Sustainability Analysis of Ecological and Conventional Agricultural Systems in Bangladesh

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Summary. — This paper examines the sustainability of conventional and ecological agricultural systems based on their environmental soundness, economic viability and social acceptability. Significant differences were found in crop diversification, soil fertility management, pests and diseases management, and use of agrochemicals. No remarkable variations were found in land-use pattern, crop yield and stability, financial and economic returns, risk and uncertainties, or food security. The findings suggest that ecological agriculture is relatively more sustainable, and it could be an economically and environmentally viable alternative to the conventional agricultural system. Ecological agriculture could become an alternative if market distortions created by subsidies were removed, and financial benefits were provided to resource-conserving farmers along with necessary support through extension, credit, research, and marketing.

1. INTRODUCTION

Agricultural production has increased tremendously in many parts of the world in the last few decades through the increased use of high-yielding varieties of seeds, inorganic fertilizers, pesticides and water, resulting in very high costs of production (Biswas, 1994; Conway, 1990; Edwards & Wali, 1993; Paoletti, Stinner, & Lorenzoni, 1989; Pretty, 1995; Repetto, 1987). Overuse and inappropriate use of agrochemicals have led to contamination of water, loss of genetic diversity and deterioration of soil quality (O’Connell, 1991; Pretty, 1995). It is estimated that 20–30 million ha of land have been severely affected, and another 60–80 million ha have been moderately affected largely by salinity and water-logging arising from overuse and imbalanced use of irrigation, inorganic fertilizers and pesticides (Biswas, 1994). Increasing evidence of human health problems associated with consumption of agrochemicals, including pesticides, is also emerging (e.g., Marquez, Pingali, & Pails, 1992; Pingali & Roger, 1995; Rola & Pingali, 1993), as toxic elements have entered into the food chain (Harwood, 1990; O’Connell, 1991). Increased vulnerability of crops to insect and pest attacks, loss of fish and other aquatic resources, declining crop yields, and deterioration of animal and human health due to agrochemical based conventional agricultural 1 have raised concerns about the long-term sustainability of such system (WRI, 1993). The Republic of Bangladesh is no an exception, as its agriculture is highly dependent upon such inputs.

In Bangladesh, where agriculture is the main source of livelihood of two-thirds of the rural population, a serious concern has arisen about the sustainability of agriculture in the face of deterioration of land quality, declining yield, and increased population. Being a land-scarce country, 2 emphasis has been given to increasing food production by intensifying the use of land, inorganic fertilizers, pesticides and water. Subsidies are provided on inorganic fertilizers, pesticides, and irrigation equipment to enable farmers to adopt these technologies for increasing crop yields (Hossain, 1988). This has caused major changes in cropping patterns, use of agricultural inputs, and management of soil fertility. Likewise, cropping intensity and the

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area under irrigation and HYV paddy have all increased considerably. Use of inorganic fertilizers increased six times during 1970–90, and the use of pesticides increased about threefold in just one decade, during 1982–92 (Rahman & Thapa, 1999).

On the other hand, the area under pulses, oilseeds, fodder and natural inland fisheries is declining rapidly (FFYP, 1998). Traditional cropping practices, such as mixed cropping, crop rotation, and intercropping, are also gradually disappearing (Hossain & Kashem, 1997). This has led to monocropping and higher dependency on external inputs such as irrigation, inorganic fertilizers, and pesticides. Monocropping along with imbalanced use of inorganic fertilizers, pesticides, and intensive use of land without application of organic fertilizers have led to deterioration of soil quality and fertility (Hossain & Kashem, 1997; Rahman & Thapa, 1999; Task Force Report, 1991). More than 65% of the total agricultural area is suffering from declining soil fertility, and about 85% of net cultivable area has organic matter below the minimum requirement (Hossain, 1990; Task Force Report, 1991). As a result, crop yields are decreasing steadily, despite increased use of agricultural inputs (Ahmad & Hasanuzzaman, 1998; Ali, 1995; Hossain & Kashem, 1997; Pagiola, 1995; Rahman & Thapa, 1999).

The increased use of inorganic fertilizers, insecticides and pesticides has led to contamination of water bodies and the spread of diseases, which have adversely affected aquatic life, livestock and people (Asaduzzaman, 1995; Hossain, Salam, & Alam, 1994; Hossain & Kashem, 1997; Rahman & Thapa, 1999). Likewise, the excessive use of ground water is suspected to be the cause of the presence of high levels of arsenic in ground water in northern and northwestern parts of Bangladesh (Siddique, Chattergy, Zheng, & Kosmus, 1998; Ullah, 1998). Given the present state of declining soil fertility, decreasing yields, increased and imbalanced use of inorganic fertilizers and pesticides, finding ways to produce food and fiber on a sustainable basis for the growing population has become a serious challenge for Bangladesh.

A number of nongovernmental organizations (NGOs), namely, UBINIG (Policy Research for Development Alternatives), Proshika, and CARE Bangladesh have launched initiatives in different parts of the country to promote sustainable agriculture. While UBINIG, emphasizes whole farm sustainability, Proshika focuses mainly organic vegetable cultivation (Akter, 1997) and CARE Bangladesh on sustainability of rice production through integrating fish with rice field and adopting integrated pest management (IPM). These initiatives are confined to certain pockets of the country, but are gaining importance gradually as there is increasing awareness of adverse health and environmental impact of conventional agriculture. UBINIG is a pioneer among a few agencies devoted to the promotion of sustainable agriculture. Since UBINIG focuses on the whole farm sustainability instead of particular production component, we chose UBINIG as case study. UBINIG’s program, locally called naya krishi andolon or new agricultural movements, started its activities in Delduar subdistrict of Tangail district of Bangladesh in 1990. By June 1997, it had expanded to 15 districts, and about 20,000 farm households were practicing this type of agriculture (Akter, 1997; Gain, 1998). This agriculture emphasizes greater use of on-farm resources, including crop residues, organic fertilizers, cropping diversification, mixed cropping, crop rotation, reduced use of inorganic fertilizers, and no use of pesticides. It tries to promote integration of crop, livestock and tree in farming systems, and conservation of water resources, preservation of seeds at households level, and maintenance and enhancement of biodiversity to make the system both environmentally and economically sustainable (Akter, 1997). Characteristically, this agricultural system is similar to what is normally known as ecological agriculture, and thus hereafter is referred to as ecological agriculture. Ecological agriculture is distinct from conventional agriculture in terms of resource use, nature of input use, pattern of crops, degree of diversity, management and cultural practices, methods of plant protection, management of resources, and degree of dependency on local external resources and knowledge.

Akter (1997) reported that ecological agriculture promoted by UBINIG is environmentally more friendly than conventional agriculture. Based on rapid appraisal, this study did not evaluate the economic performance of the system, overlooking the fact that economic performance is equally important determinant of agricultural sustainability. As farmers increasingly confront declining per capita return arisen from miniaturizing land holdings caused by steadily growing popula-
tion, they are required to make additional ef-
torts to increase agricultural production. They
will thus adopt a agricultural system only when
it is both economically and environmentally
suitable. For small farmers such as those in
Bangladesh who are struggling for food secu-
rety, current needs are more important than
future needs. Even profit-seeking large farmers
will not venture into ecological agriculture un-
less it provides sufficient income.

This study, therefore, attempts to examine to
what extent the ecological agriculture being
promoted by UBINIG differs with the conven-
tional agriculture in terms of agricultural
practices and resource management and com-
pares the two agricultural systems from envi-
ronmental, economic and social perspectives.
Although agricultural sustainability is not pre-
cisely measurable (Pretty, 1995) as externalities
of any agricultural system are very difficult to
measure, amid growing emphasis on ecological
agriculture, we have attempted to assess
whether such agriculture is showing symptoms
of sustainability according to the above men-
tioned three criteria by comparing it with the
conventional agriculture. The findings of the
study are intended to make a contribution to for-
mulation of policies for sustainable agricul-
ture development. They also provide a frame-
work useful for sustainability assessment of
different types of agricultural systems. The
organization of this article is as follows. Section 2
offers a framework adopted for assessing agricul-
tural sustainability based on the current
state of knowledge, followed by Section 3, with
a brief description of the study area and
methods of data collection. Section 4 presents
the results and interpretation of findings in
terms of relative sustainability of conventional
and ecological agriculture, based on the
framework of sustainable agriculture developed
in Section 3. Section 5 concludes by highlight-
ing policy implications for the promotion of
sustainable agriculture.

2. FRAMEWORK FOR ASSESSING THE
AGRICULTURAL SUSTAINABILITY

(a) The concept of sustainable agriculture

The concept of agricultural sustainability has
emerged in response to concerns about the
adverse environmental and economic impacts
of conventional agriculture (Hansen, 1996).
The excessive and imbalanced use of agro-
chemicals has led to increased production costs
and dependence on external inputs and energy,
a decline in soil productivity, contamination of
surface and ground water, and adverse effects
on human and animal health (Biswas, 1994;
Conway, 1985; Edwards, 1989). Overuse or
imbalanced application of agrochemicals have
led to degradation of natural resources, thereby
undermining their productive capacity (Ikerd,
1993). Sustainable agriculture is often viewed in
contrast with conventional agriculture as low
input and regenerative (Locke, 1989; Re-
jntjes, Bertus, & Water-Bayer, 1992), making
better use of farm’s internal resources through
incorporation of natural processes into agri-
cultural production and greater use of knowl-
edge and skills of farmers to improve their
self-reliance and capacities. It uses external and
nonrenewable inputs to the extent that these are
deficient in the natural environment (Pretty,
1995).

In spite of common concerns about sustain-
able agriculture, there are large differences
among the scholars and other stakeholders
about the attributes of sustainable agriculture
(Rigby & Caceres, 2001). Some (e.g., Conway,
1990; Edwards, 1987; Ouedraogo, Mando, &
Zombre, 2001; Pretty, 1995; Repetto, 1987;
Reijntjes et al., 1992; Schaller, 1993; Tisdell,
1996) consider low use of external inputs as a
major requirement for agricultural sustainabi-
ity. Others, with keen interest in enhancing
production (e.g., De Jager, Onduru, van Wijk,
Vlaming, & Gachini, 2001; Hansen, 1996;
Webster, 1997) find it necessary to increase the
use of external inputs to a some extent, so as to
maintain soil nutrient levels and crop yields.
Scholars concerned mainly about ecological
sustainability emphasize maintaining agro-
ecological health (e.g., Altieri, 1995; Conway,
1990; Edwards, Grove, Harwood, & Colfer,
1993), biodiversity (e.g., Bothun et al., 2000 in
Clemetsen & van Larr, 2000) and landscape
quality (e.g., Clemetsen & van Larr, 2000;
Stobbelaar, Kuiper, van Mansvelt, & Kabou-
arakis, 2000), and integrated nutrient manage-
ment (Edwards & Grove, 1991) as necessary
conditions for agricultural sustainability. In the
same vein, Lampkin (1994) and Henning,
Baker, and Thompson (1991) find organic ag-
riculture synonymous with sustainable agricul-
ture, as it has no adverse impact on ecological
health. But according to Hodge (1993, cited
in Rigby & Caceres, 2001), no use of inor-
ganic chemicals is not a sufficient condition
for sustainable agriculture. There are others
(e.g., Lynam & Herdt, 1989; Smith & McDonald, 1998; Tisdell, 1996) who seem to be concerned mainly about economic aspect of agricultural sustainability, such as net present value, benefit cost ratio and profitability. Recently, “social capital,” which can be considered as one of the components of social sustainability, has also been added into the concept of agricultural sustainability. Social capital, if mobilized properly, contributes to agricultural sustainability by helping farmers to enhance their knowledge and capabilities, and reducing dependency on external agencies by facilitating co-learning, information sharing, and group works (Pretty & Ward, 2001; Pretty & Hine, 2000; Webster, 1999).

Despite the diversity in conceptualizing sustainable agriculture, there is a consensus on three basic features of sustainable agriculture: (i) maintenance of environmental quality, (ii) stable plant and animal productivity, and (iii) social acceptability. Consistent with this, Yunlong and Smith (1994) have also suggested that agricultural sustainability should be assessed from ecological soundness, social acceptability and economic viability perspectives. “Ecological soundness” refers to the preservation and improvement of the natural environment, “economic viability” to maintenance of yields and productivity of crops and livestock, and “social acceptability” to self-reliance, equality and improved quality of life.

(b) Indicators for assessing agricultural sustainability

For any study on sustainable agriculture, the question arises as to how agricultural sustainability can be measured. Some argue that the concept of sustainability is a “social construct” (David, 1989; Webster, 1999) and is yet to be made operational (Webster, 1997). The precise measurement of sustainability is impossible as it is site-specific and a dynamic concept (Ikerd, 1993). To some extent, what is defined as sustainable depends on the perspectives of the analysts (Webster, 1999). Although precise measurement of sustainable agriculture is not possible, “when specific parameters or criteria are selected, it is possible to say whether certain trends are steady, going up or going down” (Pretty, 1995, p. 11). Practices that erode soil, remove the habitats of insect predators, and cut instead of plant trees can be considered unsustainable compared to those conserve these resources. According to Altieri (1995), farmers can improve the biological stability and resilience of the system by choosing more suitable crops, rotating them, growing a mixture of crops, and irrigating, mulching, and manuring land.

According to Lynam and Herdt (1989), sustainability can be measured by examining the changes in yields and total factor productivity. The workshop organized by the Institute for Low External Input Agriculture (ILEIA, 1991) mainly emphasized productivity, security, continuity, adaptability and integrity as measures of sustainability. Beus and Dunlop (1994) considered agricultural practices such as the use of pesticides and inorganic fertilizers, and maintenance of diversity as measures of sustainability. For sustainable agriculture, a major requirement is sustainable management of land and water resources. An International Working Group (Smyth & Dumanski, 1993) has viewed maintenance or enhancement of productivity, reduced risk, natural resources conservation, promotion of economic viability and social acceptability essential condition for sustainable land management.

Considerable efforts have been made to identify appropriate indicators for agricultural sustainability. Recently, OECD has developed a common framework called driving force-state-response (DSR) to help in developing indicators. Driving force indicators refer to the factors that cause changes in farm management practices and inputs use. State indicators show the effect of agriculture on environment such as soil, water, air, biodiversity, habitat and landscape. Response indicators refer to the actions that are taken in response to the changing state of environment. Using the DSR framework, OECD (1997) identified 39 indicators of issues such as farm financial resources, farm management, nutrient use, pesticide use, water use, soil quality, water quality, land conservation, greenhouse gases, biodiversity, landscape, wildlife habitats, and farm’s contextual information, including socioeconomic background, land-use, and output. Similarly, the British Government suggested 34 indicators under 13 themes such as nutrient losses to fresh water, soil P levels, nutrient management practices, ammonia emissions, green house gas emissions, pesticide use, water use, soil protection, agricultural land resource, conservation value of agricultural land, environmental management systems, rural economy and energy (MAFF cited in Webster, 1999).
Most of the indicators mentioned above are suitable to evaluate agricultural sustainability at aggregate level. They cannot, however, be used to assess sustainability at the farm level, although individual farmers take the major decision in land-use including mode of use and choice of technology (Webster, 1999). Sands and Podmore (2000) used environmentally sustainability index (ESI) as an indicator of assessing agricultural sustainability and applied it to farms in the United States. ESI represents a group of 15 sustainability subindices including soil depth, soil organic carbon, bulk density and depth of ground water. Tellarini and Caporali (2000) used the monetary value and energy value to compare the sustainability of two farms, high-inputs and low-inputs in Italy. Gowda and Jayaramaiah (1998) used nine indicators, namely integrated nutrient management, land productivity, integrated water management, integrated pest management, input self-sufficiency, crop yield security, input productivity, information self-reliance and family food sufficiency, to evaluate the sustainability of rice production in India. Reijntjes et al. (1992) identified a set of criteria under ecological, economic and social aspects of agricultural sustainability. Ecological criteria comprise the use of nutrients and organic materials, water, energy, and environmental effects, while economic criteria include farmers’ livelihood systems, competition, factor productivity, and relative value of external inputs. Food security, building indigenous knowledge, and contribution to employment generation are social criteria.

Although a large number of indicators have been developed, they do not cover all the three aspects of sustainability, ecological, economic and social. Due to variation in biophysical and socioeconomic conditions, indicators used in one country are not necessarily applicable to other countries. Therefore, indicators should be location specific, constructed within the context of contemporary socioeconomic situation (Dumanski & Pieri, 1996). In Bangladesh, where the majority of farmers are smallholders, and average landholding size is less than one hectare, their immediate concern for agricultural development is how to increase crop yield, income, and food security and reduce the risk of crop failure. The overwhelming majority of farmers lack the capital required for the purchase of inputs, but normally have an adequate labor force. Thus, in view of biophysical and socioeconomic conditions in the study area, 12 indicators, representing ecological, economic and social dimensions of agricultural sustainability, have been selected for evaluation of the conventional and ecological agricultural systems. The relevance of the indicators to assess sustainability and their usefulness both from societal and farmers’ perspective were considered in selecting them.

(c) Framework for determining indicators

(i) Framework for determining ecological indicators

Ecological sustainability was assessed based on five indicators: land-use pattern, cropping pattern, soil fertility management, pest and disease management and soil fertility status. These indicators provide insight about cropping systems and land management practices which influence agricultural sustainability. Normally, there is a higher chance of agricultural sustainability with increasing cropping diversification, mixed cropping and use of organic fertilizers (Altieri, 1995; Edwards & Grove, 1991; Hossain & Kashem, 1997). On the other hand, increased land-use intensity, and application of inorganic fertilizers and pesticides jeopardize sustainability (Biswas, 1994; Conway, 1990; Repetto, 1987). (i) Land-use pattern was examined through proportion of land under field crops, homestead and orchard. The chi-square test was employed at $p < 0.05$ level to see the difference in land-use patterns between two agricultural systems. (ii) Cropping patterns were analyzed using three criteria: cropping intensity, crop diversification and mixed cropping. Crop diversification was measured through crop diversification index using the following formula:

$$ICD = 1/((P_a + P_b + P_c + \cdots + P_n)/N_c)$$

where, $ICD$ = index of crop diversification; $P_a$ = proportion of sown area under crop $a$; $P_b$ = proportion of sown area under crop $b$; $P_c$ = proportion of sown area under crop $c$; $P_n$ = proportion of sown area under crop $n$; $N_c$ = number of crops. Crops occupying less than three percent of cropped area were excluded from the analysis. The seven major crops, paddy, wheat, jute, potato, sugarcane, oilseeds and pulses, were taken into consideration. (iii) Soil fertility management was evaluated based on proportion of farmers using inorganic and organic fertilizers, i.e., farm yard manure and compost, and cultivating legume crops. In addition, proportion of area covered
by each type of fertilizer, including legumes, and amounts of inorganic and organic fertilizers applied per unit of land were considered. Chi-square and $F$ tests were employed to test the differences between ecological and conventional agricultural systems. (iv) Management of pests and diseases was assessed based on proportion of farmers using biological, mechanical, and chemical methods. The chi-square test was used to test differences between two systems. (v) Soil fertility was examined through chemical analysis of soil samples collected from both conventional and ecological agricultural systems.

(ii) Framework for determining economic indicators

Economic sustainability was measured based on three indicators: land productivity, yield stability and profitability. These three indicators reflect the financial health of an agricultural system. If an agricultural system does not provide sufficient food and income, farmers will not adopt it. It does not matter to them what ecological benefits that system may have. (i) Land productivity was measured through physical yield of crops. Crop yield data were collected through a household survey. The $F$ test was employed to test the differences in yields between two agricultural systems. (ii) The stability of crop yield was examined by constructing an index based on farmers’ subjective responses to a question related to yield trend. The index was constructed based on the following formula:

$$ITY = (f_i \ast 1 + f_d \ast -1 + f_c \ast 0)/N$$

where, $ITY =$ index of trend of yield, $f_i =$ frequency of responses indicating increasing yield, $f_d =$ frequency of responses indicating decreasing yield, $f_c =$ frequency of responses indicating constant yield, $N =$ total number of responses. (iii) Farm profitability was determined based on financial return, economic return and value addition per unit of land. Financial return was analyzed through gross margin, benefit-cost ratio and return to per unit of labor. Economic return was calculated by deducting the subsidy given to agricultural inputs from gross returns to adjust the transfer payments. As suggested by A.P.O. (1994), value added per unit of land was calculated by deducting the value of intermediate goods such as inorganic fertilizers, pesticides, diesel and agricultural equipment from the gross revenue.

(iii) Framework for determining social indicators

Social acceptability was assessed in terms of input self-sufficiency, equity, food security, and the risks and uncertainties involved in crop cultivation. These indicators are relevant both from societal and individual perspectives, as for long-term agricultural sustainability it is necessary to reduce dependency on external inputs, to minimize risks and uncertainties in farm production, and to attain food security and equity in the society (Ikerd, 1993; Pretty, 1995; Tisdell, 1996). Input self-sufficiency was determined on the basis of the ratio of local inputs cost to the total inputs cost. The higher the ratio of local inputs, the higher the input self-sufficiency. In view of the pervasive unemployment in rural areas of Bangladesh, the ability to generate employment within the system was considered as an indicator of equity effect. Family food security was assessed in terms of adequacy of food grain produced as well as farm households’ ability to purchase food grain required for consumption. Risks and uncertainties were examined based on cropping diversification and diversity of agricultural income. An index of risks and uncertainties was constructed using the following formula:

$$I_r = \sum_{i=1}^{3} (x_i - \bar{x})$$

where, $I_r =$ index of risks and uncertainties, $x_i =$ amount of income from the $i$th source, $\bar{x} =$ size of income at minimum risk level (when the proportion of income from three agricultural enterprises, namely crop production, orchard and livestock is equally distributed), and $\sum =$ summation of absolute deviation of $i$th income from the minimum risk level. The index value is zero when all agricultural enterprises contribute equally. The higher the degree of deviation, the higher the risk involved.

3. STUDY AREA AND DATA COLLECTION AND ANALYSIS METHODS

(a) Study area

To make a comparison at the micro level, two agricultural systems, one each with conventional and ecological agricultural system, were selected from Delduar subdistrict of
**Tangail** district. *Kandapara*, one of the 13 villages where *UBINIG* had promoted ecological agriculture, was selected as representative of the ecological agricultural system. *Tukhnikhola*, an agricultural system adjacent to *Kandapara* but without a, *UBINIG* project, was selected as representative of the conventional agricultural system (Figure 1). Both agricultural systems are located in the same agro-ecological zone, named *Young Brahmaputra* and *Jamuna Floodplain* (BARC, 1997), and comprise the same soil series no. 6 characterized by loamy and sandy loam with good water-holding capacity and moderately well drained (SRDI, 1990).

(b) **Methods of data collection and analysis**

Data were collected from both primary and secondary sources. Primary data were collected
from farmers through a questionnaire survey, observation and discussions with progressive farmers, farmers’ group, extension officials, women’s groups, and NGO workers. The survey was conducted in the agricultural year 1998. The sample size for the household survey was determined by using the formula given by Arkin and Colton (1963). Altogether, 45 households were surveyed from the ecological system and 65 from the conventional system, representing about one-third of the households of each farming system. Household sampling was done through a simple random sampling method.

Twenty soil samples, 10 from each farming system, were collected from randomly selected farm plots of sampled households. Leaving a 2.5-m area along the four sides of the sample field, nine well-distributed sampling spots were selected for soil sample collection. Soil samples were collected from a 0 to 20 cm deep plough layer from the designated spot by using an auger. These samples were air-dried and were mixed thoroughly to make a composite sample for each plot. Then, samples were collected from paddy fields about one month after harvesting of paddy. Each soil sample was divided into four equal parts from which two diagonal parts were retained and the remaining two parts were removed. This process was repeated until the successive quarter reduced to a weight of about 0.5 kg. The samples were then put into plastic bags and were properly labeled showing soil sample number, the farmers’ name and address, and date of collection. Then, the soil samples were brought to the laboratory of the Soil Resource Development Institute, Dhaka, for analyzing. A total of seven properties, viz. soil pH, nitrogen (N), phosphorous (P), potassium (K), sulfur (S), zinc (Zn) and organic matter content (OM), were analyzed.

4. RESULTS AND DISCUSSION

(a) Ecological sustainability

(i) Land-use pattern

Field crop production is the dominant type of land-use in both farming systems. Nearly 90% of the agricultural land in both systems has been utilized for crop production. The remaining area is utilized as homestead, orchard, and fishpond, without significant variation between the two farming systems. But, the average number of trees grown per households was also found to be significantly higher \( p < 0.10 \) in the ecological system (25) than in the conventional system (17). The greater number of trees in the ecological system is partially attributed to the need for biomass to prepare compost to apply to the cropland, and partially to the objective of NGOs to diversify household income. Relatively more trees on the homestead help farmers not only to meet biomass requirement but also to fulfill households’ fruit and fuel wood requirements and earn cash income.

(ii) Cropping pattern

The main crops cultivated in both systems are paddy, wheat, jute, potato, sugarcane, mustard, groundnut, til (Sesamum indicum), masur (Ervum lens), khesari (Lathyrus sativa), blackgram (Cicer arietinum), and vegetables. Cereal crops, mainly paddy, occupy more than two-thirds of the cropped area. Considerable variation was found in the cropping patterns of the two systems. More than half of the cropped area is occupied by HYV paddy in a conventional agricultural system compared to about one-third in the ecological system. More than 10% of the cropped area in the ecological system is occupied by sugarcane, while this crop accounts for less than one percent of the area in the conventional system. Pulses, including masur (Ervum lens), khesari (Lathyrus sativa), blackgram (Cicer arietinum) represented more than 10% of the cropped area in the ecological system against less than 1% in the conventional system. The average land area used for HYV paddy, potato and oilseeds was found to be significantly \( p < 0.10 \) higher in the conventional farming system, whereas the area under sugarcane, pulses, jute and local paddy found significantly higher \( p < 0.05 \) in ecological system.

Variation was also found in cropping intensity, crop diversification and mixed cropping (Table 1). Cropping intensity in the ecological system was found to be higher than in the conventional system, and even higher than the national average cropping intensity of 1.76 (Rahman & Thapa, 1999). The higher cropping intensity is attributed to the practice of intercropping of legumes with sugarcane and local paddy, as well as cultivation of these crops in the dry winter season (November–March) between two main crops. Relatively more highly cropped area under sugarcane, local paddy and jute facilitates farmers to practice these cropping.
Crop diversification and mixed cropping, as well as cultivation of legume crops, suggest that cropping patterns are relatively superior in the ecological agricultural system. In particular, cultivation of legume crops contributes nitrogen, organic matter and other plant nutrients to the soil, and helps restore phosphorous and potassium extracted by crops (Islam, 1989; Mahmud, Rahman, & Johir, 1994; Wahab & Mohammad, 1954). Jute adds relatively more biomass (7.79–8.55 t dry matter/ha) to soil than paddy (1.14–2.93 t dry matter/ha) (Hossain et al., 1994). On the other hand, modern varieties of crops use relatively greater amount of nutrients than traditional varieties (BARC, 1997; Gowda & Jayaramaiah, 1998; Hossain & Kashem, 1997). The relatively greater proportion of land under jute, pulses and local paddy is an indication of relatively large amounts of biomass and plant nutrient to the soil in the ecological system. This conclusion is reinforced by our soil test results (Table 3). Likewise, the relatively high degree of cropping diversification in this type of system is conducive to making efficient use of different types of nutrients available in soil and to increasing bio-diversity (Dahal, 1996). Crop diversification reduces the risk of crop failure, thereby making farms less vulnerable to food shortage. Mixed cropping, which is found relatively more frequently in the ecological system, enhances bio-diversity, in terms of both habitat structure and species, and soil quality, and helps to control pests and diseases (Stinner & Blair, 1990).

(iii) Use of organic fertilizers
Declining soil fertility has been the major concern for agricultural sustainability in Bangladesh. It is believed that declining land productivity can, to a considerable extent, be attributed to the lack of adequate amounts of organic matter in soil (BARC, 1997; Hossain & Kashem, 1997). Traditionally, farmers used to apply farmyard manure (FYM) and mulch crop residues to land to enhance soil fertility. This tradition has been abandoned gradually due to reduced livestock herd size and increased use of dung and crop residues as fuel. As a result, most soils in Bangladesh have organic matter content less than 2%, some soils have even less than 1% (BARC, 1997; Hossain & Kashem, 1997). A significant variation ($p < 0.01$) was found between two systems in the use of organic fertilizers (Table 2). Nearly all farmers in the ecological system are applying organic fertilizers to about two-thirds of their land holdings, while only 20% of the farmers in the conventional system are applying organic fertilizers to about 10% of their farmlands (Table 2).

Significant variation ($p < 0.05$) was also found in the amount of organic fertilizers used (Table 2). In the ecological system, both FYM and compost are being applied at a much higher rate than in the conventional system.

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<tr>
<th>Agricultural systems</th>
<th>Organic fertilizers</th>
<th>Inorganic fertilizers</th>
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<tr>
<td></td>
<td>FYM used in percentage of land (Amt t/ha)</td>
<td>Compost percentage of total land (Amt t/ha)</td>
</tr>
<tr>
<td>Ecological</td>
<td>52 (10)</td>
<td>63 (19)</td>
</tr>
<tr>
<td>Conventional</td>
<td>10 (7)</td>
<td>1 (14)</td>
</tr>
</tbody>
</table>

The higher the index values, the higher the cropping intensity, crop diversity and mixed cropping.
Student $t$-test revealed the variation in the use of FYM and compost is significant ($p < 0.01$). This combined with the relatively high degree of mulching practice in the ecological system has led to the relatively high amount of organic matter content in soil (Table 3). Organic matter in the soil contributes to improve soil structure and productivity (Poincelot, 1986), as well as enhances the disease-resistant capacity of crops (Kotschi, Adelhelm, & Ann Hoesle, 1989). By recycling biomass added in soil, the ecological system is providing global environmental services, as this contributes to sequestrate carbon in soil.

(iv) Use of inorganic fertilizers

Most farmers in the conventional systems, and 80% in the ecological system, are applying inorganic fertilizers to their farmlands. The intensity of fertilizer use is, however, significantly higher ($p < 0.05$) in the conventional system (Table 2). Although the use of inorganic fertilizers is about 40% lower in the ecological system, still the absolute amount used is considerably high. Ecological farmers said that they are gradually reducing the use of inorganic fertilizers, as drastic reduction may badly affect crop yield, thereby jeopardizing their livelihood. According to conventional farmers, however, they have had to apply increasingly large amounts of inorganic fertilizers over the successive years to maintain the yield due to gradual deterioration of soil quality because of continuous cultivation of rice with irrigation and overuse of inorganic fertilizers. Farmers in other parts of Bangladesh have had similar experience (Hossain & Kashem, 1997; Rahman & Thapa, 1999).

Moreover, farmers in the conventional system are not applying fertilizers in a balanced way. N and P were found to be higher (227 and 74 kg/ha, respectively) than the recommended dose (158 and 37 kg/ha, respectively). The same situation is prevailing almost all over the country. In Bangladesh, the use of N is about one-third higher than that of on average of Asia (106 kg/ha against the recommended dose of 83 kg/ha), and about double than the world average, whereas the application of P and K is significantly lower than that of Asia and the World (Qureshi, 2002). N:P:K ratio in Bangladesh is 1:0.15:0.08, whereas in Asia and the World this ratio is 1:0.39:0.16 and 1:0.41:0.28, respectively. Such imbalanced use of inorganic fertilizers leads to depletion of N, K, and S, and accelerated soil acidity (Conway, 1990; Hossain et al., 1994; Pagliola, 1995; Sattar & Mian, 1999). Besides soil quality deterioration, this trend would eventually make farming economically unviable by demanding increased inputs and eroding farmers’ profit margin.

Would reduced application of inorganic fertilizers (about two-fifths) in the ecological system adversely affect soil nutrient levels in the long-term, as rice being a fibrous crops takes large amounts of nutrients? Evidence from Bangladesh (Hossain & Kashem, 1997), China (Wu, Xu, & Wu, 1989), Kenya (De Jager et al., 2001), Madagascar (Stoop, Uphoff, & Kassam, 2002), West Africa (Ouedraogo et al., 2001) and the United States (Pimentel, Culliney, Buttler, Reineman, & Beekman, 1989) suggest that soil fertility and productivity can be maintained and even improved by substantially reducing the external inputs if soil, water and biological resources are managed properly. Organic fertilizers though contain low percentage of energy, but they provide a variety of micronutrients to the soil in addition to contributing to good soil structure. Improved

<table>
<thead>
<tr>
<th>Soil properties</th>
<th>Soil test value</th>
<th>Interpretation$^a$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ecological system</td>
<td>Conventional system</td>
</tr>
<tr>
<td>pH</td>
<td>5.67</td>
<td>6.24</td>
</tr>
<tr>
<td>Organic matter (%)</td>
<td>2.32</td>
<td>1.08</td>
</tr>
<tr>
<td>Nitrogen (%)</td>
<td>0.12</td>
<td>0.09</td>
</tr>
<tr>
<td>Phosphorous (mg/g soil)</td>
<td>2.49</td>
<td>4.00</td>
</tr>
<tr>
<td>Potassium (mg/g soil)</td>
<td>0.12</td>
<td>0.04</td>
</tr>
<tr>
<td>Sulfur (mg/g soil)</td>
<td>45.70</td>
<td>39.61</td>
</tr>
<tr>
<td>Zinc (mg/g soil)</td>
<td>0.92</td>
<td>0.18</td>
</tr>
</tbody>
</table>

$^a$Interpretation was based on SRDI (1990) and BARC (1997).
structure helps to increase water-holding capacity of soil, improve root development of crops, enhance biological activities in soil, and prevent nutrients leaching. In addition; good soil structure acts as buffer against acidity, alkalinity, and other toxicity in soil (Altieri, 1995; Conway, 1990; Hossain & Kashem, 1997; Ouedraogo et al., 2001; Repetto, 1987).

(v) Soil fertility status

As mentioned above, soil fertility in the study area is evaluated on the basis of soil pH, and organic matter content (OM), available nitrogen (N), phosphorous (P), potassium (K), sulfur (S) and zinc (Zn). Soils in the conventional system contain higher pH and phosphorous, whereas soils in the ecological system have higher amounts of organic matter, nitrogen, potassium, sulfur and zinc (Table 3). Thus, soil fertility in the ecological farming system is better than in the conventional system. Organic matter content not only influences soil productivity but also improves its texture and structure. It helps to reduce leaching of nutrients, increases water holding capacity, supports the activities of microorganisms, improves drainage, reduces erosion and promotes plant hormones (BARC, 1997; Dahal, 1996). Nitrogen also is an indicator of soil fertility as its requirements for most of the crops are high and considered as a major determinant of growth and yield of crops (Hossain & Kashem, 1997).

(vi) Pests and diseases management

There is significant variation ($p < 0.01$) between the two agricultural systems in pest and disease control practices. Nearly all farmers in the ecological system are controlling pests and diseases by weeding and cultivating crops in time, catching insects using nets and light traps, and by applying herbal insecticides. By contrast, 90% of conventional farmers are using inorganic pesticides. Only 8% of the farmers are using both insecticides and other measures to control insects.

The type of insecticides used is also a matter of concern. Most farmers use Diazinon and Malathion, belonging to the organophosphate group, are highly toxic to almost all animals and humans, and are extremely to moderately hazardous (WHO, 1984). Chronic exposure to organophosphate can result in severe illness or death (Metcalf & Muller, 2000). Indiscriminate use of pesticides and insecticides causes many adverse effects, including soil and water pollution, and sickness among farmers (Sattar & Mian, 1999). Farmers in the conventional system reported that they have had to increase the dosage and frequency of insecticides application. As a consequence, they are facing problems that include earthworms, fish and frogs dying, diarrhoea, skin diseases, headaches and declining soil fertility. Similar experience was reported by Rahman and Thapa (1999) in Jamalpur, Jessore and Comilla regions of Bangladesh.

(b) Economic viability

(i) Productivity

The average yields of major crops in the conventional system were found to be higher than in the ecological system (Table 4), although the difference is not statistically significant. This can be attributed to the application of significantly higher amounts of inorganic fertilizers and pesticides by farmers in the conventional system. But, farmers in the conventional system mentioned that yields of staple crops were gradually decreasing due to overuse of inorganic fertilizers and pesticides. This is clearly an indication of unsustainability.

(ii) Stability of the yield

The index of yield stability constructed following the method described in Section 2(a)

<table>
<thead>
<tr>
<th>Crop name</th>
<th>Ecological system</th>
<th>Conventional system</th>
<th>Relative (conventional = 100)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paddy HYV (Boro*)</td>
<td>4,594</td>
<td>4,910</td>
<td>94</td>
</tr>
<tr>
<td>Paddy local</td>
<td>1,998</td>
<td>2,011</td>
<td>99</td>
</tr>
<tr>
<td>Wheat</td>
<td>1,914</td>
<td>2,034</td>
<td>94</td>
</tr>
<tr>
<td>Jute</td>
<td>1,890</td>
<td>1,912</td>
<td>99</td>
</tr>
<tr>
<td>Potato</td>
<td>11,255</td>
<td>12,093</td>
<td>93</td>
</tr>
<tr>
<td>Pulses</td>
<td>725</td>
<td>733</td>
<td>99</td>
</tr>
<tr>
<td>Mustard</td>
<td>780</td>
<td>812</td>
<td>96</td>
</tr>
</tbody>
</table>

*Boro = paddy cultivated in winter season with irrigation.
revealed a negative trend for all crops, in both systems, but with the exception of HYV paddy in the ecological system. The overall index value for all crops was found to be −4.12 in the conventional system, as against −2.25 in the ecological system, indicating a considerably higher rate of yield decline in the former system. This finding is consistency with what farmers said during discussions with them.

Official agricultural statistics for the district under the scope of this study are not useful to substantiate the above findings, as field-level staff responsible for data collection have a tendency to inflate production figures, because their work performance is evaluated based on these figures. But, information provided by the farmers do justify that crop yields are gradually going down. In 1987, the average yield of paddy was 5.58 t/ha in conventional agricultural system and 5.52 t in ecological system. By 1998 the yield of paddy had declined to 4.91 t in the former system and 4.59 t in the later. This is corroborated by findings of an empirical study conducted in the neighboring Jamalpur district (Rahman & Thapa, 1999).

(iii) Profitability
Profitability was analyzed from both individual and societal perspectives. Because of time and budget constraints, it was not feasible to analyze the profitability of all crops. Instead, HYV paddy was used for the profitability analysis, as it is the major crop in both agricultural systems. Costs and returns were analyzed based on variable costs, including costs of human labor, animal power, power tiller, seed, fertilizers, pesticides, and insecticides, irrigation water, and interest on operating capital. Costs of inputs were computed on the basis of respective market price whether they have supplied from home or purchased. The cost of family labor was calculated on the basis of the prevailing wage rate. Gross return was determined based on reported crop yield and the farm gate price.

Financially, the conventional system is performing better than the ecological system (Table 5). The gross profit margin was found to be 6% higher in the conventional system than in the ecological system. Labor is the major variable cost in both systems. The total variable cost was found to be slightly lower in the ecological system (Table 5), due to relatively lower

<table>
<thead>
<tr>
<th>A Financial</th>
<th>Ecological system</th>
<th>Conventional system</th>
<th>Relative (conventional = 100)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Gross return (Taka/ha)*</td>
<td>27565.00</td>
<td>29462.00</td>
<td>94</td>
</tr>
<tr>
<td>2. Total variable cost (Taka/ha)</td>
<td>22447.00</td>
<td>23569.00</td>
<td>95</td>
</tr>
<tr>
<td>3. Return to per unit labor (in Taka)</td>
<td>174.03</td>
<td>191.96</td>
<td>91</td>
</tr>
<tr>
<td>4. Operating capital–output ratio</td>
<td>0.78</td>
<td>0.77</td>
<td></td>
</tr>
<tr>
<td>5. Gross margin (Taka/ha)</td>
<td>5118.00</td>
<td>5893.00</td>
<td>87</td>
</tr>
</tbody>
</table>

Economic (Taka/ha)

| 7. Subsidy on inorganic fertilizers | 282.00 | 479.00 |
| 8. Net returnb | 4836.00 | 5414.00 | 89 |

Value addition (Taka/ha)

| 9. Cost of inorganic fertilizers | 1912.00 | 3255.00 | 59 |
| 10. Cost of pesticides | 0.00 | 630.00 |
| 11. Cost of diesel and charge of agricultural machinery used | 2398.00 | 2554.00 | 94 |
| 12. Cost of intermediate goodsc | 4310.00 | 6439.00 | 67 |
| 13. Value addition per acre (1–12)d | 23255.00 | 23023.00 | 101 |

a Taka 1 = US$ 0.021 (in 1998).
b Gross margin—subsidy.
c Cost of inorganic fertilizers, pesticides, diesel fuel and agricultural machinery hire.
d Total return—cost of intermediate goods.
use of agrochemicals. As a result, both gross margin and return per labor unit in the ecological system are lower than in the conventional system. But, the benefit–cost ratio is almost the same in both systems, indicating that the return per unit of investment in the conventional system is not as attractive as normally thought. Ecological farming is expected to be more attractive for farmers in the future, as increasingly health-concerned urban consumers may be willing to pay more for agrochemical-free products.

Financial return can be misleading, as it is based on market prices of inputs and outputs. Financial analysis does not reflect the real costs and benefits, as it overlooks the effects of taxes, subsidies, and other transfer payments on price (Williams, 1992). Assessment of economic viability of agricultural systems necessitates adjustments in transfer payment with price and cost. Economic analyses consider adjusted price, which is determined by subtracting subsidy provided to agriculture (Williams, 1992).

Inorganic fertilizers are subsidized in Bangladesh. Urea production is subsidized at the rate of Tk.1095/t, and imported urea was subsidized at the rate of Tk.1400/t (World Bank, 1998). On average, the subsidy on fertilizer was Tk.1.25/kg. Following Williams’ (1992) method, subsidy was deducted from the gross returns to determine economic return. The result of the analysis revealed an insignificant difference in economic returns between ecological and conventional systems (Table 5). Against the conventional belief, this finding suggests that ecological agriculture is as efficient as the conventional agricultural system, and can be an economically viable alternative to the conventional agricultural system, if market distortions created by subsidy are corrected. The subsidy on inorganic fertilizers encourages farmers to use more than optimal doses of fertilizers as happens in the conventional system. To assess economic viability, it is necessary to look into both tangible and intangible costs and benefits (Williams, 1992). If intangible costs of conventional agriculture such as declining crop yield and water pollution, and intangible benefits of the ecological agriculture such as improved quality of soil are taken into account, the ecological system would be economically superior to the conventional system. For instance, Brandon (1998) estimated that the loss of yield due to land degradation in Bangladesh is 2.5% per year.

(iv) Value addition

The agricultural sector uses inputs from industrial and service sectors, including inorganic fertilizers, pesticides, fuel and agricultural equipment. To determine the net contribution of agriculture to the whole economy, the value of inorganic fertilizers, pesticides, fuels, and other inputs from outside the agriculture sector has to be discounted from the value of the agricultural output (A.P.O., 1994). Accordingly, the value of intermediate goods such as inorganic fertilizers, pesticides, and diesel fuel were deducted from the total returns to determine the amount of value addition per hectare of land. The result of the analysis indicates insignificant variation between the two systems (Table 5). In fact, if the benefit of the value addition to the local society is considered, the ecological system turns out to be better as it utilizes more local resources that generate income and employment opportunities for local people.

(c) Social acceptability

(i) Input self-sufficiency

The high dependency on external inputs, such as inorganic fertilizers, pesticides, diesel, and irrigation water, increases farmers’ vulnerability to reduced profit, as they have no control over supply and price of inputs. Sustainable agriculture should seek to minimize the dependency on external inputs (Altieri, 1995; Ikerd, 1993; Pretty, 1995). There is considerable variation in the two systems in terms of dependency on external inputs. In the ecological system, there is a tendency to use more local inputs, i.e., labor, draught power, seed, organic fertilizers, and natural pesticides that account for about 66% of the total input cost. By contrast, the dependency on external inputs, i.e., inorganic fertilizers, pesticides, and diesel, and irrigation water, is greater in the conventional system, accounting for 80% of the total input cost (Table 6). What is the rationale for considering irrigation water as an external input? As it is in the entire country (Huda, 2000), ground water is the main source of irrigation in the study area, which is pumped out using diesel operated pumping sets due to lack of electricity. Diesel accounts for more than two-thirds of the cost of irrigation. Moreover, engines, their spare parts, and diesel fuel come from outside, which exposes farmers to the risk of rising production costs and dwindling profit margins arising from market distortions and
changing national and international trade. Therefore, it is justified to consider irrigation water as external input in the context of our study area. When all these above mentioned facts are taken into account, the ecological system clearly appears to be more self-sufficient in inputs than the conventional system.

(ii) Equity

About one-third of the rural people in Bangladesh are unemployed or underemployed, which is one of the major causes of poverty. Any activity that creates employment opportunities will have a higher equity effect, through a process of chain reactions across the rural economy. Thus, it is reasonable to consider labor requirements and labor cost per unit of output as indicators of the equity effect of any farming system.

Paddy is the most important crop in both agricultural systems. The cultivation of paddy is more labor intensive, though not significantly much greater, in the ecological system than to the conventional system (Table 7). As a consequence, both labor cost per unit of production and labor cost per unit of profit are higher in the former type of farming system. This implies that the ecological system has provided more equitable benefits to local people.

(iii) Risks and uncertainties

Agricultural activities in Bangladesh are frequently affected by natural calamities such as floods, cyclones, tornadoes, drought, and insects. Almost 50% of total land is flooded every year because of the concentrated rainfall during the monsoon period (Framjii, 1977). In the 1998 flood, 50% of Aman and Aus paddy was damaged (Shahabuddin, 1999). Cropping diversification helps farmers to minimize risk arising from natural hazards. In a situation of failure or damage to one crop, farmers will be able to gain some income from other crops in a diversified cropping system.

As reflected in the relative income from different agricultural enterprises, including field crops (Table 8), the ecological agricultural system is more diversified than the conventional agricultural system. Consistent with this, the risk analysis based on the method mentioned above revealed an index value of 0.74 for the former system and 0.89 for the latter system, implying that the conventional system is more vulnerable to the risk of economic loss.

(iv) Food security

Food security has remained one of the important concerns in Bangladesh due to very limited land for agricultural use and an ever-increasing population. Food security at the farm household level, according to FAO (1997), is a matter of individual households having being able to meet their daily food needs from their own production, or the means to obtain food from off-farm sources. Overall, farmers’ own food grain production in the conventional system can meet food requirements for 386 days as opposed to 324 days in the ecological system, although landholding size and land quality are almost identical in

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Ecological system</th>
<th>Conventional system</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Cost of all variable inputs (Taka/ha)</td>
<td>22447.00</td>
<td>23569.00</td>
</tr>
<tr>
<td>2. Cost of local inputs (Taka/ha)</td>
<td>16129.00</td>
<td>14862.00</td>
</tr>
<tr>
<td>3. Cost of external inputs (Taka/ha)</td>
<td>6318.00</td>
<td>8707.00</td>
</tr>
<tr>
<td>4. Input self-sufficiency ratio (2/1)</td>
<td>0.72</td>
<td>0.63</td>
</tr>
</tbody>
</table>

*a Local inputs include labor, draught power, seed, organic fertilizers, and natural pesticides.

*b External inputs include inorganic fertilizers, pesticides, diesel, and agricultural machinery.

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Ecological system</th>
<th>Conventional system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Labor requirement to produce 1 kg paddy (in man–days)</td>
<td>0.36</td>
<td>0.34</td>
</tr>
<tr>
<td>Labor cost per kg output (in Taka)</td>
<td>1.62</td>
<td>1.53</td>
</tr>
<tr>
<td>Labor cost per Taka of return</td>
<td>0.26</td>
<td>0.23</td>
</tr>
</tbody>
</table>

*Taka 1 = US$ 0.021 (in 1998).*
these two systems. This is mainly because in the conventional system, 79% of the land is used for food grain production, whereas 58% of the land is used for the same purpose in the ecological system. It should be noted, however, that the shortage of food grain in the ecological system is offset by income from other agricultural enterprises, including livestock and orchard. If the overall agricultural income is considered, there is no variation in food security between these two systems (Table 8). Moreover, due to the heavy emphasis on food grain production, conventional farmers have not been able to meet the requirement of all kinds of nutrients, including vitamins, proteins and fat required to keep the body healthy. Food security, in our opinion, is the farmers’ ability to meet the requirement of balanced diet available from their own farm or other sources. Because they grow pulses and oilseeds, and raise livestock, ecological farmers are consuming more balanced array of foods.

5. CONCLUSIONS AND POLICY IMPLICATIONS

The Green Revolution or the conventional technology is pervasive in Bangladesh, and efforts are being pursued to promote this technology to cope with the ever-growing demand for food grain. Scientific research findings on conventional agriculture have revealed that this type of agriculture has enabled farmers to fulfill their immediate needs at the cost of environmental degradation, thereby threatening the sustainability of the agriculture itself as well as the health of people consuming its products. Cognizant of this, some efforts have been made in Bangladesh during the past decade or more to promote ecological agriculture in the interest of sustainability and long-term well-being of people. In this regard, the ecological agriculture being promoted by UBINIG is a pioneering endeavor aimed at making agriculture environmentally sound, economically viable and socially acceptable.

The findings of this study reveal that even after 12 years of the implementation of the ecological agriculture promotion program, this type of agriculture is not different from the conventional agriculture, particularly in terms of land-use patterns, crop yields, stability of yields, risk and uncertainties, and food security. Likewise, there is no significant difference between the two agricultural systems in terms of financial and economic benefits, and value added. It should be noted that, although so far crop yield and stability in the conventional system have been maintained on par with the ecological system by applying ever-increasing amounts of inorganic fertilizers, farmers’ have experienced declining yields over successive years. Farmers mentioned that crop yields would decrease substantially, thereby jeopardizing their food supply, if the amount of fertilizers is not increased. This suggests a trend of agricultural unsustainability.

One of the main reasons why ecological farming has not been economically more attractive is that so far there is no difference in market prices of products from the two systems. UBINIG is presently running a shop of organic products in Dhaka. They offer farmers per kg one Taka higher than the local market price of rice and vegetables, and sell these farm produces at very low prices, resulting in small amount of profit. Still, there is very low demand for organic products due to poor publicity of advantages of such products and lack

<table>
<thead>
<tr>
<th>Enterprises</th>
<th>Ecological system</th>
<th>Conventional system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field crops</td>
<td>8843.0</td>
<td>9601.0</td>
</tr>
<tr>
<td>Cereals</td>
<td>5042.0</td>
<td>7664.0</td>
</tr>
<tr>
<td>Cash crops</td>
<td>3801.0</td>
<td>1937.0</td>
</tr>
<tr>
<td>Livestock</td>
<td>2110.0</td>
<td>1550.0</td>
</tr>
<tr>
<td>Orchard</td>
<td>650.0</td>
<td>550.0</td>
</tr>
<tr>
<td>Total income</td>
<td>11603.0</td>
<td>11701.0</td>
</tr>
</tbody>
</table>

Table 8. Average household income*

*Income is calculated based on households reported income from different enterprises maintaining capital stock.

**Taka 1 = US$ 0.021 (in 1998).
of formal certification. Most consumers in Bangladesh are as yet little concerned about the health effects of agrochemical-based products yet. In the future, ecological agriculture will probably be economically attractive as increasingly health-concerned urban people may be ready to pay higher prices for produce free of inorganic fertilizers and toxic pesticides. Promoting ecological agriculture requires changes in consumption patterns from eating agrochemical-based products to organic products. In this regard, it is necessary to make people aware of advantages of organic products and disadvantages of inorganic products through mass media and educational campaigns. Own life is dear to most human beings; everybody wants to live a healthy and long life. Capitalizing this human characteristic, awareness creation programs should highlight health effects of organic products, so that consumers will be increasingly attracted to such products.

Regarding cropping patterns, there is no significant variation in terms of area under different types of crops, as the major percentage of landholdings are still being cultivated with paddy in both conventional and ecological farming systems. Significant variation was found if varieties of crops cultivated are taken into consideration. Because of the promotional efforts made by the project, the ecological system is considerably more diversified than the conventional system, which is a step toward sustainable agricultural systems.

Significant variation between the conventional and ecological systems is reflected in the use of inorganic fertilizers and insecticides, which are the primary causes of land, water and atmospheric pollution, as well as degradation of food quality. Although the majority of ecological farmers still apply inorganic fertilizers, the amount that they apply is significantly lower than the amount that conventional farmers use. The most remarkable achievement made by the project in the ecological farming system is that only a few farmers are applying insecticides to crops. Using their indigenous knowledge, most farmers control insects through the use of herbal insecticides and other measures, including traps. These qualities have made the ecological system environmentally more sustainable than the conventional system. Moreover, the ecological system has provided environmental services to the society by reducing the use of inorganic fertilizers and by carbon sequestration in soil. In addition the ecological system is considerably less dependent on external inputs than the conventional system, thereby reducing farmers' vulnerability to external forces.

The findings of this study suggest that the agricultural system being promoted by UBINIG is so far not very ecological in the strictest sense. But it has many advantages over conventional agriculture, as it provides improved quality of foods, conserves resources and environmental quality, without compromising output and financial benefits. Relatively higher yields and financial returns in the conventional system accrue through the application of much higher amounts of inorganic fertilizers and pesticides, which have resulted in severe costs on the environment and society. If these costs and benefits are taken into account, the ecological agricultural system would be even better both financially and economically. To make this agricultural system a financially attractive activity, these costs have to be accounted in cost–benefit analyses, as degradation of natural and environmental resources reduces productivity and longevity of these resources and ultimately adversely affects the sustainability of the system (Tisdell, 1996).

The most serious challenge for policy-makers in Bangladesh is how to reduce dependency on inorganic fertilizers and pesticides and maintain soil fertility to provide sufficient food and income to farmers without degrading environmental quality. Possessing very small landholdings, on average less than 0.1 ha per capita, farmers have to at least maintain the present level of crop yield. Since today's food security is more important than tomorrow's for these farmers, they cannot reduce the amount of inorganic fertilizers unless effective biological means of soil fertilization are available. Discussions held with farmers revealed their concern about long-term negative implications of the application of inorganic fertilizers at an ever-increasing rate. Still they cannot avoid this, because of the lack of alternatives, on the one side, and the risk of food shortage, on the other.

Crop diversification, integrated nutrient management, and balanced use of inorganic fertilizers contribute to maintaining soil fertility. Although a large number of crops, including spices, vegetables, pulses and oilseeds, appear financially superior than rice and wheat (e.g., Biswas & Mandal, 1993; Mahmud et al., 1994; Rahman, 1998), these two cereal crops are being cultivated continuously year after year due to inadequate extension, research,
marketing and credit facilities, and farmers’ concern about food security. Since so far cereals have been the main thrust of research and extension programs, little attention has been paid to other crops, despite their great potential to increase farmers income and maintaining soil fertility. Changing the policy thrust from gaining self-sufficiency in food production to agricultural development according to local comparative advantages and reorienting research, extension and other institutional support, including credit and marketing facilities, will help to promote crop diversification as well as increase farmers’ income. Despite not producing food by themselves, increased farm income would enable farmers to purchase adequate food and other daily necessities.

Provision of alternative sources of energy, efficient use of biomass fuel through the promotion of improved stoves, and promotion of multipurpose agroforestry species will help control the use of biomass and manure, and increase the supply of FYM required to maintain soil structure and fertility. Compost is considered to be better than FYM in terms of nutrient contents. Farmers should therefore be trained and encouraged to make compost-utilizing biomass and animal wastes available in their farms. Application of FYM to crops was a long-established common practice of farmers in Bangladesh. This practice has been considerably reduced, as in the absence of alternative affordable fuels, crop residues, manure and other biomass are being used as fuel for cooking and heating.

Overuse and inappropriate use of inorganic fertilizers and pesticides are largely due to market price distortions and lack of knowledge about adverse impacts of these products, stemming from policy failure to address these issues and provision of inadequate extension services. Inorganic fertilizers subsidizes increase the marginal return of using additional units of inorganic fertilizers over marginal cost that encourages the overuse of inorganic fertilizers. This is further reinforced by farmers’ lack of awareness of adverse impacts of overuse and imbalanced application of agrochemicals. Although it is trying to phase out direct subsidies on inorganic fertilizers, the government is still indirectly subsidizing inorganic fertilizers by making natural gas, which is an important ingredient of fertilizers, available at a highly subsidized price. The price charged for gas used for fertilizers, for example, is less than half the normal price of gas; and on average the subsidy on fertilizer is Tk.1.25 ($0.028)/kg (World Bank, 1998). Elimination of direct subsidy and gradual reduction of indirect subsidy on inorganic fertilizers along with the provision effective extension services will help to reduce the overuse and imbalanced use of inorganic fertilizers and pesticides.

Withdrawal or reduction of subsidies may not, however, be enough to motivate farmers to reduce the use of agrochemicals, as the major off-site costs such as water pollution, depletion of aquatic life and biodiversity caused by the overuse of agrochemicals are not borne by farmers. Moreover, due primarily to their small landholdings, particularly small farmers’ time horizons are much shorter and their discount rates much higher than those of society at large. Therefore, as in the case of developed countries, major policy reforms are necessary to divert financial benefits toward resource conserving farmers and provide more support to them through tax reduction or exemption, dissemination of information, extension, credit, research and marketing facilities. The challenge for policy makers in Bangladesh is how to implement and regulate policies, programs and support services in favor of farmers contributing to resources conservation and providing clean food by practicing ecological farming systems.

Given the small landholdings and large population, it is necessary to diversify the farming systems comprising livestock, fish raising, and agroforestry to make better use of available resources and to gain their synergetic effect. Rice–fish culture has, for example, proved potential to increase farmers’ income and nutrition status substantially as well as to maintain environmental quality without hampering crop yield (Pretty & Hine, 2000). Livestock and agroforestry also have potential to improve farmers’ income and stability by efficient use of resources, but so far farmers have not adopted these practices much due to limited knowledge and skill, and unavailability inputs credit and other support services. Proper policy and institutional support along with coordinated efforts with NGOs will help to promote diversified ecological farming, resulting in increased high-value products and farmers’ income.

Sustainable agriculture, indeed, demands intimate knowledge and information about crop, soil, pest, insects, market, price and environment. Dissemination of knowledge and other information through existing government
extension agencies does not seem to be efficient and effective, because of lack of motivation and inadequate number of extension staff, arising from a number of factors, including low salary. Overdependency on external agencies including extension department, input dealers, make the extension system unsustainable. Therefore, attempt should be made to build and enhance social capital by organizing farmers in groups, encouraging farmers to farmers extension and sharing information conducive to build cooperation, trust, reciprocity and cohesiveness among farmers, which facilitate social institutions, common rules, norms and sanctions of behavior (Pretty & Ward, 2001). This will ultimately help to share knowledge and experiences, to take common decision to promote sustainable agriculture, such as adoption of IPM, better management of irrigation water, tree plantation and other common benefit providing initiatives, which cannot be undertaken by an individual farmer.

NOTES

1. Conventional agriculture is defined as the agricultural system which is generally practiced. But different people characterize it in different ways. Hansen (1996) characterized it as capital-intensive, large-scale, and highly mechanized agriculture with monoculture of crops and extensive use of agrochemicals. Pretty (1995) characterizes it as an intensive industrialized farming system with high levels of external inputs, and resource degradation. In this paper, we used conventional agriculture to refer the agricultural system broadly characterized by intensive use of land with high external inputs, and low use of on-farm resources, as majority of farmers adopted this type of agriculture.

2. Bangladesh being one of the most densely populated countries of the world (865 persons/km²), has one of the lowest land–person ratios of about 0.06 ha (Ali, 1995; UNDP, 1995). The high population growth (around 2% annually) further reduces the availability of land for agriculture by creating increased demand for land for settlements, roads, industry, and other nonagricultural uses (Ali, 1995; FAO, 2000; Rahman & Thapa, 1999).

3. Ecological agriculture is defined as abstaining from using all inorganic fertilizers and pesticides and in that sense UBINIG’s agricultural system is not ecological as it uses inorganic fertilizers. But, ecological agriculture, synonymous with “regenerative agriculture,” “organic agriculture,” or “low input agriculture,” “alternative agriculture,” is a diversified system that emphasizes the incorporation of natural resources in the production process and makes better use of local resources and conserve and manage resources by rational use of external inputs to make the agriculture environmentally and economically sustainable. In this paper, we use the term ecological agriculture as synonymous with the above mentioned agricultural systems.

4. The difference between conventional and ecological agriculture is both means and ends. While the object of the conventional system is to maximize yield and profit by exploiting resources as much as possible, the aim of the ecological system is to attain long-term sustainability of yield and profit by rational use of resources and judicious mix of internal and external resources. For details see Lockeretz (1989), Pretty (1995) and Zhengfang (1995).

5. The major policy thrust of Bangladesh agriculture for the last few decades has been gaining self-sufficiency in food production. Food self-sufficiency is equated with food security. The findings of the study indicate that although food production is relatively greater in the conventional system, there is no difference between the two systems in terms of food security. Although, total rice production increased slightly from 1989 to 1999, 0.8% annually (FAO, 2000), production of pulses and oilseeds largely declined and their import increased. Imports of pulses almost doubled between 1991–92 and 1997–98, from 56,000 to 108,000 t. Oil seeds imports increased about three times from 15,000 to 309,000 within the same period (Majumder, 2002).

REFERENCES


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