Environmental impacts of technological change in Bangladesh agriculture: farmers' perceptions and empirical evidence

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ENVIRONMENTAL IMPACTS OF TECHNOLOGICAL CHANGE IN BANGLADESH AGRICULTURE: FARMERS' PERCEPTION AND EMPIRICAL EVIDENCE[◆]

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ABSTRACT

Concern on the environmental impacts of technological change in agriculture and studies exploring farmers' perception of this issue are nascent. The present paper provides an insight on environmental impacts of modern agricultural technology as perceived by Bangladeshi farmers, which are then supported by material evidences, such as, soil fertility and time-series analyses of fertiliser and pesticide use, foodgrain production, and fish catch.

Farmers are well aware of the adverse environmental impacts of modern agricultural technology although their awareness remains confined within visible impacts closely related to livelihood sources, such as 'soil fertility', 'fish catch' and 'health effects', also supported by empirical evidences. Strength of farmers' perception is weak for intangible impacts, such as 'toxicity' in water and soils. Raising farmers' awareness of tangible and intangible environmental impacts of modern agricultural technology is urgently needed for sustainable development of agriculture.

ENVIRONMENTAL IMPACTS OF TECHNOLOGICAL CHANGE IN BANGLADESH AGRICULTURE: AN ANALYSIS OF FARMERS' PERCEPTION

Farmers' perception on the environmental impacts of modern agricultural technology is important since perception is viewed to contain goals including those achieved and those yet to be achieved and, therefore, looked upon as a guiding concept of behaviour and/or decision-making[1].

Agriculture is characterised by its environmental, behavioral and policy aspects[2]. Though farmers' behavioral and government's policy dimensions of agriculture has been rigorously analyzed in the past, the environmental dimension is largely neglected and remains unclear despite the fact that ecological integrity of agricultural production system is a pre-requisite for sustainability. The concern of environmental impacts of technological change and sustainability in agriculture has been a recent phenomenon spurred by studies such as Shiva[3] Wossink[4], Brown[5] and Wolf[6] though, it was cautioned by Bowonder[7] and Clapham[8] during the early eighties. Environmental and social factors comprising agriculture are closely tied together and the environmental problem of agriculture largely stems from the phenomena associated with agricultural development[9]. The present paper attempts to provide an insight to this less studied dimension in agriculture by eliciting a picture of environmental impacts of modern agricultural technology as perceived and ranked by farmers of Bangladesh, one of the most vulnerable countries in terms of food security. Moreover, these perceptions are substantiated and validated by examining the status of soil fertility and the trends of relevant indicators over time.

Research Design

Primary data for the study pertains to an intensive farm-survey conducted during February to April 1997 in three agroecological regions of Bangladesh. Samples from eight villages of Jamalpur Sadar subdistrict of Jamalpur representing wet agroecology, six villages of Manirampur subdistrict of Jessore, representing dry agroecology, and seven villages of Matlab subdistrict of Chandpur, representing wet agroecology and agriculturally developed area were collected. A total of 406 farm households were selected for data collection following a multistage stratified random sampling procedure.

Farmers' perception on the environmental impacts of technological change is elicited in two steps. First, a set of 12 specific environmental impacts is read to the respondents. The selection of these indicators is based on the Focus Group Discussion (FGD) with the farmers conducted during the pre-testing of structured questionnaire (please see Table 2 for specific impacts). Farmers were asked to reveal their opinion on these impacts. Respondents confirming statements were are asked to provide weights on a five-point scale. And for disagreement of these impacts a zero weight was enumerated. It is believed that undergoing these two step procedures helped in avoiding leading statements and loaded responses[10].

Status of soil fertility of the study area was determined through a detailed bio-physico-chemical analysis of a total of 15 composite soil samples (5 from each agroecological region) of crop fields selected randomly from within the sampled households. A total of 8 properties – *soil reaction* (pH)*; available nitrogen* (N)*, available phosphorus* (P)*, available potassium* (K)*, available sulphur* (S)*,* and *available zinc* (Zn)*; organic matter content* (OM)*,* and *textural class* were analyzed.

Technological Change in Bangladesh Agriculture: An Overview

The technological breakthrough in Bangladesh agriculture has been primarily in the foodgrain sector, that is the introduction of rice-based ‘Green Revolution’ technology package followed by a gradual introduction of wheat-based technology package. The overall policy thrust for the past four decades (1960 – till date) has been in provision of technical inputs complementing the expansion and diffusion of these ‘Green Revolution’ technologies. The selected indicators of technological change over the past 45 years from 1949/50 to 1993/94, using triennium averages of four periods, is presented in Table 1.

Land area under agricultural production in Bangladesh is operating at its frontier since the 1980s with declining net-cropped area owing to transfer of land for other uses. The total rice area also reached its upper limit and making way for expansion of area under wheat. It is interesting to note that the wheat acreage, which picked up in early 1980s, primarily represents modern varieties, while the area under modern rice varieties, introduced since 1963, accounted for only 50 percent of the total. Such stagnation in the diffusion of modern rice varieties is attributed primarily to slower expansion of modern irrigation facilities, susceptibility to pest and disease attack, and requirement of heavy capital investment. The fertiliser use rates per hectare of gross cropped area increased about six folds in response to increase in areas of foodgrain under modern varieties (see Table 1). Pesticide use, negligible until the 1970s, recorded dramatic increase in recent years, as it became an integral part of modern agricultural technology. The yield rates of modern rice varieties fell sharply from the 1970 levels due to decline in soil fertility while the yield rates of local rice varieties is on the rise probably owing to the use of modern inputs and variety screening. The falling yield rate of modern rice is posing a threat to sustain the foodgrain production required to feed the growing population. However, the rising trend in wheat yield rates is encouraging.

Farmers' Perception of Environmental Impacts of Modern Agricultural Technology

'Decline in soil fertility' featured at the top of the list of adverse environmental impacts of technological change followed by 'health effects', 'decline in fish catch', 'increase in crop disease', 'soil compaction', 'increase in insect/pest attack' and 'soil erosion and soil salinity' (see Table 2). It is interesting to note that the perception of adverse impact of modern technology on water resources is very weak as evident from sharp decline in index values. This implies that though farmers are aware of the adverse environmental impacts of modern agricultural technology, their awareness level remains confined to the visible impacts most closely related to their farm field and sources of livelihood (crops and fish) on which they depend. The awareness of indirect impacts such as 'contamination of soil and water bodies' is not very strong as indicated by low index values primarily due to high level of illiteracy and poor exposure to messages on health and hygiene. The consistency of these response patterns across region is evident from the analyses of rank correlation. All relative rankings of impacts across regions are significantly ($p<0.01$) positively related with the value of r varying within a range of 0.70 to 0.99.

Evidences Supporting Farmers' Perceptions

Soil fertility status of Bangladesh is on the decline[11] resulting in declining productivity, particularly for the modern varieties of rice[12]. Evidence from the present study, the bio-physico-chemical analysis of soil parameters, also suggests poor status of soil fertility (see Table 3) consistent with farmers' perception and ranking.

A number of factors may be responsible for decline in soil fertility. One of the crucial factors may be application of unbalanced dosage of fertilisers required to supplement nutrient uptake by crop. Dependency on chemical fertilisers might be another important explanatory factor as it was observed that farmers using high doses of fertilisers tend to avoid organic fertiliser application. A negative association ($r = -0.23$) is estimated between fertiliser application rate and organic manure use rate in the study area, thereby, confirming the notion. As deficiency of organic matter content in soil cannot be supplemented by application of chemical fertilisers, such avoidance results in degradation of soil quality[13].

Analysis of nutrient uptake through harvested crops revealed that modern rice varieties alone account for 71 percent (highest is Jamalpur 84 percent) of total nutrient (N, P) uptake. The share is relatively lower in areas with diversified cropping system, i.e., Jessore region where modern varieties absorbed 60 percent of total uptake. Baanante[14] noted that the current production of food crops in Bangladesh take up an estimated 0.92 million tons of nutrients (NPK and S) from the soil. The recommended fertiliser doses for modern varieties of Aus, Aman and Boro rice, with a medium production target on land with low soil nutrient status, is 170 kg, 170 kg and 240 kg of nutrient (NPK) per ha, respectively[15]. The fertiliser use rate in the study areas for modern varieties of Aus, Aman and Boro rice is estimated at 109 kg, 100 kg and 128 kg of nutrient (NPK) per ha, respectively which are consistently lower than the recommended dose, thereby, explaining the cause of poor soil fertility. Therefore, knowledge and application of appropriate types and dosage of fertilisers is vital to replenish the soil fertility.

The phenomenon of ‘declining soil fertility’ is further substantiated by the time-trend analyses[16] of fertiliser use rates and fertiliser productivity for the study regions as well as Bangladesh for a period of 29 years (1961/62 – 1991/92). Results revealed that fertiliser use rate per ha of gross cropped area grew at an estimated rate of 10 percent and above for all regions and is highly significant ($p<0.01$). However, the fertiliser productivity (aggregate output per kg of fertiliser application) significantly ($p<0.01$) declined at an annual rate of about 10 percent. The rate of decline in fertiliser productivity is almost equivalent to the growth rate of fertiliser use per ha of land. Also, yield rate of modern rice varieties declined ($p<0.05$) at an annual rate of 1.2 percent over the 26-year period (1967/68 – 1993/94), further reinforcing the farmers' perception of 'soil fertility decline'.

Though 'adverse effect on human health' is perceived as the second most important environmental impact of technological change, validation of this statement with material support is beyond the scope of this study. However, an inference is attempted by analysing categories of pesticides used by the farmers of the study regions and its potential danger. It is needless to mention that health effect of modern agricultural technology directly stems from the use, inhalation, and handling of the hazardous pesticides which became a vital input in crop production in recent times[17].

Investigation on the use of pesticides in the study area revealed that about 77 percent of farmers (highest 94 percent in Comilla) apply pesticides at least once in a crop season. Also, the types of pesticides used raises alarming concern. A large majority of farmers in Jamalpur (86 percent) and Jessore (77 percent) followed by Comilla (53 percent) use organophosphate pesticides which are rated as extremely to highly hazardous according to World Health Organisation (WHO) standard[18]. The Comilla farmers, whose perception of adverse effects of pesticides is relatively stronger, use carbamate (37 percent) which is classified as between highly to moderately hazardous by WHO. The use of extremely hazardous pesticides, the organochlorine group, is relatively less in all regions. Nevertheless, the combination remains alarmingly dangerous if proper application and handling regulations, which are largely non-existent and are not maintained. Further, time-trend analysis[19] (1976/76 – 1992/93) of pesticides use revealed an estimated 8.6 percent annual growth rate for Bangladesh. The rate is highest in Jessore (10 percent) closely followed by Jamalpur (9 percent) while it is highly fluctuating in Comilla region, thereby, showing a lower growth rate (5 percent). Such, sharply rising use rate, combined with negligence in handling of pesticides, is no doubt a potential threat to farmers' health.

'Reduction in fish catch' was ranked as the third major environmental impact of technological change by farmers. There has been increasing concern about the contamination of fisheries resources by the application of pesticides to particularly modern rice cultivation[20] and is seen as the major cause for decline in fish production[21]. Floodplains in Bangladesh, which are recaptured during the off-flooding season for rice production, are affected by accumulation of chemicals and toxic elements released through the application of fertilisers and pesticides, thereby, damaging fish habitat and spawning ground particularly in rice fields[22]. During the Focus Group Discussion (FGD), farmers confirmed that the sharp decline of fish from and around the rice fields was caused by use of pesticides and chemical fertilisers. However, it has to be noted that the construction of Flood Control Drainage and Irrigation Project (FCD/I) to support diffusion of modern agricultural technology in crop production as well as rising population pressure have adversely affected fishery resources[23]. Ali[24] noted that due to embankments constructed under Chandpur FCD/I Project, the overall fish production declined by 35 percent over the first two years of implementation. Trend analyses of fish catch[25] in rivers in regions encompassing the study areas for a 10-year period (1983/84 – 1993/94) confirmed the reduction. The annual average rate of decline is about 6 percent for Bangladesh and as high as 14 percent for Jamalpur region which is very alarming as fishery is a supplementary source of food and household earnings of the overwhelming majority of farmers possessing small landholdings.

Arsenic Pollution in Water and Soil: An Indirect Effect of Technological Progress

Presence of arsenic in groundwater in most part of the Bangladesh is believed to be due to geological reason, particularly, in the region alluvial land rich in pyrite minerals[26]. The widespread diffusion of 'Green Revolution' technology, wherein irrigation is an important input, resulted in an increased demand for groundwater, which is the major source of irrigation in Bangladesh. As a result, excessive groundwater is being used for both agricultural as well as drinking purposes leading to fluctuation of water-table from pre-monsoon to post-monsoon season and aeration of groundwater aquifers. The result is the decomposition of pyrites and acids containing arsenic from the sediments, which is later uptaken through lifting groundwater[27], finally bringing pollution to the surface. An intensive testing of arsenic contamination in groundwater in Hajiganj subdistrict conducted by BRAC revealed that 11,093 (93 percent of the total) tubewells are contaminated with arsenic concentration greater than the acceptable limit set by WHO[28]. As a whole, an estimated 40 million people are believed to be affected by arsenic contamination in groundwater in all over Bangladesh[29].

In addition to the widespread contamination of arsenic in groundwater, surface soil irrigated with these waters is also found contaminated. An estimated 42 districts covering an area of 87,400 sq. km contains arsenic in toxic levels[30]. Irrigation with groundwater contaminated with arsenic levels above 10 mg As/litre resulted in increasing the levels of arsenic concentration in soils upto 83 mg As/kg soil in Comilla while the allowable limit is 20 mg As/kg soil[31]. Therefore, it can be stated that though arsenic contamination in groundwater is geogenic, the arsenic contamination of surface soil is largely anthropogenic spurred by the diffusion of modern agricultural technology that relies largely on irrigation and water control.

Conclusions and Policy Implications

The present study dealt with one of the least touched upon issues associated with the diffusion of modern agricultural technology, specifically its impact on the environment. Another feature of this study is that, it explored farmers' perception and awareness of this issue since the goal of sustaining agricultural production largely depends on the actions of farmers/producers rather than the policy makers, researchers, and extension agents.

Results revealed that farmers are well aware of the adverse environmental impacts of modern agricultural technology. However, their awareness level remains confined within the visible impacts that are most closely related to their farm field and sources of livelihood, reflected in their ranking of 'decline in soil fertility', 'effect on human health' and 'reduction in fish catch in open water bodies' as the three major impacts. The soil test results as well as time-trend analyses of relevant indicators rendered support and validated farmers' perceptions.

However, the strength of farmers' perception ranking declines sharply as one moves from visible and direct impacts to intangible and indirect impacts. For example, knowledge on 'contamination of water source', 'increase in toxicity in soil and water' are highly limited. Therefore, raising awareness on both tangible and intangible environmental impacts of technological change in agriculture at the farm level is needed. Also, knowledge on the widespread arsenic contamination in groundwater and surface soil is highly limited. Not only the farmers are unaware of this contamination, but also the entire society at large. As such, there is an urgent need to undertake mass awareness raising activities as well as research in areas that can contain the unwanted and undesired impacts of technological change in agriculture in order to achieve the goal of sustainable agricultural development in Bangladesh.

Farmers' awareness of direct environmental impacts of the 'Green Revolution' technology forms the basis of implementation of a comprehensive agricultural development strategy conducive to maintain or even increase agricultural production without polluting land and water resources. In this pursuit, emphasis should be laid on cropping diversification[32], balanced application of chemical and organic fertilisers and efficient utilisation of water resource.

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Table 1 Selected indicators of technological change in Bangladesh agriculture, 1949/50 – 1993/94.

	Indicators		Period[a] 1950-52	Period[a] 1968-70	Period[a] 1980-82	Period[a] 1992-94
1	Total cropped area (TCA) (‘000 ha)		10,614	12,871	13,103	13,753
2	Net cropped area (‘000 ha)		8,274	8,787	8,531	7,812
3	Cropping intensity (%)		128.3	146.5	153.6	176.0
4	Total rice area (‘000 ha)		8,071	10,049	10,310	10,135
5	Rice as percent of total cropped area (%)		76.0	78.1	78.7	73.7
6	Modern rice as percent of total rice area (%)		nil	1.5	20.3	49.0
7	Total wheat area (‘000 ha)		39	105	520	609
8	Modern wheat as percent of total wheat (%)		nil	6.1	96.2	98.0
9	Total irrigated area (IA) (‘000 ha)		< 1	1,057[b]	1,865	3,257
10	Irrigated area as percent of TCA (%)		na	8.2[b]	14.2	23.7
11	Foodgrain irrigated area as percent of IA (%)		na	85.8[b]	78.4	91.2
12	Irrigation by methods	Modern (%)	na	31.5[b]	67.2	70.9
		Traditional (%)	na	68.5[b]	32.8	29.1
13	Total fertiliser used (‘000 mt of nutrients)		< 1	113.1	380.8	664.8
14	Fertiliser use rate per TCA (kg of nutrients/ha)		na	8.8	29.1	48.3
15	Pesticide use (‘000 mt)		na	na	2.2	6.5
16	Rice production (‘000 mt)		7,367	11,504	13,417	18,211
17	Rice yield (kg/gross ha)	Modern variety	nil	3,809	2,297	2,409
		Local variety	913	1,103	1,048	1,208
18	Wheat production (‘000 mt)		22	86	932	1,124
19	Wheat yield (kg/gross ha)		564	819	1,792	1,846

Note: [a] Period 1950-52 refers to average of 1949/50, 1950/51 and 1951/52. Period 1968-70 refers to average of 1967/68, 1968/69, and 1969/70. Period 1980-82 refers to average of 1979/80, 1980/81 and 1981/82. Period 1992-94 refers to average of 1991/92, 1992/93 and 1993/94.

[b] 1968/69 and 1969/70 only.

Source: *Statistical Yearbook of Bangladesh,* (various issues), Bangladesh Bureau of Statistics, Dhaka; M. Alauddin, and C. Tisdell, C., *The Green Revolution and Economic Development: The Process and its Impact in Bangladesh,* Macmillan, London, 1991; M.A. Hamid, *A Database on Agriculture and Foodgrains in Bangladesh (1947/48 – 1989/90*), Bangladesh Agricultural Research Council/ Winrock International, Dhaka, 1991; and M. Hossain, *Green Revolution in Bangladesh: Impact on Growth and Distribution of Income,* University Press Limited, Dhaka, 1989.

Table 2. Ranking of farmers' perception on 12 specific environmental impacts of modern agricultural technology by study regions, 1996.

Sl. no.	Environmental impacts of modern agricultural technology	Index weighted by rank of responses[a]							
		Jamalpur region		Jessore region		Comilla region		All region	
		Index	Rank	Index	Rank	Index	Rank	Index	Rank
1	Reduce soil fertility	0.82	1	0.94	1	0.63	1	0.79	1
2	Affects human health	0.60	2	0.79	2	0.45	4	0.60	2
3	Reduce fish catch	0.55	3	0.59	4	0.57	2	0.56	3
4	Increase disease in crops	0.51	4	0.61	3	0.45	3	0.52	4
5	Compact/ harden soil	0.36	7	0.57	6	0.37	5	0.42	5
6	Increase insect/ pest attack	0.43	5	0.58	5	0.12	9	0.37	6
7	Increase soil erosion	0.39	6	0.49	7	0.11	10	0.33	7
8	Increase soil salinity	0.28	8	0.43	8	0.24	6	0.30	8
9	Contaminate water source	0.26	9	0.24	9	0.08	11	0.20	9
10	Increase toxicity in soil	0.14	11	0.16	11	0.13	7	0.15	10
11	Creates water logging	0.14	10	0.18	10	0.05	12	0.13	11
12	Increase toxicity in water	0.12	12	0.07	12	0.13	8	0.11	12
	All impacts	0.38[b]	2	0.47[b]	1	0.28[b]	3	0.37	

Note: The higher the index the stronger the perception.

[a] Ranking done by weighting individual responses by their ranks.

Index = $\{R_{VH}\ (1.0) + R_H\ (0.8) + R_M\ (0.6) + R_L\ (0.4) + R_{VL}\ (0.2) + R_0\ (0.0)\}\ /\ N$

where R_{VH} = very high rank, R_H = high rank, R_M = medium rank, R_L = low rank, R_{VL} = very low rank, and R_0 = farmers responding in the negative, respectively. N = sample size.

[b] = Ranking done across 3 regions.

Source: Field Survey, 1997.

Table 3. Soil fertility evaluation of the study regions, 1997.

Soil variable	Mean values (index values) and interpretation			
	Jamalpur region	Jessore region	Comilla region	All region
Soil texture	Silt loam	Silty clay	Silt loam	Silty clay loam
Soil reaction (pH)	6.0 Slightly acidic	7.8 Alkaline	7.2 Neutral	6.7 Neutral
Organic matter content (%)	2.01 (1.6) Low	6.47 (2.6) High	1.45 (1.2) Low	3.32 (1.7) Medium
Available nitrogen (µg/g)	16.0 (1.0) Low	19.1 (1.0) Low	25.5 (1.0) Low	20.2 (1.0) Low
Available phosphorus (µg/g)	26.7 (2.6) High	22.3 (2.2) Medium	20.4 (2.0) Medium	23.1 (2.3) Medium
Available potassium (µg/g)	32.2 (1.0) Low	52.4 (1.0) Low	20.3 (1.0) Low	34.9 (1.0) Low
Available sulphur (µg/g)	7.8 (1.0) Low	10.2 (1.4) Low	5.5 (1.0) Low	7.8 (1.1) Low
Available zinc (µg/g)	5.0 (2.4) High	7.6 (2.8) High	4.1 (2.2) Medium	5.5 (2.5) High
Overall fertility index value and status	(1.6) Low	(1.8) Medium	(1.4) Low	(1.6) Low

Note: The index value (in parentheses) are rated as: **< 1.67 = low, 1.67 – 2.33 = medium, and > 2.33 = high** following M.R. Motsara, 'Soil testing services for ensuring balanced fertilisation and profitable crop production', In Proceedings of the FADINAP Regional Workshop on Co-operation in Soil Testing for Asia and the Pacific, Bangkok, 16-18 August, 1994.

Index = $\{(n_1 * 1) + \{(n_2 * 2) + \{(n_3 * 3)\}/ n$

where n_1 …. n_3 are respective number of samples in each class, and 1, 2, and 3 are weights for low, medium and high class and n = sample size.

The interpretation is based on suitability classification provided by Soil Resource Development Institute in *Soil Guides for Crop Production, 1991 (in Bangla)* on a given range of levels of nutrients for all macro and micronutrients.

Source:Field survey, 1997.