications on rice, by value, in 1989-90. Nevertheless, the amounts used per unit area and the total area affected are both relatively small. In 1989-90, only about 10 to 20 percent of the area planted to modern variety rice was treated. Pesticide use on rice is mainly reactive rather than prophylactic—applications are only made upon detecting insect infestations in the fields. Use of insecticides on vegetables follows a pattern almost diametrically opposed to that found in rice. It is common to spray vegetables such as eggplant and country beans several times a week. There are indications that resistance to pesticides is well established among several vegetable pests.

Health problems. The toxicity of pesticides threatens the health of users. A study of rice farmers in the Philippines, for example, found health costs associated with pesticide use to be so high as to completely outweigh any benefits arising from pesticide use. The level and nature of pesticide use in Bangladesh, however, differ significantly from those in the Philippine study area, except in the case of vegetable farmers. In rice production, pesticide use is widely dispersed and doses are low, so exposure is low. In vegetables, doses are high and applications frequent. Vegetable production is concentrated in a few areas and among a subset of farmers, so the population exposed is small but at high risk. Vegetables are often grown close to the household (because of their management intensity) and next to ponds or waterways (to facilitate irrigation) thus creating the potential for exposure of women and children and for water contamination. Consumption patterns also create a very significant potential for pesticide residues on vegetables affecting the health of consumers.

Water pollution. Use of agro-chemicals can also result in health problems through pollution of drinking water by residues. The flushing effect of annual floods and monsoon, however, limits the danger that residues will accumulate. Recent tests of groundwater taken from village hand-pumps found traces of pesticides in only ten of 78 samples, despite the samples having been drawn from areas considered most at risk of contamination. All the pesticides detected were longer-lived organo-chlorines, whose use is now banned; no traces of the moderately persistent organo-phosphates which account for the bulk of current pesticide use were found. Greater evidence was found of nitrate contamination, but even the highest concentrations found were below WHO safe drinking water guidelines. The degradation of inland capture fisheries has been attributed to a variety of factors, including overfishing, modifications to water flows resulting from water control programs, draining of *beels* for use in agriculture, and the effects of agricultural and industrial pollution. The relative importance of these factors is impossible to determine from currently-available data, however. Given the low overall level of use, however, pesticides appear unlikely to have been a major cause of the decline.

Need for intervention. Except for use on vegetables, the available evidence does not suggest the existence of significant current problems resulting from pesticide use in agriculture. It is feared that the extent of problems might increase as intensification continues. However, more recent modern rice varieties have been bred for increased pest-resistance, thus reducing the need for pesticide. Newer pesticides also tend to have lower concentrations of active ingredients and to be less persistent. By lifting the subsidies that it paid towards the use of pesticides, Bangladesh has already adopted policies which help reduce the risk of substantial environmental problems arising from pesticide use. Nevertheless, a number of relatively simple policies and reforms could reduce pesticide use even further and make it safer. Reform of the regulatory framework would help ensure that the pesticides that are used are safe both for their users and for the environment. The current system is slow, excessively concerned with pesticide effectiveness rather than safety, and consumes valuable research resources. In many instances, it has resulted in older, more toxic pesticides such as heptachlor (an organo-chlorine) continuing to be used because they are registered, even though safer pesticides are available and in widespread use worldwide. Increased use of Integrated Pest Management (IPM) practices would allow the low current levels of pesticide use to be reduced substantially without adverse consequences for agriculture. An FAO pilot project has led to 85 percent reductions in pesticide use among trained farmers and slight yield increases. However, the complexity of the knowledge required for successful use of IPM practices has limited diffusion beyond the trained group. Given the cost of this extension, the relatively low rate of pesticide use in rice, and the general weakness of the extension service, it may prove beneficial to look for subsets of IPM which could be extended more simply, with more complete IPM training being concentrated on areas with the highest pesticide use. There is also an urgent need for research on IPM techniques for vegetables.

Conclusions

Given the scarcity of land and the continued growth of population, there is no alternative but to continue intensifying agricultural production in Bangladesh. As currently practiced, however, intensive agriculture is degrading the soil resource base, posing a threat to its sustainability. These sustainability problems result primarily from the difficulties of learning how to manage complex new agricultural production systems, not from distortions or market failures inducing inappropriate behavior. They are not, therefore, amenable to traditional forms of intervention through manipulation of the price structure or by rules and regulations on land use. Farmers have amply demonstrated that they have both the incentive and the will to respond to degradation problems. What they need is a supporting infrastructure that will aid them in doing so. There is considerable scope for the research and extension service to assist farmers in developing appropriate responses to degradation problems. This will require a re-orientation of research and extension efforts towards an increased focus on site-specific conditions, on long-term research, and on cropping systems and practices used by farmers.

Environmentally, intensive agricultural practices appear to pose much less of a threat than is sometimes feared, with the important exception of pesticide use on vegetables. Here too, what problems there are generally do not result from the impact of distorted policies. Several relatively simple interventions can help ensure that they do not grow and may reduce them further. The most pressing need for action is in vegetables, where numerous factors indicate a high risk of damage to the health of farmers and consumers and to the environment more generally. Research is urgently needed to determine the magnitude and exact nature of problems—including threats to the health of farmers and their families, of pollution of waterbodies, and of pesticide residues on food—and to develop appropriate solutions. Reform of pesticide regulation will help to ensure that pesticides in use are safe for users and the environment.

1. Introduction

Substantial increases in irrigated area and use of modern rice varieties have led to rapid production growth in Bangladesh in the last decade. Continued and accelerated agricultural growth, which is important both for national economic growth and for poverty alleviation, will require further intensification. There has been rising concern, however, that intensive agriculture may be undermining Bangladesh's natural resource base and its environment. This concern has two components. The first is that intensive agriculture may not be sustainable. The second is that it may be damaging to the environment or to other productive sectors—such as fisheries—particularly through water pollution. Various aspects of these concerns feature prominently in the recently-prepared National Environmental Management Action Plan (NEMAP).

This report examines these concerns. Section 2 describes the intensification of agriculture which has taken place in Bangladesh. Intensification has been the driving force behind increases in production and average yields. Section 3 examines the sustainability of intensive agriculture in Bangladesh. Numerous sources of evidence show that, despite rising input levels, modern variety yields have been declining in many areas. Yield declines have been particularly marked in areas which have been under intensive cultivation the longest. Nutrient depletion problems seem to be the main cause of declining yields, although other factors have also contributed. These degradation problems are to some extent self-correcting, however, since farmers have incentives to respond to them, and are in fact doing so. Section 4 discusses the environmental consequences of intensive agriculture. Rising use of pesticides has led to fears of adverse health consequences and of water contamination. The evidence suggests, however, that the actual impact of pesticide use has been minor, since use is both low and dispersed. Furthermore, numerous trends suggest that environmental problems tied to pesticide use are unlikely to increase substantially; some simple policy interventions can help ensure that this is the case. Pesticide use on vegetables is an exception to this general trend; heavy and frequent applications of pesticides on vegetables suggest considerable danger of both health problems and water pollution.

The analysis is based on a wide variety of information sources, on extensive consultations with numerous scientists and others who have worked on agriculture in Bangladesh in the last decades, and on field trips to agricultural areas. Comparisons to the experience of other countries which have adopted similar practices are often illuminating, although due account has to be taken of Bangladesh's particular characteristics. In many instances, data are insufficient to establish clearly the magnitude of environmental and natural resource problems or to determine conclusively the relative importance of various contributing factors. Sufficient data are available, however, to arrive at a broad understanding of the relative importance of environmental and natural resource problems and to delineate priorities for action. Throughout the report, the emphasis is on rice production and cropping systems in which rice dominates, since rice is by far the most important crop in Bangladeshi agriculture, accounting for about 50 percent of agricultural output.

The scope of this report is limited to natural resource and environmental problems resulting from intensive agriculture. Accordingly, it does not cover several important natural resource and environmental problems relevant to the agricultural sector, including (i) the possible effects of measures to be implemented under the Flood Action Plan, (ii) bio-diversity and critical habitat conservation, (iii) erosion and deforestation problems, and (iv) problems tied to shrimp cultivation. The problem of the decline of inland capture fisheries is likewise not treated, except to the extent that it is directly linked to agricultural intensification.

2. Intensive Agriculture in Bangladesh

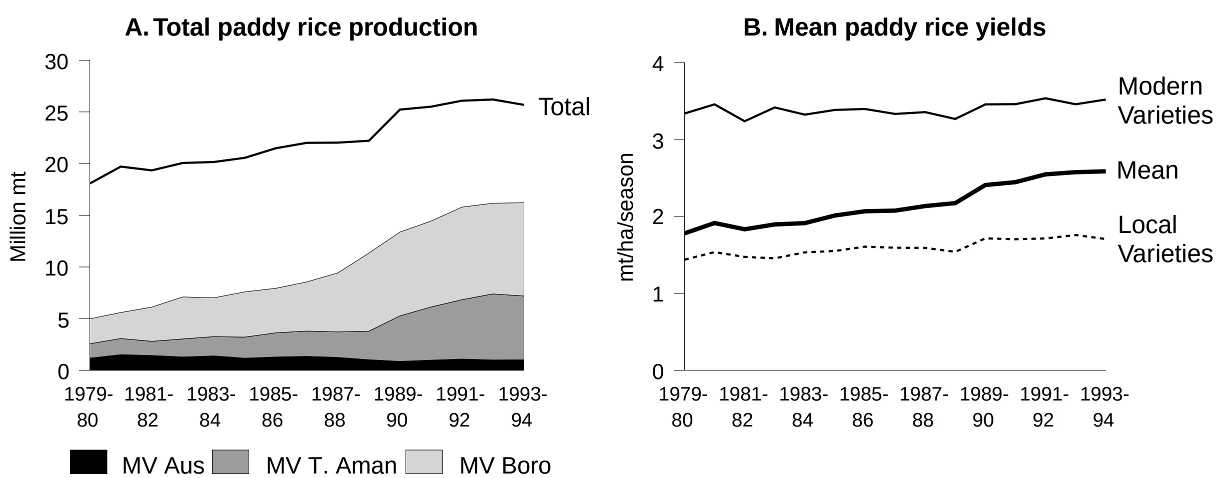
Agriculture continues to be the most important sector in Bangladesh's economy, contributing about 36 percent of GDP and employing about 60 percent of the labor force. Bangladeshi agriculture has made considerable strides in the last decade. Real agricultural GDP has grown by about 2 percent annually, with foodgrains leading the growth. Both production and mean yields of rice have risen consistently (Figure 1). This growth has resulted in foodgrain self-sufficiency being reached in good years—an objective few had thought achievable.

Production increases have resulted from a substantial intensification of agriculture rather than from increases in cultivated area; indeed, the area planted to rice has fallen slightly in the last decade. Intensification has taken several forms:

- Adoption of modern rice varieties (MVs) has increased substantially, with about half of the rice area now planted to modern varieties (Figure 2, Panel A). Modern variety adoption has been particularly rapid in *boro*, where it is almost complete. Increased use of modern varieties, especially in *aman* and *boro*, has been the driving force in increasing both total production (Figure 1, Panel A) and average yields (Panel B). The shift to modern varieties has been accompanied by a seasonal redistribution of production, with *boro* growing rapidly at the expense of *aus* (Table 1).

- The irrigated area has expanded rapidly, especially after the liberalization of minor irrigation in the late 1980s (Figure 2, Panel B). Most irrigated area is devoted to *boro* production.

Figure 1
Total paddy rice production and mean paddy rice yields, 1979-80 to 1993-94



Source: BBS Data

- Cropping intensity has grown substantially, with an increasing proportion of land being double- or triple-cropped (Figure 2, Panel C). This growth in intensity was driven by increased cultivation during the dry (*rabi*) season, made possible by the growing availability of irrigation. Increased cropping intensity has also led to a concentration of rice production in areas most suited to it and the release of some land formerly planted to rice to other crops.
- Use of chemical fertilizers has doubled since the early 1980s (Figure 2, Panel D), although growth has slowed in recent years. The progressive liberalization of fertilizer distribution during the 1980s, helped increase fertilizer availability throughout the country.

There is still room for further growth along Bangladesh's current path of agricultural intensification. Despite the growth experienced in the

Figure 2
Intensification in Bangladeshi agriculture, 1978-79 to 1993-94

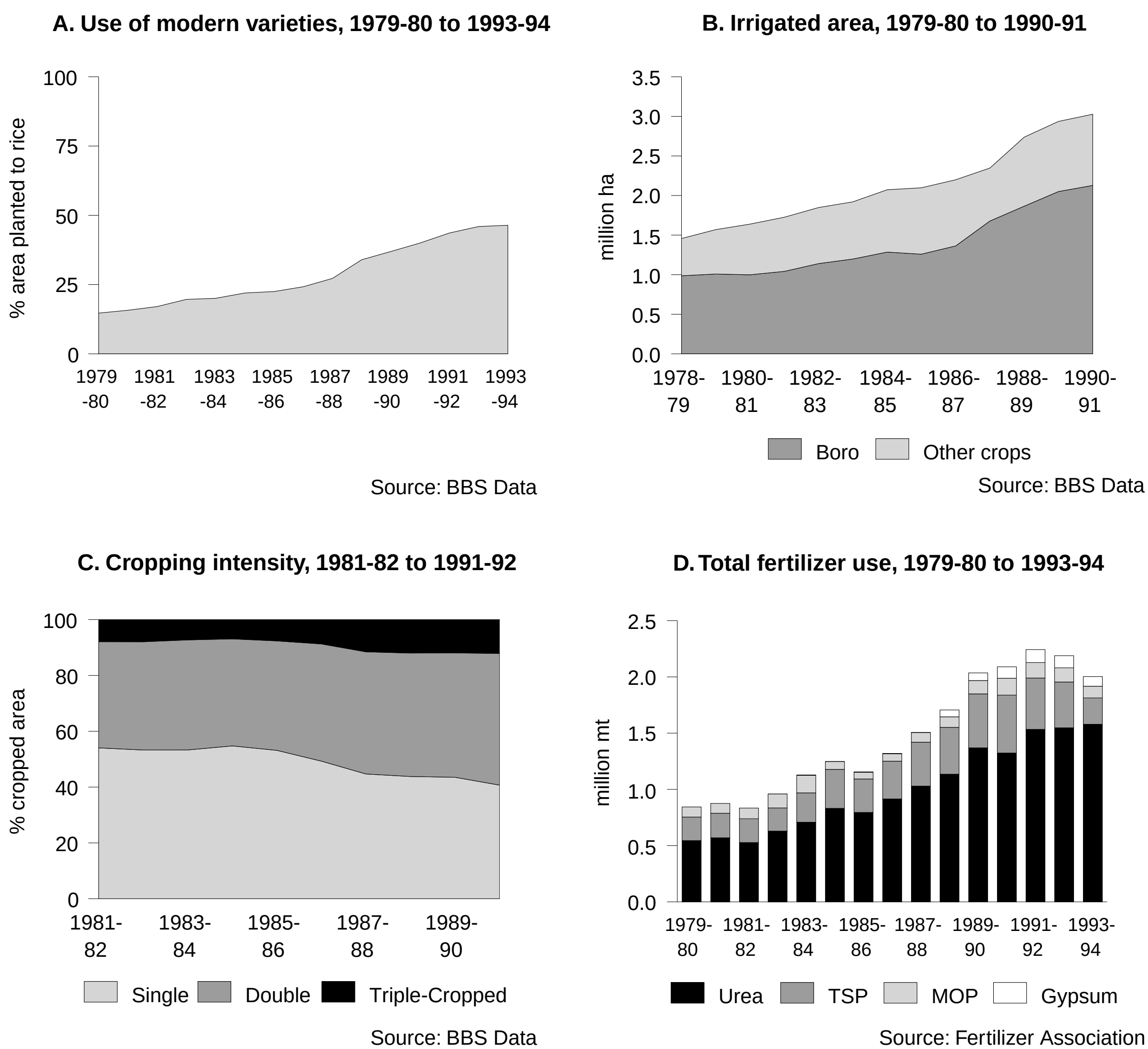


Table 1
Change in mean rice area and yields by variety and season, 1979-80 to 1993-94

		Area ('000 ha)				*Mean Yields (mt/ha)*			
		1979	*1991*	*Change (%)*		*1979*	*1991*	*Change (%)*	
Variety	*Season*	*-82*	*-94*	*Total*	*Annual*	*-82*	*-94*	*Total*	*Annual*
Local	*Aus*	2,645	1,371	-48	-5.5	1.17	1.35	16	1.3
	b. *Aman*	1,584	886	-44	-4.8	1.36	1.44	6	0.5
	t. *Aman*	3,493	2,644	-24	-2.3	1.71	1.98	16	1.2
	Boro	414	265	-36	-3.7	2.07	2.05	-1	-0.1
	Total	8,136	5,166	-37	-3.8	1.48	1.73	16	1.3
Modern	*Aus*	480	394	-18	-1.6	2.91	2.65	-9	-0.8
	t. *Aman*	483	1,895	293	11.4	2.99	3.22	8	0.6
	Boro	706	2,297	226	9.8	3.88	3.88	0	0.0
	Total	1,668	4,585	175	8.4	3.34	3.50	5	0.4
Total	*Aus*	3,125	1,767	-43	-4.7	1.43	1.64	15	1.2
	b. *Aman*	1,584	886	-44	-4.8	1.36	1.44	6	0.5
	t. *Aman*	4,426	4,862	10	0.8	1.93	2.51	30	2.2
	Boro	1,204	2,605	116	6.4	3.20	3.69	15	1.2
	Total	10,339	10,120	-2	-0.2	1.84	2.57	39	2.8

Note: Pajam area is included in the total but not shown separately
Source: Computed from BBS data

past decade, only about half the land classified as suitable or very suitable for irrigation in the *rabi* season is irrigated.

Intensification, however, cannot continue indefinitely. The switch from traditional to modern varieties is essentially complete in *boro* and well underway in *aman*. Further expansion of irrigation is possible, but will become progressively more difficult. Modern varieties and irrigation were initially adopted on land most suitable to them; further increases in their area are likely to be costlier and may not have as large a yield effect as previous ones. As in other Green Revolution countries, therefore, growth in production and average yields will require increasing the yields of modern varieties.

Unfortunately, there is increasing evidence that intensive agricultural practices may be degrading the natural resource base on which agricultural production depends. Yields of modern varieties, far from increasing, may actually be declining despite higher input levels.

3. Sustainability of Intensive Agriculture

This section discusses the sustainability of the intensive agricultural production practices being increasingly used in Bangladesh. First, the experience of other Green Revolution countries is reviewed. A widely noted slowdown of rates of agricultural growth throughout these countries is raising concern over the sustainability of intensive agricultural practices; their experience provides valuable insight into the problems being experienced by Bangladesh. Second, available evidence on declining productivity of agriculture in Bangladesh is reviewed. Farmer reports, national statistics, and the results of long-term cropping trials at BRRI all indicate that yields are stagnating and productivity is declining,[1] although data are insufficient to establish precisely the rate of decline. The causes and consequences of this decline are then discussed, as are the farmers' responses and ways in which government policies can help.

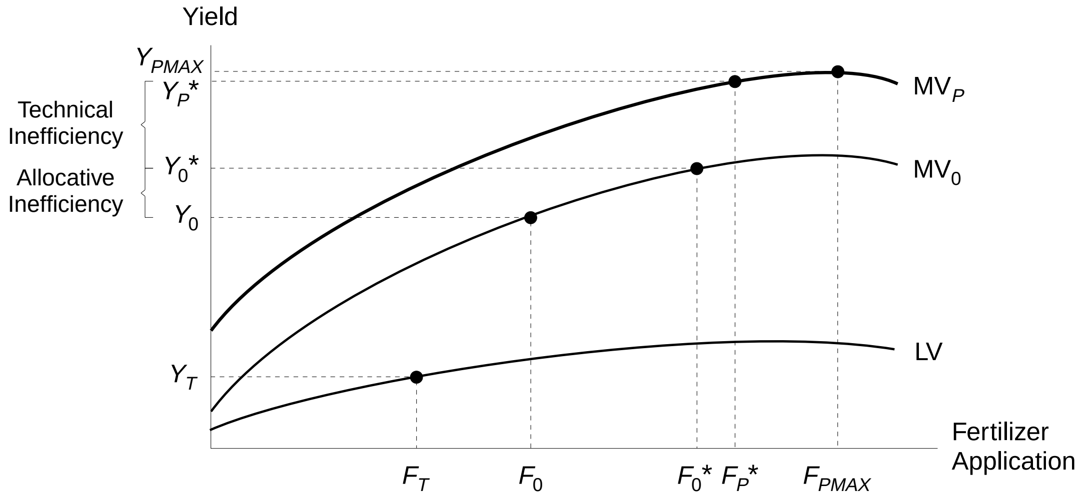
Post-Green Revolution productivity declines

Figure 3 provides a framework for examining how the Green Revolution affects the technological possibilities available to farmers.

- Traditional local varieties use low input levels and have low returns. This technology is illustrated by curve LV. Optimal fertilizer use, given the relative price of outputs and inputs, is F_T, which produces output Y_T.[2]

- Introduction of modern varieties increases the yield potential dramatically, as illustrated by curve MV_P, but requires higher input levels. Under this technology, optimal fertilizer use is F_P*, which produces output Y_P*.

Figure 3
Technology changes in the Green Revolution



- However, because of inexperience with the new systems, in practice the achievable yield from modern varieties is initially lower, as illustrated by curve MV_0. Under this technology, optimal fertilizer use is F_0*, which produces output Y_0*.

- Farmers often use inputs below their optimum level because of limited availability, risk aversion, or problems such as credit constraints, which prevent them from financing high input levels. So farmers use inputs at a level such as F_0, which produces output Y_0.

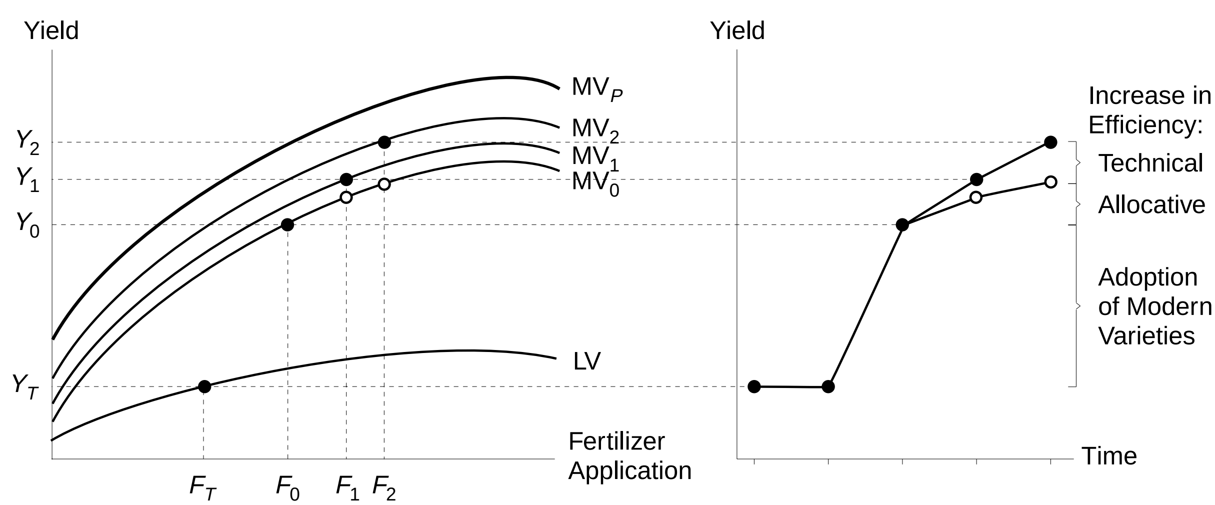
Using this formulation, the 'yield gap' between achieved and potential yields can be decomposed into two components. The first gap results from shortfalls in *allocative efficiency* ($Y_0^* - Y_0$). This gap is between achieved yields and optimal yields given the current technology. The second gap results from shortfalls in *technical efficiency* ($Y_P^* - Y_0^*$). This gap is between optimal yields under the current technology and potential yields.[3]

Green Revolution yield increases have generally occcured in a series of stages, as illustrated in Figure 4. Adoption of modern varieties led to a significant immediate yield increase. Following this transition, further yield increases have tended to come first from increasing allocative efficiency and then from increasing technical efficiency [Byerlee, 1992]; these are shown as movements along a production function and as upward shifts of the achievable production function, respectively. As illustrated in the figure, the stages of improving allocative and technical efficiency overlap, with improvements in allocative efficiency dominating initially and improvements in technical efficiency becoming most important later.

There has been a widely-noted slowdown in the rate of growth of production and yield in Green Revolution countries [Bouis, 1993; Byerlee, 1992; Pingali, Moya, and Velasco, 1990]. This slowdown is partly due to the completion of the transition from traditional to modern varieties. The potential for further expansion of modern varieties and irrigation is limited in most countries. The slowdown is also partly due to the reduction in rice prices which has resulted from the earlier production increases. At the same time, governments have often retreated from the policies of high input subsidies that many adopted in the early stages of the Green Revolution. These adverse price changes have reduced incentives to increase yields.

There is growing evidence, however, that more fundamental problems are also at work. The rate of growth of total factor productivity (TFP) in

Figure 4
Stages in the Green Revolution



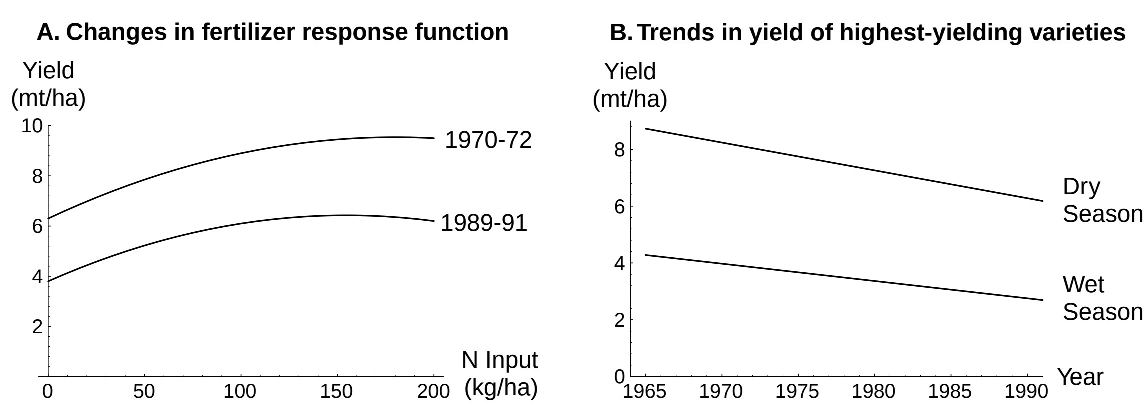
India fell from 1.22 percent annually during 1965 to 1975 to 0.98 percent annually in the following decade; in Pakistan, the decline was even sharper, with an annual TFP growth rate of 1.86 percent in the period 1965-75 giving way to a 0.36 percent annual *decline* in 1975-85 [Rosegrant and Evenson, 1992]. A decomposition analysis of sources of growth in the Pakistani Punjab shows that growth was about 20 percent lower than would have been expected from the continuing switch from traditional to modern varieties, the growth in input levels, and the genetic improvements in the newer modern varieties which have become available [Byerlee and Siddiq, 1994]. These statistical data are reinforced by evidence from long-term cropping trials conducted at IRRI and elsewhere in Asia, which found persistent declines in yields over time even under optimal mana-gement practices [Cassman *et al.*, forthcoming]. Figure 5 shows the overall yield trends observed in the long-term IRRI trials and the underlying shift in the fertilizer response function.

The literature on the Green Revolution suggests several possible explanations for productivity declines in intensive rice cultivation systems:

- *Degradation of the soil resource base*. The intensive cropping systems introduced by the Green Revolution impose much heavier demands on crop nutrients than traditional systems had; nutrient deficiencies, therefore, are a common problem. Intensive agricultural practices can also result in changes in soil physical and chemical properties. In irrigated rice, the formation of a plowpan is a frequent problem, impeding root growth and limiting access to nutrients. Irrigation can also cause salinization or waterlogging. The yield declines observed in the IRRI long-term cropping trials are thought to result from anaerobic conditions in irrigated rice production leading to changes in soil physical and chemical properties which make it less able to supply nutrients to growing crops [Cassman *et al.*, forthcoming].

- *Degradation of ancillary resources.* Most Green Revolution success stories depend heavily on irrigation. The water used for irrigation is itself a natural resource, which can be degraded through misuse or overuse. In many areas, extraction of groundwater is greater than replenishment, leading to a drawdown of the aquifers which threatens the long-term sustainability of agriculture and increases pumping costs. Over-use of water has often been encouraged by substantial subsidies to irrigation, either directly or indirectly by subsidies to the energy used for pumping. In some areas, degradation of irrigation infrastructure resulting from insufficient maintenance has also begun to affect production [Rosegrant and Pingali, 1994].

Figure 5
Evidence of yield declines under intensive rice cultivation in long-term fertility experiments at IRRI



Source: Cassman *et al.*, 1995

- *Build-up of pest pressure.* The intensive production practices introduced by the Green Revolution provide an ideal environment for pest build-up. Multiple cropping and overlapping seasons facilitate the perpetuation of pest populations, and the existence of large homogeneous area favors the build-up of specialized pests. Moreover, early modern varieties were often highly susceptible to local pests. Estimates of production loss to pests in Asia range as high as 20-30 percent annually. In response to these problems, regular prophylactic pesticide applications were a standard part of the early Green Revolution package and pesticide sales were often subsidized. The consensus of opinion today is that this approach was misguided on two counts.[4] First, large-scale and frequent use of pesticides bred resistance into target pests, thus requiring ever-increasing doses to be used. Second, pesticides often proved equally lethal to beneficial pests which preyed on crop pests. In many cases, therefore, pesticide use actually resulted in lower yield as crop pests, freed of their natural predators, multiplied without constraints.

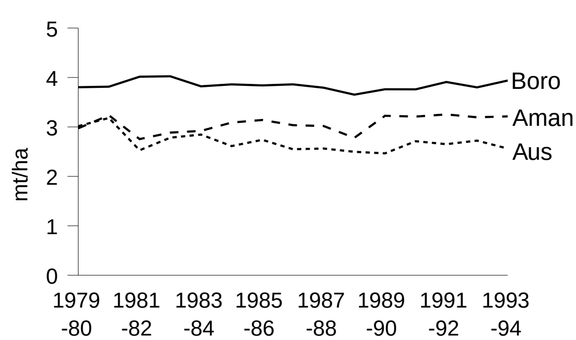
Evidence of declining productivity

The overall picture of rising average yields and rising production in Bangladesh has tended to camouflage evidence of stagnating and declining productivity. Despite occasional expressions of concern from scientists and policy-makers (eg Bhuiyan [1991]), the problem has received relatively little attention. Indeed, the possibility that Bangladesh's soil resources are being degraded received surprisingly little attention in the recently-prepared NEMAP. Yet evidence from farmer perceptions, national statistics, and long-term cropping trials at the Bangladesh Rice Research Institute (BRRI) all indicate that, in many parts of the country, productivity is stagnating or declining.

Farmer perceptions. There is a widespread perception of declining productivity among farmers. All farmers interviewed during field trips to the northwestern and southwestern regions of Bangladesh in the fall of 1994 claimed that yields had been declining and that higher fertilizer applications were necessary to maintain yields. Farmer perceptions of declining productivity have also been noted in numerous surveys conducted in recent years. A pilot survey of Kaliganj Thana in Gazipur District, for example, found that 69 percent of respondents in one village and 17 percent of respondents in another thought fertility was declining; only 5 percent in either village thought it was increasing [SFFP, 1994]. Alauddin and Tisdell [1991] report that all farmers in the village of South Rampur, in Comilla District, and 88 percent of farmers in the village of Ekdala, in Rajshahi District, said they had to apply more fertilizer than before to maintain yield. Saunders [1990, 1991] found that up to a fifth of wheat farmers surveyed in the Jessore / Kushtia area and in Dinajpur thought rice and wheat yields were declining.[5]

Statistical data. Since 1972-73, the Bangladesh Bureau of Statistics (BBS) has collected data on production of rice and other important crops from a sample of 5,000 five-acre plots nationwide. These data allow a close analysis of modern variety yields.[6] Figure 6 shows average modern variety rice yields from 1979-80 to 1993-94 in each of the rice production seasons.[7] The changes in yields in this period are also summarized in Table 1. Although *average* yields increased by almost 40 percent during this period (equivalent to an average annual increase of about 2.8 percent), modern variety yields have experienced very little growth, if any. The changes in modern variety yields shown in Table 1 are not significantly different from zero in any of the seasons.[8]

Figure 6
Modern variety rice yields by season, 1983-84 to 1993-94

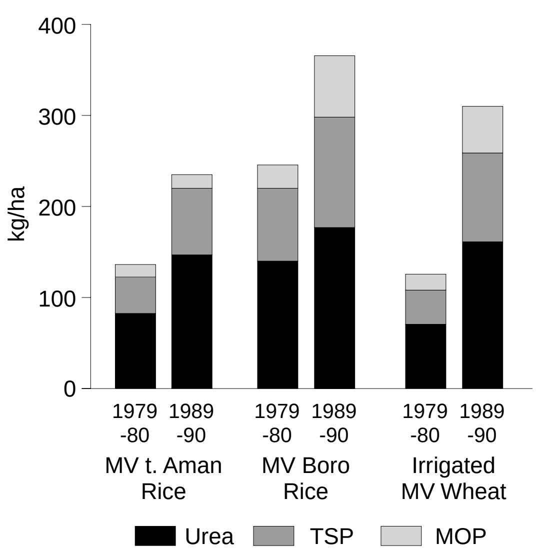


Source: BBS data

Use of district-level data allows yield trends to be examined in more detail. Regression analysis of the time trends of modern variety yields at the district level shows considerable differences between yield trends in different districts (see Appendix). Eleven districts, representing just under half the *boro* area, have experienced declining yields in the last decade, while yields have stagnated in a further three districts. In several instances, increasing yield trends at the beginning of the period became declining trends in more recent years. Only seven districts, representing just over a third of the area currently planted to modern variety *boro*, have experienced rising yields in the last decade, and in two of these the rate of yield increase has slowed in the last five years. In *aman*, on the other hand, modern variety yields appear to have stagnated in most districts; few yield trends are significantly different from zero.

The implications of yield stagnation or decline for productivity are severe, since these trends have occurred despite rapid growth in the use of chemical fertilizers. Figure 7 shows that use of chemical fertilizers on modern variety crops has increased markedly in the last decade. As in other Green Revolution countries, input use was initially very low. Cash-constrained, risk-averse Bangladeshi farmers had difficulty in financing the required high input levels. Moreover, in the early stages of the Green Revolution in Bangladesh the fertilizer distribution system was controlled by a state monopoly, the Bangladesh Agricultural Development Corporation (BADC), whose performance proved woefully inadequate. Although there is evidence that some allocative inefficiency persists, input use has gradually increased over time. Despite these increases in fertilizer use, *boro* yields have stagnated or declined in two-thirds of the area planted to them, and *aman* yields have stagnated throughout Bangladesh.

Figure 7
Comparison of mean fertilizer application rates on selected modern variety crops, 1979-80 to 1993-94



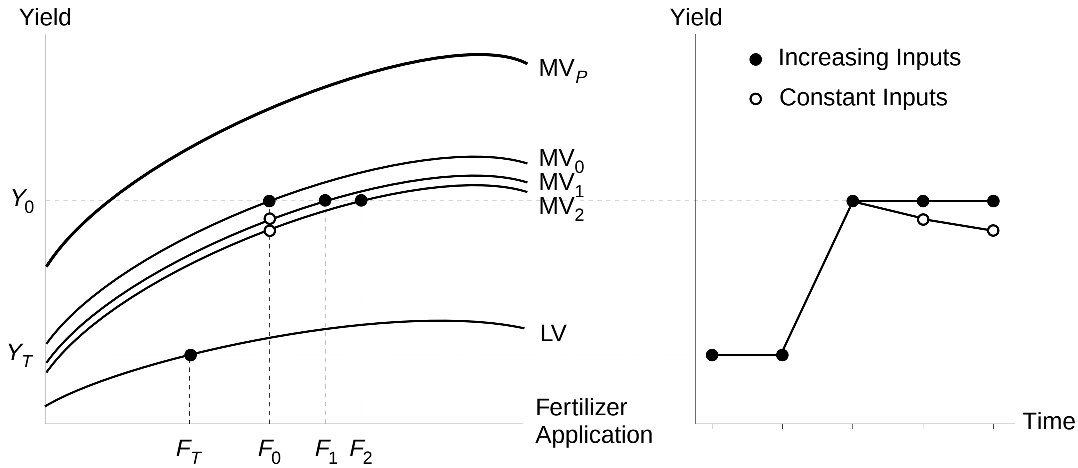
Sources: 1979-80: IFDC; 1989-90: BBS

That yields should stagnate or decline despite rising input use indicates that productivity is falling and strongly suggests that land degradation is reducing achievable yields (Figure 8). If increases in input use had not counteracted the effects of degradation, yields might have fallen even further. Examination of district-level data provides further evidence of degradation.

- District-level patterns of yield change are negatively associated with the length of time that intensive production practices have been employed (Figure 9, Panel A). Since increases in technical efficiency through learning-by-doing and increases in allocative efficiency should both be leading to gradual yield increases in areas where modern varieties are well established, the opposite might have been expected. That yields should be either stagnating or declining suggests that degradation is offsetting any positive effects of increasing technical and allocative efficiency.

- District-level patterns of yield change are positively associated with rapid growth in the area under *boro* (Figure 9, Panel B). Again, the opposite might have been expected: since modern varieties are likely to be planted first in areas most suitable to them, the average suitability of land under modern varieties tends to decline as the area expands. Other things equal, this should lead to lower average yields. That average yields should increase under these

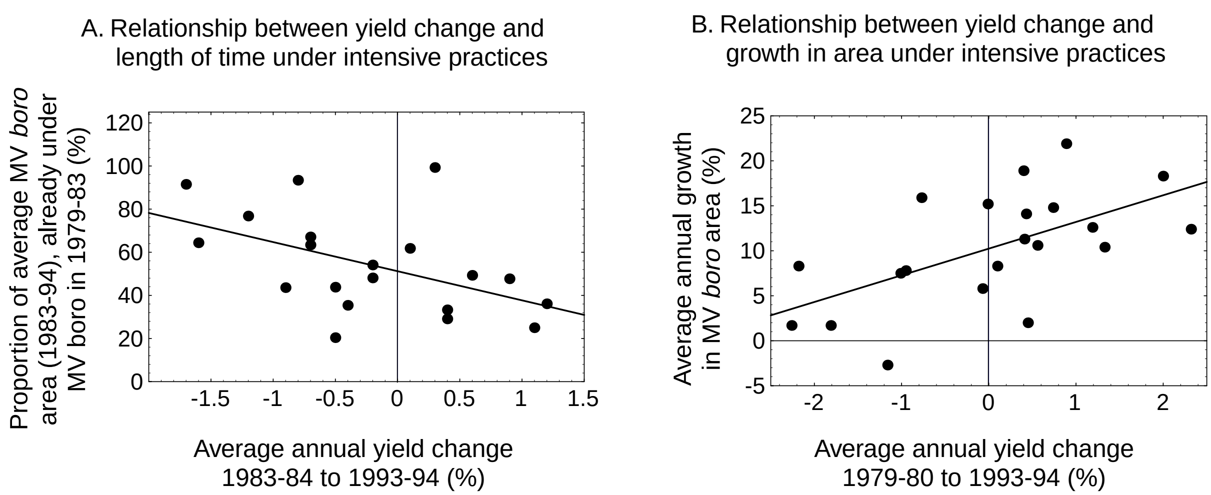
Figure 8
Effects of degradation on yields over time



conditions suggests that the land being brought under modern varieties is less degraded than land which has been cultivated intensively for a longer period.

These results suggest that intensive agriculture in Bangladesh is following a path similar to that of other Green Revolution countries: yields initially rise after modern varieties are adopted, reflecting improvements in allocative efficiency and the benefits of learning-by-doing. After intensive practices have been in use for some time, however, degradation begins to set in and yield growth is slowed or reversed.

Figure 9
Relationship between yield and area changes in modern variety *boro*



Adj. R^2 = 0.203
Yield Change = 0.760 – 00181 Initial Area
(1.73) (–2.41)

Adj. R^2 = 0.316
Yield Change = –1.19 + 0.118 Area Change
(–2.68) (3.20)

Source: Authors' calculations

Experimental station data. Data from long-term yield trials at the BRRI research station at Joydebpur also indicate that intensive rice cultivation can result in declining yields (Figure 10), even when full recommended doses of all nutrients are applied. In this respect, the BRRI results parallel those obtained in the long-term cropping trials at IRRI (Figure 5 above). The overall yield level is lower and the rate of yield decline faster when lower doses of fertilizers are applied. T. *aman* paddy yields, on the other hand, do not seem to show any clear downward trends in the long-term Joydebpur trials.

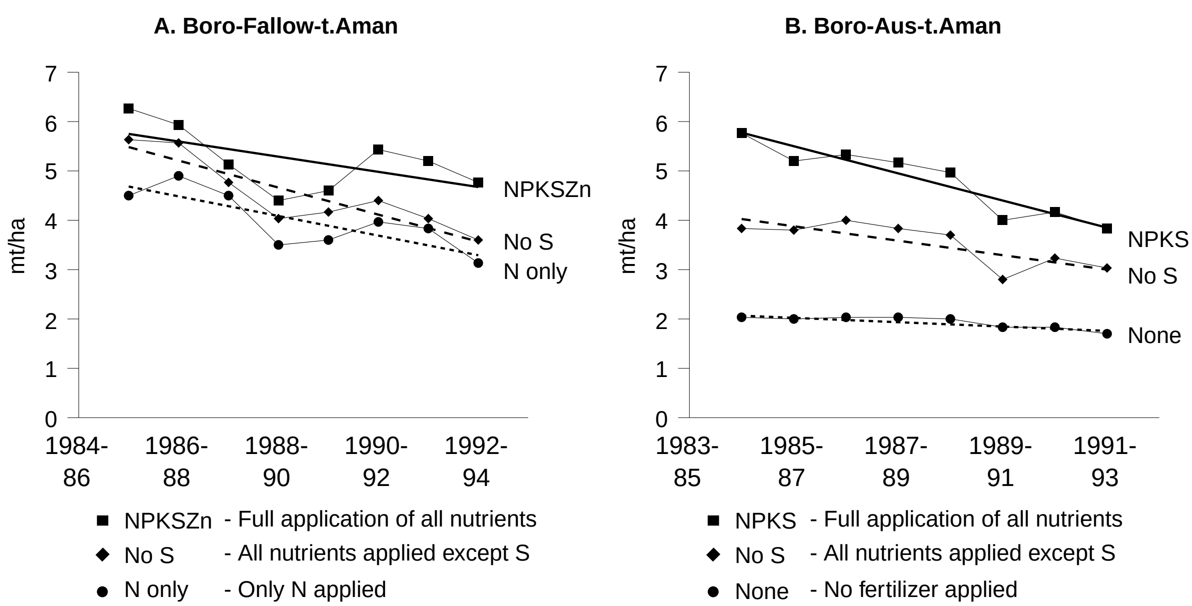
These various sources of data demonstrate that productivity under intensive agricultural practices, using modern varieties and high input levels, is declining in many parts of Bangladesh. Unfortunately, time series of inputs that distinguish between input use on different crops, on different varieties, and in different seasons are not available.[9] Without such data, the rate and magnitude of productivity decline cannot be measured quantitatively.

Causes of declining productivity

As in other Green Revolution countries, there is considerable debate over the exact causes of declining yields. This section reviews the available evidence on causes of declining productivity in intensive agriculture in Bangladesh. Considerable evidence points to imbalances in nutrient availability as the main source of most of the current productivity decline, but data are insufficient to clearly establish the importance of the numerous factors at work.

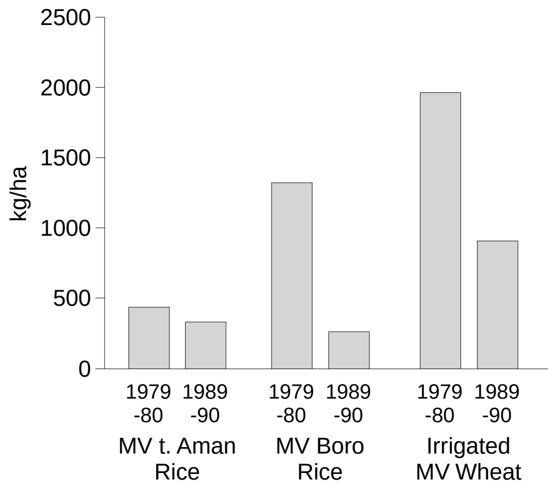
Nutrient imbalance. High-yielding modern varieties are far more demanding of soil nutrients than local varieties had been. Demands on nutrients are all the more severe given the increasing prevalence of multiple cropping. Although additions of chemical fertilizers have increased substantially (Figures 2D and 7), they have not increased sufficiently to offset the higher rates of offtake. Moreover, the increase in chemical fertilizer applications has been to some extent offset by reductions in applications of farmyard manure, which is in increasing demand for use as fuel (Figure 11). Nutrient balance analysis shows

Figure 10
Paddy yield declines in boro crop under different treatments and rotations in long-term yield trials at the BRRI experiment station, Joydebpur, 1984 to 1994



Source: BRRI data

Figure 11
Comparison of mean manure application rates on selected modern variety crops, 1979-80 and 1989-90



Sources: 1979-80: IFDC; 1989-90: BBS

that nutrient removals often exceed additions (Table 2).

- *Macronutrients*. Applications of nitrogen (N) are generally adequate, reflecting the ready availability of nitrogenous fertilizer (urea is produced in the country), its relatively low price, and the easily-observed yield effects of N applications. Applications of phosphorus (P) are also generally adequate. Potassium (K) balance, however, is often inadequate. In the past, potassium had not been thought to be a problem because many of the sediments from which Bangladeshi soils are derived are potassium-rich. But intensive removal through high-yield rice production is making potassium limiting. The problem would be less severe if rice straw were returned to the soil, since most of the potassium removed by rice is in the straw. Straw is in high demand for use as fuel and animal fodder, however, and very little of it is returned to the soil; in fact, in many areas even the crop stubble is removed.

- *Micronutrients*. In the case of rice, sulphur (S) and zinc (Zn) are the main sources of concern. BRRI trials show that sulphur deficiencies in particular have an adverse effect on yields (Figure 10). Sulphur and Zinc deficiencies are a common problem in intensive rice production, because conditions in flooded paddies have a strong negative effect on their availability [DeDatta, 1981; Tandon, 1990].

Evidence of high fertilizer responses also supports the hypothesis of inadequate fertilization [Islam, 1990]. If the hypothesis is correct, then it is possible that productivity decline will bottom out at some point even without greater fertilizer applications, since lower yields will mean lower nutrient removal. Evidence from long-term trials in India and some evidence from Bangladesh itself suggests that, at least in the short to medium term, yields can be sustained with appropriate balanced fertilizer applications. However, the data in Table 2 indicate that nutrient applications can be unbalanced even when full recommended doses of each nutrient are applied to every crop in the rotation.

Changes in soil physical and chemical properties. Numerous analysts have pointed to the low organic matter content of Bangladeshi soils and to their deficiency of certain nutrients. But all the data available consist of single observations. Whether soil physical and chemical properties are in fact declining, and if so at what rate, cannot be determined.

- In general, soil organic matter tends to increase under Green Revolution-style intensive production practices. Given the drastic reductions in manure applications and the common practice of removing practically all crop straw and stubble from the fields (for use as fuel or fodder), however, this may not be occuring in Bangladesh. Even if it were, research at IRRI suggests that changes in the nature of organic matter under long-term irrigated conditions make it less capable of supplying nutrients to growing crops; this is thought to be an important reason for the continuous decline in rice yields seen in the long-term trials at IRRI. Periodic drying of irrigated rice fields appears to play an important role in preventing, or at least slowing, the emergence of these problems. Since triple-cropping of rice is rare in Bangladesh, soils are not flooded as long as in some

Table 2
Nutrient balances observed in experiment station trials and farmers practices

	Nitrogen			Phosphorus			Potassium		
Rotation, Treatment	*Added*	*Removed*	*Balance*	*Added*	*Removed*	*Balance*	*Added*	*Removed*	*Balance*
A. BARI experiment station trials									
Janokinathpur FRS, Rangpur									
Wheat - Mungbean - MV t. Aman									
NPKSZn - NPK - NPK	180.0	192.1	-12.1	160.0	78.1	81.9	100.0	218.1	-118.1
NPKSZn- N½P½K - N½P½K	180.0	183.4	-3.4	110.0	74.6	35.4	70.0	207.9	-137.9
NPKSZn - N - N	180.0	180.4	-0.4	60.0	74.0	-14.0	40.0	205.6	-165.6
N - N - N	180.0	114.1	65.9	0.0	50.0	-50.0	0.0	143.2	-143.2
Narhatta FRS, Bogra									
MV Boro - Fallow - MV t. Aman									
NPKSZN - - NPK	180.0	168.5	11.5	120.0	89.2	30.8	80.0	267.6	-187.6
NPKSZN - - N½P½K	180.0	147.6	32.4	90.0	78.1	11.9	60.0	234.4	-174.4
NPKSZN - - N	180.0	140.1	39.9	60.0	74.2	-14.2	40.0	222.4	-182.4
N - - N	180.0	122.6	57.4	0.0	64.9	-64.9	0.0	194.7	-194.7
B. Farmer practices									
Jessore/Kushtia Area									
Wheat - Aus	147	120	27	95	55	40	45	148	-103
Wheat - Aus - Aman	242	195	47	158	93	65	82	264	-182
Wheat - Aman	198	160	38	124	75	49	64	206	-142
Meghna, Chandpur Irrigation Project									
Potato - MV boro - MV t aman	250	258	-8	61	44	17	148	339	-191
Potato - MV boro - MV t aman	319	257	62	103	44	59	164	338	-174
Dakatia, Chandpur Irrigation Project									
LV b. Aman - MV Boro	192	117	75	22	19	3	28	158	-130
MV Boro	151	93	58	32	15	17	22	122	-100
MV t. Aman - MV Boro	175	142	33	32	24	8	22	192	-170
LV t. Aman - MV Boro	128	150	-22	37	25	12	50	204	-154

Sources: BARI from Abedin and Mukhopadhay, 1990; Jessore/Kushtia from Saunders, 1991; Chandpur from ISPAN, 1993

other Green Revolution countries. Under typical current practices with double-cropped rice, however, soils are dry for only about one month each year, just before the *boro* season, which may not be sufficient.

- The development of a plowpan under irrigated rice production is often pointed to as an unfavorable change in physical structure. Although the formation of a plowpan is desirable in the short term, since it allows easier control of irrigation water (indeed, puddling of the soil prior to transplanting rice deliberately encourages the formation of a plowpan), in the long term it can be harmful by reducing the crops' access to nutrients. Periodically breaking the plowpan by planting deep-rooted crops such as jute seems to have a beneficial effect on yields. There is some evidence, for example, that rice-wheat rotations which include break crops tend to have fewer yield decline problems [Saunders, 1991].

Decline in properties of modern varieties. This hypothesis has two variations. One focuses on the productivity of the seed. Most farmers plant seed retained from their harvest rather than renewing their seed stock by buying certified seed. No trials have been conducted on the optimal time for seed renewal. Questions have also been raised about the adequacy of current seed multiplication practices. The other variation is that the modern varieties themselves are losing their vigor. Very little research has been undertaken on this latter possibility, and none in Bangladesh.

Irrigation-related problems. Problems related to irrigation, including decreasing availability of water, salinization, and waterlogging, have been an important reason for declining productivity in some areas, such as the Pakistani Punjab. These problems do not appear to be significant in Bangladesh. Unlike some other Green Revolution countries, groundwater in Bangladesh is replenished at rates that exceed current rates of use. The overall availability of water is unlikely to become a constraint to agricultural production in Bangladesh. Seasonal problems may develop in certain areas, however, if water extraction drives the water table below the reach of some wells at the end of dry season. This appears to be happening in parts of the Barind Tract, for example. In times of drought, the area affected is likely to be larger, as was in fact the case during the 1994-95 *boro* season. These are temporary problems, however, which do not cumulate over time. Salinization, another problem often encountered in irrigated areas, also does not appear to be a problem in Bangladesh, except for a small area west of Comilla, thanks to the annual flushing effect of the monsoon and of flooding. Waterlogging is reported in some areas, but appears to be a consequence of inappropriate construction of roads and other obstacles to proper drainage, rather than from misuse of water at the field level. That irrigation-related problems are generally minor does not mean, however, that water management is unimportant. Although the potential exists for irrigation to continue to grow, inadequate water management could reduce its benefits.[10] The situation in coastal areas is particularly delicate, since changes to the local hydrology can result in saline water intrusions into both ground and surface water.

Build-up of insects and diseases. Continuous rice monoculture creates conditions that are favorable to outbreaks of insects and diseases. Conditions are particularly favorable in the southern part of the country, where winter temperatures are high. Infestations by rice hispa have occurred regularly since 1978 and are thought by some to be increasing. Recent years have also seen outbreaks of other pests. An outbreak of brown plant hopper (BPH) in the Rajshahi-Dinajpur area in 1993, for example, caused considerable damage. Since pest outbreaks tend to be very irregular, however, it is difficult to determine whether their incidence and severity are increasing. The relatively low use of pesticides on rice suggests that growing resistance is unlikely to be as important a problem as it has become in other countries, such as Indonesia.

The various types of problems discussed above can be categorized broadly as medium-term and long-term causes of yield decline.

- *Medium-term problems.* Problems such as nutrient imbalances are medium-term problems since their effects, while not immediate, are felt relatively rapidly. Their effects can also be reversed relatively rapidly, once appropriate changes are made in management practices.

- *Long-term problems.* Changes in soil physical and chemical properties, on the other hand, often tend to be longer-term, both in terms of the time it takes for their effects to be felt and the time it takes to reverse them. The deterioration in soil properties noted in long-term experiments at IRRI appears to fall in this latter category. Since the adoption of modern varieties is more recent and still less complete in Bangladesh compared to most other Green Revolution countries, these long-term degrading effects of intensive production practices are unlikely to already be having a significant effect, except perhaps in areas where modern varieties were adopted relatively early. These are problems that Bangladesh may well encounter in future years, however.

In addition to these medium-term and long-term problems, there are many short-term problems which affect current productivity without necessarily causing resource degradation. Improvements in the timing and mode of application of fertilizers, in water management, and in cultivation practices would all help improve current productivity, as would improvements in seed quality. The yield gap between farmer yields and potential yields remains large, even in districts which have not experienced yield declines. In other Green Revolution countries, the yield gap has become very small. In the Ludhiana District of the Indian Punjab, for example, the gap between farmer yields and the best yields obtained on experiment stations has fallen from almost 3 mt / ha to about 1.5 mt / ha [Byerlee, 1992]. In the Philippines, the top third of irrigated farms now have yields that are very close to experiment station yields [Pingali, Moya, and Velasco, 1990]. In Bangladesh, in contrast, the yield gap has remained essentially unchanged. Farmer *boro* yields, for example, range from about 3 to 4 mt / ha, depending on location, while experiment station *boro* yields are generally in the 6 to 7 mt / ha range.

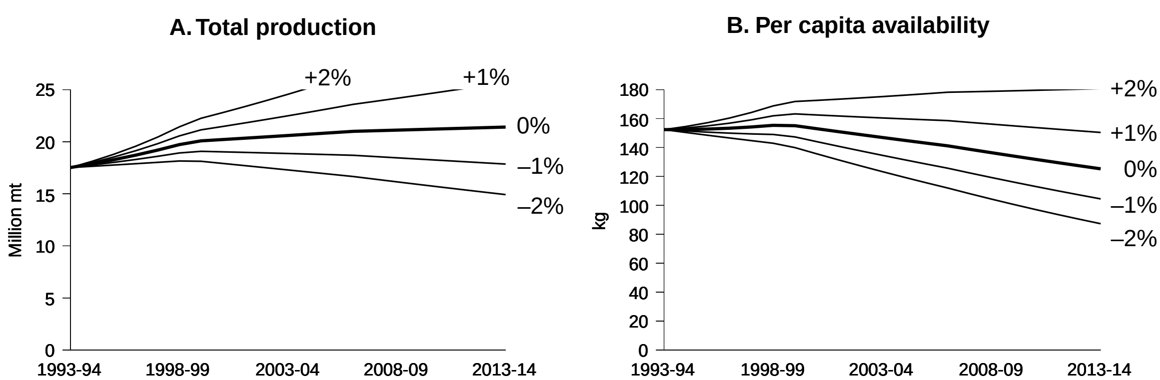
Consequences of declining productivity

Projections of growth under different scenarios of productivity change indicate the likely consequences of declining productivity for agricultural growth.

A seasonally and varietally disaggregated model of rice production is used to project growth patterns under different scenarios of productivity change. Output in each period depends on the total area planted to rice in each season, on the proportion planted to modern varieties, and on the yield of modern and local varieties. The area planted in each season and the proportion planted to modern varieties are assumed to continue changing at the same rate as was experienced in the period 1983-84 to 1993-94. However, there are season-specific limits on the proportion of land which can be planted to modern varieties. In the *boro* season, the limit is 100 percent. In the other seasons, however, the possibility of flooding prevents the entire area from being planted to modern varieties. A limit of 80 percent adoption is assumed for both *aman* and *aus*. The initial levels of areas and yields are set at their average over the three-year period from 1991-92 to 1993-94.

The results of the model's projections of total production over the next 20 years, under a range of assumptions for modern variety yield changes, are shown in Panel A of Figure 12. If modern variety yields are indeed stagnating, then the prospects for future production are fairly grim. Some growth will continue as a result of the continued switch from local to modern varieties and from changes in the relative importance of the different seasons (in particular, the decline of *aus* and the growth of *boro*). But the transition to modern varieties is already essentially complete in *boro* and will be completed in about the year 2000

Figure 12
Projected changes in total clean rice production and per capita clean rice availability, 1994-95 to 2013-14, under a range of assumptions about annual growth in modern variety yields



Source: Author's calculations

in *aman*, at current growth rates. Once the transition in these two important seasons is completed, production growth will slow dramatically, as can be seen by the kink in the time paths of production. If modern variety yields are stagnant, the only source of growth remaining at this point will be that resulting from the continued relative decline in *aus* area and growth in *boro* areas.[11] If yields are in fact declining, this effect alone will be insufficient to counteract the effects of yield decline and production will fall.

The implications of these projections for per capita rice production, assuming that population will continue to grow at the current rate of about 2 percent per annum, are drawn out in Panel B of Figure 12. Unfortunately, if yields are in fact stagnating, the current situation of rice self-sufficiency will prove very short-lived; by about the year 2000, per capita production will begin to fall. If yields are in fact declining, this will occur even sooner. Continued efforts to slow population growth will help ease this pressure, but are unlikely to eliminate it entirely.

The results shown in Figure 12 should be cause for concern but not for despair. First, they show that except under fairly pessimistic assumptions of current yield changes, continuing adoption of modern varieties and changes in the relative importance of the different seasons will probably be sufficient to sustain per capita production at roughly current levels for several years. There is, therefore, some time for action to be taken. Second, they show that if reasonable rates of yield growth can be achieved, per capita production can be sustained and perhaps improved. In light of the large yield gap that continues to exist between current and potential yields, there is still considerable room for growth in yields by improvements in allocative and technical efficiency.

Farmer responses

Whether the adverse consequences described above come to pass will depend primarily on the farmers' responses to degradation problems. Ultimately, it is farmers who make land use decisions, and not government analysts and planners in the capital.

Farmers generally have strong *incentives* to respond to soil degradation problems: a decline in land productivity affects them directly. And in fact, available evidence suggests that farmers are already responding to degradation problems, by using higher and more balanced fertilizer applications. In particular, many farmers have recently adopted fertilizers supplying micro-nutrients such as gypsum (a source of sulphur), zinc sulphate, and borax (a source of boron). Practically all farmers interviewed during field trips to the northwestern and southwestern regions of Bangladesh in the fall of 1994, for example, had begun using gypsum within the last five years. Other surveys have made similar findings (see also Figure 2C). Saunders [1991], for example, found that over 60 percent of farmers surveyed in Jessore and Kushtia districts had begun applying gypsum to their *aman* crop, almost all within the preceding four years. Farm households are also planting large numbers of trees, which will help ease the pressure to use cowdung and crop stubble for fuel. Renters and sharecroppers are a possible exception to the rule that farmers have strong incentives to respond to degradation problems; whether they do or not depends on the specific features of their rental and sharecropping contracts. Evidence from several case studies, however, indicates that factors such as fertilizer use and modern variety adoption do not differ between owner-operated and crop-shared or rented land [Taslim and Ahmed, 1994].

For farmers to respond appropriately to degradation problems, they require *information* on the long-term consequences for productivity of different agricultural practices and on appropriate corrective measures. In general, farmers usually have very good knowledge of their soil conditions and of the effects of agricultural practices upon them. But this is knowledge that results from long experience. The intensive agricultural practices being used today are too recent for such experience to have accumulated to any substantial degree. In a dynamic setting such as that introduced in the Green Revolution farmers depend much more on information provided by research and extension systems. Unfortunately, in Bangladesh that system does not appear to have, except in the broadest qualitative sense, the required information. Greater use of chemical fertilizers is part of the answer, but since use has already been increasing, further increases in input use alone are unlikely to be sufficient; better use of existing inputs is required. This task is more knowledge-intensive and less amenable to simple government interventions like the input subsidies of yester-year.

- *Research*. Research is required into fertilizer needs for long-term sustainable production. As discussed above, evidence from cropping trials undertaken by the Bangladesh Agricultural Research Institute (BARI) suggests that current recommendations are inadequate to maintain long-term fertility in many cases (as well as being inadequate in other ways, having been developed primarily on a single-crop, single-season basis). Research also needs to go beyond documenting yield declines to understanding the causes of these declines. Perhaps as important as fundamental research, however, is the need for applied, site-specific research; farmers need assistance in fine-tuning their cropping practices to improve yields and avoid degradation, not fundamental qualitative changes.

- *Extension*. If the results of research are to be of use to farmers, a much improved extension system, which must not only deliver information to farmers but also convey information back to the research system on farmers' needs and constraints, is required. Efforts are underway to improve the effectiveness of the Department of Agricultural Extension (DAE), but much work remains to be done. Extension is an area in which NGOs in particular might play a useful role; already, NGOs such as BRAC have made important contributions.

Bangladesh's research and extension system, and particularly research institutions such as BRRI and BARI, have made important contributions to agricultural development in the past. What is required now is a re-orientation of research and extension efforts towards an increased focus on site-specific conditions, on long-term research, and on cropping systems and practices used by farmers. It is important to ensure that both research and extension are responsive to farmers' needs and constraints. Fertilizer recommendations, for example, need to reflect site-specific nutrient needs rather than standardized guidelines. Recent years have seen some moves in this direction, but much more needs to be done. There have been recent efforts in several countries to establish soil testing and advisory services for farmers [Hanson, 1994]; the possibility of developing such services for Bangladeshi farmers should be investigated.

Farmers also need to have the *means* to respond. Unless farmers have reliable and timely access to inputs, including irrigation, fertilizers, and credit, they will be unable to increase the efficiency of their cropping practices. The liberalization of irrigation and fertilizer distribution in the late 1980s was largely responsible for the sharp increase in growth in that period.

- *Credit.* Increased input use will create higher financing requirements. An efficient and effective credit delivery system and appropriately-designed financial instruments will be required, particularly to meet the needs of smaller / poorer households.[12]

- *Fertilizer availability*. To be useful, fertilizer must be available in a timely way. Poor experience with government control of the fertilizer sector led to a policy of gradual deregulation during the 1980s which has improved supply substantially. Problems persist, however, in the supply of urea, for which a government parastatal is the only source. The problems in urea supply need to be addressed and must be prevented from causing any back-tracking in liberalization efforts.

- *Fertilizer price.* The need for higher and more appropriate fertilizer applications should not be interpreted as a call for the re-introduction of subsidies. Indeed, the current subsidies on urea are probably having a harmful effect by encouraging relatively more nitrogenous fertilizer to be used. Additions of nitrogen fertilizer alone can give a short-term boost to yields, but only at the cost of further depleting other nutrients.

The impact of efforts to diversify agricultural production on the sustainability of intensives agricultural practices is uncertain. Introduction of crops with lower or different nutrient requirements can help slow or reverse nutrient depletion problems; in such cases, rice yields might themselves improve. On the other hand, some alternative crops, such as sunflower, are known to be very demanding of soil nutrients. Their introduction into a rotation would probably not be as helpful from the perspective of sustainability. Diversification can also help in other ways. Wheat, for example, has similar nutrient requirements to rice so a rice-wheat rotation might encounter the same nutrient deficiency problems as a rice-rice system. By keeping soils dry for several months, however, some of the adverse changes in soil physical and chemical characteristics that result from long-term irrigation might be avoided. Here too, more research is needed to determine both the nature and the extent of the sustainability impacts of different cropping systems.

Notes

1. It is important to distinguish between observed *yields*, which measure output per unit land, and *productivity*, which measures the effort required to obtain that output. If input use is increasing, yields can increase even if productivity is declining.

2. Optimal fertilizer use is determined by the necessary condition for profit maximization, that the marginal cost of fertilizer application equal its marginal value product.

3. In practice, however, the nature of available data means that the ‘yield gap’ that is generally reported is that between current yields and maximum potential yields ($Y_{PMAX} - Y_0$).

4. Over-use of pesticide also led to health problems and environmental pollution, as discussed below.

5. Even where yields are reported to be increasing, the reasons are instructive. Farmers in the Jessore-Kushtia area attributed yield increases to adoption of modern varieties, higher fertilizer inputs, and irrigation [Saunders , 1991]. These factors involve switching *between* systems rather than yield increases *within* a given system.

6. The accuracy of BBS data, particularly data collected prior to the 1983-84 agricultural census, has been questioned in many instances [Rashid, 1989; Boyce, 1985]. Comparison of BBS data with data from the 1983-84 agricultural census showed that *aman* area in particular had been under-estimated. Collection and sampling procedures were revamped in light of these results. The analysis in this report relies primarily on data collected after the census, and on pre-census data adjusted to correct for the observed discrepancies.

7. BBS yield data are given in terms of metric tonnes (mt) of clean rice per acre. In this report, all yields are quoted in terms of mt of paddy per hectare. The recovery rate of clean rice from paddy is about 70 percent.

8. Paradoxically, local varieties appear to have experienced significant yield increases in the last fifteen years (Table 1), probably due to spill-over effects from improved management and input availability resulting from modern variety use. In particular, increasing availability of irrigation has allowed supplementary irrigation of *aman*.

9. National-level statistics (Figure 2, Panel C) provide a long-term time series of input use, but do not distinguish between uses. Surveys which distinguish between use on different crops, varieties, and seasons were carried out in 1979-82 by the International Fertilizer Development Center (IFDC) and in 1989-90 by the BBS. However, differences in sample design make it risky to compare their results except at the national level, as in Figure 7.

10. Similarly, although flood control and drainage structures (FCD) can help growth by reducing or eliminating the potential for damage to irrigation equipment and standing crops by floods, improperly designed FCD can lead to drainage problems which can adversely affect productivity. Flood control measures can also reduce or eliminate the benefits of silt and nutrient deposition by floodwater. The extent of the benefits derived from such deposition is the subject of some debate, but there is very little hard evidence on the issue.

11. The simulations do not allow for the small observed increases in local variety yields. They would make only a very small contribution to growth since the area planted to local varieties is declining rapidly.

12. This does not imply a need for subsidized credit. Evidence from throughout the developing world indicates that the traditional supply-led approach to rural finance, which aims to provide ‘cheap’ credit to poor farmers, results in a system that bypasses the poor and that is financially unsustainable.

4. Environmental Problems

In addition to sustainability problems, concern has been expressed that intensive agriculture harms the environment more generally. In particular, the rapid increase in the use of pesticides is thought to pose two threats:

- adverse health effects for farm workers and others exposed to pesticides; and
- contamination of ground- and surface water, harming downstream users of that water and damaging inland fisheries.

This section examines the environmental damage that might arise from intensive practices. The emphasis is again on the impact of the more intensive production practices in rice. Since environmental damage results from the collective impact of pesticides from numerous sources, however, use of pesticides on other crops is also examined. Differences in pesticide use across crops is of particular concern in the context of on-going efforts to diversify production away from rice.[1]

Pesticide use in Bangladeshi agriculture

Pesticide use grew rapidly in the early 1970s, following the introduction of modern rice varieties. Use fell dramatically in 1973-74, however, following the halving of pesticide subsidies (which were removed entirely in 1978). Use has since increased again; sales of pesticides doubled in the second half of the 1980s. Granular pesticides have grown in importance, and currently account for almost 80 percent of total pesticide use. Since granular pesticides contain lower concentrations of active ingredients (ai), the quantity of active ingredients used has increased more slowly than total quantity. There has also been a trend towards increasing use of non-persistent synthetic pyrethroids and moderately persistent organo-phosphates and carbamates and away from highly persistent organo-chlorides. Use of most organo-chlorines has been banned, and production of DDT at Chittagong was halted in 1992.[2] Heptachlor, which is registered for use on sugarcane, is the sole exception to the ban on organo-chlorines.

Even more so than with chemical fertilizers, it is difficult to obtain an accurate picture of the level of use on specific crops and how it has changed over time.[3] Moreover, the threat of environmental damage depends not only on the quantity applied but also on the specific types of pesticides being used and on their mode and timing of application. In this respect, the trend towards increasing use of granular pesticides is a positive one, since they are less likely to contaminate water than foliar pesticides and, because of their lower concentration of active ingredients, are often less toxic. Synthetic pyrethroids pose particular problems: although their very low persistence makes them generally very safe for human use, they can be extremely toxic to fish even in small concentrations.

Rice. About 70 percent of pesticides are used on rice. Almost all pesticides used on rice are insecticides, although fungicides are occasionally used against rice blast. Almost 90 percent of pesticide applications on rice in 1989-90, by value, were on modern varieties. Usage is heaviest on *boro*, which received over 50 percent of pesticide applications on rice, by value, in 1989-90. Nevertheless, the amounts used per unit area and the total area affected are both relatively small. In 1989-90, only about 10 to 20 percent of the area planted to modern variety rice was treated with some kind of pesticide (compared to about 1 to 3 percent of the area planted to local varieties).

Insecticide use on rice is mainly reactive rather than prophylactic. Although the initial Green Revolution package called for three scheduled applications of pesticides, few farmers seem to have followed this practice since subsidies were removed in the mid-1970s. All the farmers interviewed during field trips to the northwestern and southwestern regions of Bangladesh in the fall of 1994, for example, used insecticides only upon detecting insect infestations in the fields. Farmers generally could not identify the specific insecticides used; the type of insecticides, the dosage, and the mode of application were generally recommended by local dealers based on the farmers' descriptions of the symptoms. Most farmers seemed aware of the safety precautions required, and reported taking at least elementary precautions such as wearing long-sleeved clothes, covering the face with a scarf, and washing after use. Again, the dealers appeared to be a primary source of information on precautions.

The three most commonly used insecticides are carbofuran, diazinon, and phosphamidon. Phosphamidon is a foliar insecticide, while carbofuran and diazinon are both granular. All three are relatively short-lived. Depending on the formulation, carbofuran is classified as a class IA, IB, or II insecticide by the World Health Organization (WHO), indicating that it is moderately to extremely hazardous. Phosphamidon is classified in class IB (highly hazardous) and diazinon in class II (moderately hazardous). Carbofuran is also dangerous to fish. In 1989-92, carbofuran accounted for about 13 percent of all pesticides sold, by active ingredient; this was a substantial increase over its roughly 5 percent share in 1985. Phosphamidon's share, on the other hand, declined from about 37 percent in 1985 to about 20 percent in 1989-92. Diazinon, with about 29 percent, has the largest share of the insecticide market—essentially unchanged since 1985.

Vegetables. Use of insecticides on vegetables follows a pattern almost diametrically opposed to that found in rice. Whereas rice is sprayed—if at all—only 2 or 3 times a season, it is common to spray vegetables such as eggplant and country beans several times a week. A survey of eggplant producers in the Jessore area showed a range of application from 17 to 150 times for one crop cycle [Kabir *et al*, 1994]. Other vegetables have lower rates of use, but still generally higher than on rice. It is common to spray cauliflower and cabbage 3 to 4 times, for example. A large variety of pesticides are used, of varying hazard classes; phosphamidon, for example, is again widely used. Even low-toxicity pesticides can cause problems, however, at the high rates of use found on vegetables. There are indications that resistance to pesticides is well established among several vegetable pests—in particular among pests that attack eggplant and country beans.

Other crops. Commercial crops such as tea, cotton, jute, and sugar cane, have the longest history of pesticide use. Although most generally cover relatively small areas, significant proportions are treated with pesticides. Of particular concern is the continued use of heptachlor, an organochlorine, in sugar cane production. Sugar mills often provide heptachlor as in-kind credit to cane producers. Although use of heptachlor is only authorized on sugar cane, inevitably its use spills over onto other crops. Several farmers interviewed in a sugar-growing area west of Bogra in November 1994 had used heptachlor on their potato fields, for example. Saunders [1991] also reports use of heptachlor on wheat.

Main concerns

Health problems. The toxicity of pesticides threatens the health of users. Health hazards can be either acute, generally resulting from short-term exposure to relatively high doses, or chronic, resulting from prolonged low-level exposure. Use of toxic chemicals by illiterate farmers has led to concern. A study of rice farmers in the Philippines, for example, found substantial health costs associated with pesticide use. Indeed, the extent of health problems was sufficient to completely outweigh any benefits arising from pesticide use [Rola and Pingali, 1993]. The level and nature of pesticide use in Bangladesh, however, differ significantly from those found in the Philippine study area, where heavy doses of pesticides were applied on a prophylactic basis with few precautions. The only farmers in Bangladesh who might have levels of exposure to pesticide as high as—or perhaps even exceeding—those of Filipino farmers are vegetable farmers. Awareness of the toxicity of pesticides appears to widespread among Bangladeshi farmers. Indeed, pesticides are colloqially referred to as *bish*, which means poison. As discussed above, farmers do take some precautions in using pesticides.

No systematic studies of the health effects of pesticides have been undertaken in Bangladesh. Anecdotal evidence from doctors indicates that cases of acute poisoning occasionally occur. The majority of these are associated with suicide attempts (which is evidence of the awareness of pesticides' toxicity). There is no evidence of substantial chronic problems, but this is far from conclusive given the relatively short history of pesticide use in most areas, suggesting that cumulative exposure may not yet have reached dangerous levels, and the possibility that pesticide-related problems are mis-diagnosed by health workers unfamiliar with them.

Heavy pesticide use on vegetables poses particularly important dangers. Although rice accounts for the greatest share of pesticide use, pesticide use is widely dispersed and doses are low. In vegetables, on the other hand, doses are high and applications frequent. Because vegetable production is concentrated in a few areas and among a subset of farmers, the population exposed is small but at high risk. Moreover, because of their management intensity, vegetables are often grown close to the household, thus creating the potential for exposure of women and children and of household animals. Vegetable plots are also often located next to ponds or waterways to facilitate irrigation, thus creating the potential for contamination. Finally, vegetables tend to be sprayed heavily up to the time of harvest, and then shipped directly to market with no waiting period; moreover, many are consumed whole. This creates a very significant potential for pesticide residues causing negative health effects on consumers.

In light of the substantial adverse health effects encountered among Filipino rice farmers, a careful study of possible problems among Bangladeshi rice farmers is warranted, even though the risk factors do appear to be lower. The greater priority, however, is to ascertain the extent and exact causes of health problems among vegetable farmers, and whether pesticide residues on vegetables pose a threat to the health of consumers.

Water pollution. Use of agro-chemicals can also result in health problems through pollution of drinking water by residues. Here the effects of fertilizer use are also a concern. Nitrates can be carcinogenic, for example, and can lead to blue baby syndrome. The very shallow water table found in much of Bangladesh makes groundwater —the major source of drinking water for the rural population—particularly vulnerable to contamination. An important factor which needs to be taken into consideration in any discussion of water pollution in Bangladesh is the flushing effect of floods and monsoon. There is some potential for chemical residues to accumulate during the dry season, when use is heaviest and runoff from agricultural land flows into *beels* and *baors*, but residues generally won't accumulate year after year. The threat of their reaching dangerous levels, therefore, is substantially lower than in many other countries.

Until recently, little hard evidence existed of actual levels of groundwater contamination. Tests of groundwater taken from village hand-pumps carried out by the National Minor Irrigation Development Project (NMIDP) have begun to fill this gap. Traces of pesticides were found in only ten of 78 samples, despite the samples having been drawn from areas considered most at risk of contamination. All the pesticides detected were longer-lived organo-chlorines; no traces of the moderately persistent organo-phosphates which account for the bulk of pesticide use were found. Greater evidence was found of nitrate contamination, but even the highest concentrations found (20-30 µg/l) were below the WHO safe drinking water standard of 50 µg/l [de Zanger, 1995].

Degradation of fisheries. Fish provide a substantial proportion of proteins consumed; the rural poor in particular depend on fish from open-access capture fisheries.[4] The output from capture fisheries appears to be declining, although the rate and extent of this decline are hard to determine from available data, especially in light of the inherently high variability in fisheries output.[5] The decline in capture fisheries has been attributed to a variety of factors, including overfishing, modifications to water flows resulting from flood control programs, draining of *beels* for use in agriculture, and the effects of agricultural and industrial pollution [Ali, 1990], but the relative importance of these factors cannot be determined from available data. Given the low overall level of use, however, pesticides appear unlikely to have been a major cause of the decline. There is some anecdotal evidence of fish kills resulting from pesticide applications. These appear to be related primarily to the use of highly toxic pesticides of Indian origin, which are easily available in border areas. Samples of fish collected near Tangail by the Flood Action Plan fisheries study found no organo-phosphate residues but low levels of organo-chlorine pesticides [FAP 17, 1993]. The study was too limited, however, for general conclusions to be drawn from it.

Rice-fish culture, in which fish are grown directly in the flooded rice fields, poses particular problems. Rice-fish culture is said to have been prevalent in the past, and its small scale today is often blamed on the use of pesticides; however, this conclusion is hard to reconcile with the small proportion of total rice area which is treated with pesticides, particularly during the rainy season, when conditions are especially suitable for rice-fish culture. Nevertheless, it does appear that pesticide use is incompatible with the various rice-fish culture practices being introduced by NGOs such as CARE.

Possibilities for action

With the exception of pesticide use on vegetables, the available evidence does not suggest the existence of significant current problems resulting from pesticide use in agriculture. There is substantial concern, however, that the extent of problems might increase as intensification continues.

Predicting future rates of pesticide use is difficult. Since most pesticides are used on modern variety rice, total use will undoubtedly increase as conversion to modern varieties continues. Two opposing tendencies will be acting on this general trend, however. First, more recent modern rice varieties have been bred for increased pest-resistance, thus reducing the need for pesticide use. BR23, which was first released in 1988, is much less susceptible to brown plant hoppers and green leaf hoppers, for example, than the earlier BR11 variety which is currently widely used in *aman*. Second, and counteracting this first effect, intensification promotes pest populations, as discussed above. The net effect on the need for pesticides, therefore, is uncertain. Efforts to stimulate diversification add a further element of uncertainty, since alternative crops may entail either higher or lower pesticide use and may introduce new pesticides whose toxicity, persistence, and other characteristics differ from those in current use.

Despite the apparent low level of current problems, there is room for improvement. A number of relatively simple policies and reforms could reduce pesticide use further and make it safer. These same policies will also help to push future growth away from the most damaging paths that it could take. In general, the need for intervention is greater in the case of environmental problems than in that of the natural resource problems discussed in section 3. Most environmental problems are externalities, in which the agents causing the problems have no incentive to take those problems into account. Health problems do have a direct impact on farmers using pesticides, but the link between pesticide use and health problems—especially chronic health problems—is often sufficiently unclear that farmers may not take it into account.

In one important respect, Bangladesh has already adopted policies which help reduce the risk of substantial environmental problems arising from pesticide use in agriculture. By lifting the subsidies that it paid towards the use of pesticides, Bangladesh has avoided stimulating high levels of pesticide use, as has happened in other Green Revolution countries. Countries such as Indonesia came to learn the hard way of the environmental and natural resource damage that such policies can cause [World Bank, 1994].

Integrated pest management. Integrated Pest Management (IPM) practices would allow the low current levels of pesticide use to be reduced substantially without adverse consequences for agriculture. One of the interesting aspects of IPM is that it can be justified solely by on-site benefits, including (i) higher yields, resulting from less damage being done to beneficial insects and a reduced risk of resistance building up; and (ii) lower costs. IPM has proven extremely successful throughout South and Southeast Asia. The FAO has executed a pilot IPM project in Bangladesh as part of its Inter-Country Rice IPM Project. It consists of a 30-hour farmer field school (implemented through the Department of Agricultural Extension) in which IPM principles and techniques appropriate to rice production are taught. It appears to have been relatively successful in reducing pesticide use among trained farmers, with pesticide use falling by about 85 percent and yields increasing slightly [Ramaswamy, 1993]. Both UNDP and DANIDA are planning follow-on projects. CARE is also having substantial success with IPM techniques in its Integrated Rice-Fish (InterFish) Project.

One problem with IPM is that being very knowledge-intensive, it is relatively expensive to extend to farmers. The FAO's pilot project requires 30 hours of training, divided into 8 sessions spread through the crop season. To date, about 77 field schools have been carried out, with 50 farmers each, for a total of about 3,500 farmers; CARE has trained an additional 6,000. Although the results have been very positive among trained farmers, the complexity of the knowledge required for successful use of IPM practices has limited diffusion beyond the trained group. Given the cost of this extension, the relatively low rate of pesticide use in rice, and the general weakness of the extension service, it may prove beneficial to look for subsets of IPM which could be extended more simply. IRRI has had good results, for example, with a rule of thumb which calls for refraining from spraying pesticides to combat defoliating insects during the first 40 days of the rice season [Carlson, 1994]. More complete IPM training could then be concentrated on areas in which pesticide use is highest. The other significant limitation is that while IPM practices for rice are well-established, there are currently few available IPM practices for vegetables, in which the need to reduce pesticide is most urgent. Some promising research on IPM techniques for eggplants has been carried out by BARI in cooperation with the Pesticide Manufacturers' Association, but much work remains to be done in this field.

Regulatory reform. Reform of the regulatory framework would help ensure that the pesticides that are used are safe both for their users and for the environment. The current system, which is based on regulation of pesticides by brand name, has proven cumbersome and slow. In some cases, older, more toxic pesticides continue to be used because newer, less toxic ones have not yet been registered. This is the case of heptachlor, for example. Alternatives that are far less toxic and persistent are in widespread use around the world, but cannot be used in Bangladesh because they have not been registered. Registration of pesticides by brand name is also locking up scarce research resources in essentially repetitive testing; reform would release these resources for some of the more important research needs mentioned in the previous section. Ensuring that the costs and time requirements for pesticide certification are reduced will become particularly important if current efforts to encourage diversification of agricultural production bear fruit, since many of the new crops will require different, specialized chemicals. Current registration efforts are also focused entirely on assessing the effectiveness of pesticides, with very little attention being paid to safety aspects, either for users or the environment.

Regulatory reform efforts cannot be completely divorced from the situation in neighboring India, where many highly toxic pesticides continue to be produced and sold. Many Indian pesticides are readily available in border areas of Bangladesh, where they are known to farmers for their "effectiveness", their high toxicity, and their relatively low price. Recent policy changes in India will help reduce the price discrepancy between India and Bangladesh and thus reduce the extent of the problem.

Notes

1. In addition, significant environmental problems are also often associated with the manufacture, transportation, storage, and disposal of pesticides. For lack of data, these are not discussed here.

2. Stocks of DDT still exist, however, and its use is still approved in public health programs such as malaria eradication. Inevitably, some of these stocks have leaked out and been used in agriculture. The problem should diminish in importance as existing stocks are exhausted.

3. The 1979-80 IFDC surveys, for example, report the percentage of farmers using pesticides and total use in quantity terms (lbs / acre), whereas the 1989-90 BBS surveys report the proportion of area on which pesticides are applied and total use in value terms (tk / acre).

4. Capture fisheries include fish which reproduce naturally and which are spread over the floodplain by the annual floods.

5. Since aquaculture output is increasing, however, the total production of fish may actually be increasing. The decline of capture fisheries has poverty implications, however, since the poor have less access to pond fisheries than to capture fisheries.

5. Conclusions

Given the scarcity of land and the continued growth of population, there is no alternative but to continue intensifying agricultural production in Bangladesh. As currently practiced, however, intensive agricultural production practices are degrading the soil resource base on which they depend, posing a substantial threat to their sustainability. Changes will be necessary to ensure that the achievement of self-sufficiency was not just temporary. Environmentally, intensive agricultural practices appear to pose much less of a threat than is sometimes feared, with the important exception of pesticide use on vegetables.

The sustainability problems being experienced in Bangladesh are not caused by distortions or market failures inducing inappropriate behavior. Rather, they result primarily from the difficulties of learning how to manage complex new agricultural production systems. The switch from local to modern varieties is much more than a change in type of seed. It is a change from a low-input, low-management system to a high-input, high-management system. These sustainability problems, therefore, are not amenable to traditional forms of government intervention through manipulation of the price structure. Nor are they appropriately addressed by rules and regulations on appropriate land use. Farmers have amply demonstrated that they have both the incentive and the will to respond to degradation problems. What they need is a supporting infrastructure that will aid them in doing so.

There is considerable scope for the research and extension service to assist farmers in developing appropriate responses to degradation problems. This will require a re-orientation of research efforts towards an increased focus on site-specific conditions, on long-term research, and on cropping systems and practices used by farmers. The days of 'blanket' messages which are equally applicable to all farmers are over; what farmers need is assistance in fine-tuning their cropping practices to improve yields and avoid degradation, not fundamental qualitative changes. This effort will also require a much improved extension system, which must not only deliver information to farmers but also convey information back to the research system on farmers' needs and constraints. Efforts are already underway to achieve these aims, but much remains to be done.

For farmers to be able to increase the efficiency of their cropping practices, they will also need reliable and timely access to inputs, including irrigation, fertilizers, and credit. The liberalization of irrigation in the late 1980s was largely responsible for the sharp increase in growth in that period. Liberalization of the fertilizer distribution system during the 1980s has resulted in substantial improvements in fertilizer availability at the farm level. Problems persist, however, in the supply of urea; these problems need to be addressed and must be prevented from resulting in back-tracking on liberalization efforts.

Although the threat to the environment posed by intensive agricultural practices appears to be low, several relatively simple interventions can help ensure that they do not grow and may reduce them. Here too, what problems there are generally do not result from the impact of distorted policies. The most pressing need for action is in vegetables, where numerous factors indicate a high risk of damage to the health of farmers and consumers and to the environment. Research is urgently needed to determine the magnitude and exact nature of problems, including threats to the health of farmers and their families, of pollution of waterbodies, and of pesticide residues on food. Reform of pesticide regulation will help to ensure that pesticides in use are safe for users and the environment. The current registration system is slow, excessively concerned with pesticide effectiveness rather than safety, and consumes valuable research resources. In many instances, it has resulted in older, more toxic pesticides continuing to be used because they are registered even though safer pesticides are available and in widespread use worldwide.

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Appendix

Regression analysis of time trends of modern variety *boro* yields, 1979/80 to 1993/94
(t-statistics in parentheses)

Division	District	Adj R^2	DW	Intercept	Time	Dummy 1	Dummy 2
Barisal	Barisal	0.0363	2.51	3.51	0.0128		
				(37.2)	(1.24)		
	Patuakhali	0.418	2.66	4.16	-0.194		0.375
				(12.1)	(-3.45)		(3.12)
Chittagong	Chittagong	0.344	2.39	4.00	-0.0619		
				(20.6)	(-2.89)		
	Chittagong HT	0.659	2.44	4.12	-0.101		0.114
				(30.8)	(-4.60)		(2.44)
	Comilla	-0.0704	2.86	3.96	0.00300		
				(41.0)	(0.283)		
	Noakhali	0.107	2.40	3.72	-0.0261		
				(25.6)	(-1.64)		
	Sylhet	0.457	2.14	3.47	-0.0521		
				(26.2)	(-3.58)		
Dhaka	Dhaka	0.213	1.83	4.45	-0.0332		
				(32.2)	(-2.19)		
	Faridpur	0.141	2.60	4.07	0.0463		
				(17.6)	(1.82)		
	Jamalpur	0.226	1.32	3.01	0.236	-0.259	
				(9.57)	(2.45)	(-0.36)	
	Kishoreganj	-0.0490	1.82	3.41	0.100	-0.107	
				(11.7)	(1.12)	(-1.05)	
	Mymensingh	0.764	1.81	2.73	0.196	-0.172	
				(18.4)	(4.32)	(-3.33)	
	Tangail	0.349	1.34	3.74	0.195	-0.251	
				(14.0)	(2.39)	(-2.69)	
Khulna	Jessore	0.680	2.53	3.16	0.156		-0.228
				(17.8)	(5.36)		(-3.67)
	Khulna	0.182	2.00	3.31	0.0560		-0.105
				(21.9)	(2.26)		(-1.98)
	Kushtia	0.410	1.46	3.02	0.133		-0.256
				(12.7)	(3.41)		(-3.09)
Rajshahi	Bogra	0.283	1.54	4.29	-0.0469		0.0518
				(34.6)	(-2.31)		(1.20)
	Dinajpur	0.519	1.84	4.19	-0.0807		0.219
				(27.4)	(-3.22)		(4.10)
	Pabna	0.110	1.99	3.60	0.208	-0.248	
				(9.66)	(1.82)	(-1.91)	
	Rajshahi	0.203	2.05	4.11	-0.0458		0.164
				(18.5)	(-1.26)		(2.12)
	Rangpur	0.360	2.24	3.99	-0.0453		0.105
				(41.4)	(-2.87)		(3.12)

Note: Dummy 1: slope change in 1983; Dummy 2: slope change in 1988
Source: computed from BBS data

Regression analysis of time trends of modern variety *aman* yields, 1979/80 to 1993/94
(t-statistics in parentheses)

Division	District	Adj R^2	DW	Intercept	Time	Dummy 1	Dummy 2
Barisal	Barisal	-0.0878	2.76	2.78	0.0228		-0.0544
				(16.6)	(0.831)		(-0.930)
	Patuakhali	0.488	2.732	3.37	-0.0546		
				(25.7)	(-3.79)		
Chittagong	Chittagong	-0.0498	1.78	3.15	0.00929		
				(21.6)	(0.579)		
	Chittagong HT	0.274	2.44	3.43	-0.138	0.192	
				(12.2)	(-1.61)	(1.96)	
	Comilla	0.420	2.11	2.51	0.0970		-0.123
				(13.2)	(3.13)		(-1.86)
	Noakhali	0.0489	2.54	3.39	-0.2018	0.224	
				(8.52)	(-1.65)	(1.61)	
	Sylhet	0.363	2.00	3.34	-0.188	0.249	
				(12.1)	(-2.22)	(2.58)	
Dhaka	Dhaka	0.190	3.03	3.03	-0.0936	0.136	
				(11.5)	(-1.17)	(1.49)	
	Jamalpur	0.244	2.25	3.07	-0.157	0.221	
				(8.62)	(-1.44)	(1.78)	
	Kishoreganj	0.141	2.16	3.28	-0.0292		0.123
				(16.03)	(-0.870)		(1.73)
	Mymensingh	-0.0581	3.10	3.07	-0.0797	0.0971	
				(11.8)	(-0.997)	(1.07)	
	Tangail	0.256	2.87	2.30	0.114	-0.102	
				(10.5)	(1.70)	(-1.33)	
Khulna	Jessore	0.0560	1.63	3.42	-0.147	0.183	
				(10.2)	(-1.43)	(1.56)	
	Khulna	0.691	1.60	2.91	0.0135		0.101
				(24.2)	(0.686)		(2.41)
	Kushtia	0.187	1.48	3.51	-0.162	0.184	
				(15.1)	(-2.28)	(2.28)	
Rajshahi	Bogra	0.132	1.92	3.46	-0.0982	0.133	
				(14.0)	(-1.30)	(1.55)	
	Dinajpur	-0.0136	1.44	3.30	-0.0387		0.0783
				(18.5)	(-1.32)		(1.26)
	Pabna	0.488	1.74	2.58	0.0607		-0.0147
				(16.6)	(2.34)		(-0.235)
	Rajshahi	0.537	1.86	2.80	-0.0479	0.121	
				(10.6)	(-0.594)	(1.32)	
	Rangpur	-0.00004	1.94	2.87	0.0843	-0.0870	
				(13.4)	(1.28)	(-1.16)	

Note: Dummy 1: slope change in 1983; Dummy 2: slope change in 1988
Source: computed from BBS data