A COMPARISON BETWEEN ECOLOGICAL AND CONVENTIONAL RICE FARMING SYSTEMS IN BANGLADESH

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ABSTRACT

General trends in Asia indicate that rice yields are declining. Long-term research plots in experimental stations, which tend to give greater yields than farmers' fields, have found they need to increase the fertilizer input to maintain yields. Similarly, farmers are finding it increasingly difficult to maintain productivity using current management practices, this is mostly due to a decline in soil fertility and organic matter. Integrated farming practices are now becoming more attractive to rural communities. Organic practices declined with the increased access to inorganic fertilizers, which provided a ready supply of nutrients to crops. In Bangladesh PROSHIKA, an NGO, has been promoting ecological farming as an integral part of their social development program. They provide information and training on organic management practices. This paper considers the effects on the soil properties of a minimum of 3 years eco-farming as compared with conventional farming practices. The investigation into the two farming systems is being conducted on farmers' fields in 4 different locations, e. g., Gabtali, Shibgonj, Daulatpur and Dhamrai, in Bangladesh. This 3-year investigation began in May 1997 and initially a base-line soil survey was conducted with samples from the plough layer taken from all 4 locations. The soils were analyzed for macro and micro-nutrients, together with physical properties. Physical and chemical properties associated with soil fertility were generally enhanced in fields under ecological management with soils having a better granular structure and being more friable than soils under conventional management. Soil bulk densities were significantly ($P<0.01$) lower, except at Shibganj, and CEC, BSP and exchangeable Ca^{++} contents were significantly higher in ecological fields than in conventionally managed fields. No impact of ecological management on total soil organic matter (OM) content was found, however the differences measured in other soil properties such as CEC may infer changes in the quality rather than quantity of OM in soil.

INTRODUCTION

Crop production and its sustainability depends on the status of soil fertility. Soil fertility is a function of the physical, chemical and biological properties of the soil environment. These properties together influence plant nutrient supply and subsequently crop productivity (Bhuiyan, 1999). Soil fertility, whether intrinsic or artificially maintained, is a major determinant of the success or failure of a crop production system.

The nature of changes in agricultural practice that led to the development of a double- and triple-cropped rice pattern in Bangladesh. Similar changes occurred in rice based cropping systems throughout Asia. There are concerns that in the 20-30 years that followed these changes, yields, particularly of rice, have declined (Cassman and Pingali, 1995). However, the evidence is not clear as much information of it from managed fields experimental stations. Anecdotal evidence from farmers suggests that productivity factors rather than yields may be changing, i.e. greater inputs (labour, fertilizer, pesticide etc.) are required to maintain the same level of yield. Declining crop productivity has been attributed to declining soil fertility in Bangladesh by many authors (Saunders, 1991; Bhuiyan, 1992; Ali, 1998), although none of these latter studies conducted a statistical analysis of the trend. Hence, research scientists and policymakers have mainly focused on the issue of soil fertility. It is not clear whether soil fertility is truly on the decline, but it is perceived to be the case because unexplained factors other than soil fertility are influencing yields.

There are however, some interesting features of farming in Bangladesh suggesting that farmers' may have a more complex view of soil fertility. For instance, it is common practice for farmers to remove surface soil from paddies to construct embankments, homesteads or for brick making. This may suggest that, (a) farmers may not realise that a decrease in soil fertility occurs with soil depth. Or this may be a strategy to remove soil where fertility has declined to access 'fresh' soil below, which they perceive to be more fertile; (b) the monetary return from the use of soil in this way has greater value than that of fertility for crop production; (c) soils perceived to be of low fertility are selected to be used as construction materials; and (d) farmer's recognized that soil fertility can be eventually replenished after removal of topsoil by the addition of vast quantitative of manure and inorganic fertilizer.

In Bangladesh soil fertility status is assessed by analysing (i) the total nutrient composition of soils (i.e. total N, P, K and S, and organic matter content) using strong acid digestion; (ii) the exchangeable base fraction (i.e. K^+, Ca^{++} and Mg^{++}) using ammonium acetate extraction; and (iii) cation exchange capacity using KCl. Soil fertility is classified on the basis critical limits (BARC, 1997). The categories - very high, high, optimum, medium, low, very low, used as the basis for making location specific and yields goal based on fertilizer recommendation for crops. Further, combined with land type (elevation), the soil fertility status is used to recommend cropping patterns. Soil chemical properties are markedly influenced by the pattern of pH change. For example, Ponnamperuma (1972) found that soil pH was highly correlated with exchangeable bases and the base saturation percentage (BSP). Therefore, soil pH and BSP may be important measurements of soil fertility. Soil organic matter influences soil physical, chemical and biological properties upon which soil fertility depends (Gaunt *et al.,* 1995). The BARC recommendations emphasise the soil nutrient status as the major determinant of soil fertility. However, soil physical properties are also important determinants of fertility. A well-granulated soil is considered to have the best structure for most crops, allowing free percolation of excess water and simultaneously enables roots to grow freely in the pore space between the soil aggregates (FitzPatrick, 1986). Further, anecdotal evidence from farmers in this study suggested that increasing hardness of soil is associated with a perceived decline in soil fertility.

The introduction of chemical fertilizers and the subsequent subsidises to farmers to ensure they were able to afford them has been a compounding factor that has influenced the use of organic matter within the farming systems (Khan *et al*., 1996). Past government policy emphasised the use of nitrogen fertilizers, but not of other nutrients, such as K and P. Farmers prefer to use chemical fertilizers particularly N, because of a quick yield response and reduction in labour required. Consequently, the application of organic manure in crop production declined. Despite this preference for fertilizers, farmers also say that the soil becomes ‘addicted’ to fertilizers, if they stop this organic matter input into the soil. Anecdotal evidence from farmers suggests that greater inputs (i.e. labour, fertilizer, pesticides etc.) may be required to maintain the same level of yield. These farmers report that the soil becomes hard due to a lack of OM inputs.

Concern about the reactive nitrogen load from agriculture has led to calls for greater utilization of organic N sources and regulations reducing N fertilizer use. “Organic” production systems rely entirely on organic N sources. While only 1% of the world’s cropland (about 16Mha) is currently under certified organic production, demand for organic food is expected to grow, especially in developed countries, and organic agriculture may become a more widespread alternative to traditional agriculture in the next 30 years (FAO, 2002). Although it is generally believed that organic agriculture offers many environmental benefits, the scientific basis for such a perception is weakly developed. Recent results indicate that controlling the fate of N from organic sources is just as difficult as managing the fate of mineral N fertilizer (Poudel *et al*., 2002).

Yield reductions are often associated with agricultural systems that follow organic practices (Mader *et al.,* 2002; Eltun *et al.,* 2002), and these systems appear to require both premium prices and government subsidies to remain economically viable. While this is feasible in industrialized countries, organic or low-input agriculture cannot secure the future food supply in the developing world, where maintaining low food prices contributes most to reducing poverty and increasing economic wealth (Dawe, 2002; Senauer *et al.,* 2001). Organic N sources are critical components of the agricultural N cycle and should be utilized when they are available and cost effective.

Scientists also report that rice yields may be declining under such intensive cultivation in several Asian countries including Bangladesh (Cassman and Pingali, 1995). However, the evidence on yield trends come from experimental stations rather than farmers fields. In response to such concerns, some organisations are promoting organic farming. For example PROSHIKA, a non-government organisation (NGO) recommends ‘ecological farming’ as an alternative to the use of chemical fertilizers. Ecological farming as promoted by PROSHIKA is based on use of ‘quick compost’ (a mixture of cow dung, rice bran and oil cake in the ratio 4:2:1) and recycling of plant residues to soils instead of reliance on chemical fertilizers and pesticides. Farmers are also encouraged to add more FYM, household wastes, oil cake and green manures. Farmers working with PROSHIKA pointed out that fields, which they converted to ecological practice, were relatively soft and more friable. They cited improvements in soil physical properties, described ease in ploughing and cultivation, and an increased biological activity as indicators of these changes. Given the concerns of scientists and farmers regarding the sustainability and profitability of rice based farming systems that are based on mineral fertilization, the manuscript examines soil fertility status of fields under current and ecological farming practices.

MATERIALS AND METHODS

This study is underpinned by the comparison of conventional and ecological management as practiced by farmers. Conducting such research may seem relatively easy, however, finding experimental sites on working farms, where soil forming factors are invariant and both farming system are in place, is difficult and yet necessary (Daniels *et al.,* 1987). In the four sites Dhamrai, Daulatpur, Gabtali and Shibganj, farmer’s fields under conventional, the farmers’ current practice using both organic matter inputs and agro-chemicals, and ecological management, where fields are managed using only organic matter inputs were selected after discussions with farmers. It should be noted that in both farming management, farmers also made variable inputs of organic matter, although management are almost in similar (Hossain, 2001). A maximum of ten fields for both conventional and ecological farming fields were selected at each site. Selected fields were a minimum size of 420 m^2, but on average were larger, about 739 m^2.

At each site ecological fields had been established by farmers working with PROSHIKA prior to this study. At Dhamrai, fields had been under ecological management for seven years; at all other sites fields had been under ecological management for between three and five years. Conventional fields selected next to the existing ecological fields, to create pairs on the same soil. In this way, it was possible to reduce site variability for samples taken within each site. If this was not possible samples were taken from ecological and conventional fields that were as close together as possible and judged to be on the same soil type (based on soil profile observation).

The validity of this research is based on the assumption that all soil properties within each experimental site were similar before first being cultivated or before the two management systems were in place. Historically, both systems had natural vegetation on them up to the time of establishment of the sites, after which both farming systems have had similar crop rotations throughout the period of study. Hence, it is assumed that changes in soil properties over time after the establishment of the experiments can be attributed to differences in land management.

A baseline survey of soils was conducted as specified by Anderson and Ingram (1993). Composite soil samp les were taken and archived from all monitoring plots. Soil samples were collected from a plough layer depth of 0-12 cm. Five samples were collected from each plot. These were mixed to obtain a composite sample and carried to the laboratory in labelled polythene bags. The soil samples were air dried at room temperature and ground to pass a 2 mm sieve (0.15 mm for organic C and total N determinations) and were stored in plastic containers. All physical and chemical analyses were done by the method described of Anderson and Ingram (1993).

RESULTS AND DISCUSSIONS

Soil consistencies in both dry and moist condition were also distinctly different between the two farming systems. Whereas structure deals with the shape, size and distinctness of natural soil aggregates, consistency is relevant to tillage and traffic by farm machinery, being related to forces of strength (Soil Survey Staff, 1951). Consistency is relevant to tillage and traffic by farm machinery; if it is too dry and hard, undue strain will be placed on the implements (FitzPatrick, 1986). The dry consistency of ecologically farmed soil was slightly hard (i.e. easily broken between thumb and forefinger). The conventionally farmed soils by contrast were hard to very hard (i.e. difficult to break down between thumb and forefinger) (Table 1). The moist consistency of the ecological farmed soil was friable (i.e. crushes easily under gentle to moderate pressure between thumb and forefinger), whereas conventional farmed soil was slightly firm to firm (i.e. crushes under moderate pressure between thumb and forefinger but resistance is distinctly noticeable). There were no distinct differences between wet consistencies (i.e. degree of stickiness and plasticity). Since soil consistency is a measure of the ease with which a soil can be reshaped or ruptured, mechanical tillage should be easier on the ecologically farming soil because it is less hard (when dry) and more friable (when moist). Such finding support the statements made by the farmers involved in the project.

Table 1: Structure and consistency of soils from all four sites.

Farming System	**Thickness**	**Structure**	**CONSISTENCY**		
	(cm)		**Dry**	**Moist**	**Wet**
Dhamrai					
Conventional	13	medium angular to subangular blocky	hard	slightly firm	slightly sticky, slightly plastic
Ecological	15	granular	slightly hard	friable	slightly sticky, slightly plastic
Daulatpur					
Conventional	14	subangular blocky to granular	hard	slightly firm	slightly sticky, slightly plastic
Ecological	15	granular	slightly hard	friable	slightly sticky, slightly plastic
Gabtali					
Conventional	11	angular to subangular blocky	hard to very hard	firm	slightly sticky, slightly plastic
Ecological	12	granular	slightly hard	friable	slightly sticky, slightly plastic
Shibganj					
Conventional	12	subangular blocky to granular	hard to very hard	firm	sticky, plastic
Ecological	14	granular	slightly hard	friable	sticky, plastic

**This table summarises from a large number of data.*

Soil structure can have a profound effect on the growth of crop roots and consequently on the crop plant as a whole. The lack of a good soil structure can result in poor crop establishment and may even lead to complete crop failure. This point is often over looked and in some cases can be an important limiting factor for plant growth, crop productivity and yield (Russell, 1973). Although the common practice of puddling soils for rice superimposes temporary changes in the morphological characteristics of a soil profile. Changes in morphology (structure and consistency) of soils, under waterlogged conditions, are often of minor taxonomic importance (Dudal and Moormann, 1964). Further, the characteristics observed above have practical implications with respect to the ease of cultivation of both upland and lowland crops. The plough layer of the ecologically farmed fields gave the impression that it was comparatively deeper by a few centimetres than the plough layer of the conventionally farmed fields. For example, topsoil (Ap1) thickness, represented by the mean depth of the plough layer, was almost 12-15 cm in the ecologically farmed fields and 11-14 cm in the conventionally farmed fields (Table 1). However, on further examination the difference in depth in the ecological fields was due to these fields having a lower bulk density leading to 'fluffiness' of the soil. In reality, there was no difference in plough depth between the two farming systems. In all subsequent calculations the mean value for plough layer depth of 12 cm was used this obtained by taking the means of both ecological and conventional farming systems. The depth of the plough layer is important because, the compacted plough pan has a profound effect on the growth of roots. In the rice crop it determines the volume of soil exploited by plant roots. Upland crops may penetrate the plough pan (depending on soil moisture). Further soil moisture retention is also a function of the depth of the plough layer, with deeper plough layers being less prone to drying out than shallow plough layers.

Comparing conventional and ecological fields at all sites there were no significantly differences in the particle size characteristics, except at Daulatpur where the ecological fields had significantly ($P<0.01$) more clay than conventional fields. The reason for this difference in clay content is not clear. It may be because although the fields were located close together, in a superficially uniform area, ecologically farmed fields were situated towards the centre of a basin. Clay serves as a binding agent in soil aggregate formation and stability because it interacts with organic and inorganic substances, thus affecting virtually all soil properties that are colloidal in nature (Christoper, 1996). Further, it affects the physical characteristics of the soil. The evidence at Daulatpur may suggest that farmers select fields with particular characteristics to manage ecologically.

Bulk density was significantly lower ($P<0.01$) under ecological farming compared to conventional farming at all sites except at Shibganj (Table 2). Overall, ecological farming resulted in a wider range of BD (0.94g cm^{-3} to 1.31g cm^{-3}) as compared with conventional farming (1.07g cm^{-3} to 1.29 g cm^{-3}). The fields at Dhamrai had been under ecological farming for longer than any of the others (7 years from the start, compared to 3-5 years for the others), and they also had greater inputs of OM (Hossain, 2001). This is reflected in the magnitude of the difference (0.13) compared to Daulatpur (same region; 0.06) and Gabtali (0.07). The reasons for conflicting findings at Shibganj are not clear. The Shibganj site is located on the level Barind Tract and the soil at this site has a different parent material (Madhupur Clay), than the other three sites and these three sites derived from the same parent material (Brahmaputra Clay). Madhupur Clay differs in mineralogy from the Brahmaputra Clay containing less kaolinite. As a consequence this soil is susceptible to compaction and undergoes plastic deformation when wet, leading to increase in soil density (Ghildyal, 1978). This does not however explain why bulk density was lower in the conventionally managed fields. Thus as with the case of Daulatpur above it may be that farmers have selected fields with greater bulk density to manage under ecological practice.

However, overall these findings appear confirm farmers' perception that fields under ecological practice are less hard than fields under conventional practice and as a consequence are easier to cultivate. The frequent addition of easily decomposable organic residues leads to the synthesis of complex organic compounds that bind soil particles into structural units called aggregates (Marshall *et al.,* 1979). As discussed in earlier, both conventional and ecological management involves, in most cases, the incorporation of manures. Therefore, the mechanism by which management influences this soil property is not clearly associated with the quantity of organic matter added. It may be that differences in the quality rather than quantity of organic matter added may influence the soil physical properties (Gaur, 1998). Alternatively, it may be that the timing and rates of manure addition are important. PROSHIKA recommend a single relatively large application of compost to initiate ecological management (Hossain, 2001), this may have a greater impact on soil physical characteristics than regular but smaller additions (Arden-Clarke *et al.,* 1988). Alternatively, these differences may reflect inherent differences in the characteristics of fields selected by farmers for ecological management.

In the plough layers of both the conventional and ecological fields, the soil structures were found to be distinctly different to each other. Under the conventional management the soil was medium angular to sub-angular blocky and medium angular to granular whereas, under ecological management soils were granular (Table 1). A well-granulated soil is considered to have the best structure for most crops (Brady, 1984), allowing free percolation of excess water and simultaneously enables roots to grow freely in the pore space between the soil aggregates (FitzPatrick, 1986). Organic matter is the necessary precursor for granular type aggregation in soils (Brady, 1984), for example, plants root decay and other viscous microbial products (e.g. polysaccharides). These together with the disruptive action of root movement, the chemical properties of humus and clay, encourage granular aggregate development and stabilisation. Other factors affecting the genesis of granules are wetting and drying, freezing and thawing, and soil tillage.

Soil pH ranged from 6.10 to 6.40 at Dhamrai, 6.11 to 6.19 at Daulatpur, 5.73 to 6.13 at Gabtali and 6.08 to 6.03 at Shibganj sites (Table 2). At the Dhamrai (Koitta) site, on average ecological fields had significantly ($P<0.01$) higher pH (6.4) values compared to the conventional fields (6.10), whereas at Gabtali ecological fields had the significantly ($P<0.01$) lower (5.73 compared to 6.13, respectively) pH values. There was no significant difference in pH at the other two sites between conventional and ecological fields. Soil pH was significantly correlated with exchangeable bases, except at the Shibganj site (Ca^{++}; $r = 0.58^{*}$ and $r = 0.83^{***}$ at Dhamrai; $r = 0.57^{*}$ and $r = 0.75^{**}$ at Daulatpur; and $r = 0.80^{**}$ and $r = 0.20^{ns}$

at the Gabtali sites for both conventional and ecological farming, respectively; (data not shown). Application of mineral N fertilizers is likely to cause a reduction in soil pH due to the production of H^+ during nitrification in the soil compared to the addition of organic manures. This is a consequence of the more chemically reactive natures of inorganic fertilizers. Both hydrolysis of urea and breakdown of organic matter under flooded conditions produce carbonic acid. Urea that is added in conventional fields will dissolve and undergo enzymatic hydrolysis to $(NH_4)_2CO_3$ in the soil solution, which then immediately dissociates to NH_4^+ and CO_2 whereas microbial decomposition of organic matter produces CO_2. Carbon dioxide reacts with H_2O to form carbonic acid, which dissociates into H^+ and HCO_3^- ions causing acidification. Under aerobic conditions nitrification of NH_4^+ to NO_3^- leads to soil acidification. This process is regarded as important source of acidification of soils (Ponnamperuma, 1972). The leaching of Ca^{++}, Mg^{++} and other ions from the soil by water containing carbonic acid, tends to make the soil acidic (Manaham, 1994). The buffering capacity of a soil will counteract acidification. Thus, in addition to the dissociation of acidification due to breakdown of organic matter, as described above, organic manuring practices, which raise SOM levels, will enhance the soil's buffering capacity. This is reflected in the findings of Stoor and Alexander (1986).

The reasons for the contrasting results at Gabtali are not clear. Generally, FYM application does not have an unduly acidifying effect on the soil solution. However, an exception to this is poultry manure, which has particularly low calcium content, when compared to other manures, and therefore tends to acidify the soil (Arden-Clarke *et al.* 1988). The farmers at Gabtali reported using poultry litter as the principal ingredient in their manure. If this mechanism of acidification can be verified as the cause of the low pH under ecological farming at Gabtali, then this indicates the importance of providing guidance on the preparation of manures. However, at Gabtali topsoil had been removed from the ecological fields during 1995 to construct roads. Thus, the removal of soil that is typically enriched with organic matter may have led to a loss of buffering capacity.

Soil organic carbon, TN and C: N ratio comparing treatments, the SOC content of ecological fields was only significantly different from the current farmers practice at Daulatpur. At Daulatpur SOC was significantly ($P<0.01$) larger than that of conventional fields (24,000 compared to 17,000 kg C ha^{-1}, respectively; Table 2). However, it is not clear that the difference in SOC measured at Daulatpur directly reflects management because at Daulatpur, SOC was positively correlated with clay content ($r=0.85^{***}$ and $r=0.77^{**}$ for conventional and ecological fields, respectively; data not shown). As discussed earlier, the ecological fields at Daulatpur were located in the basin centre with higher clay content than the conventional fields. The concentration of OC was significantly ($P<0.01$) higher in ecological fields than in conventional fields (Table 2) at Dhamrai site. However, when the SOC was calculated in kg C ha^{-1} there was no significant difference between the two management practices because of the corresponding lowering of bulk density in ecological fields. All soils in this study fell into the low to medium percent carbon category above the critical limit set by BARC (1997). In Bogra district, the ecological farming fields at Gabtali and Shibganj tended to have a lower amount of SOC when compared with conventional farming fields at these sites (Table 2).

This research has reported beneficial differences in soil properties (structure, consistency, bulk density, pH, CEC and exchangeable Ca^{++}) that determine soil fertility in fields under ecological management when compared to conventional practice. The lack of sensitivity of SOC to these changes may suggest that SOC is an insensitive measure, in this situation, of soil fertility. Alternatively, it may be that the method of sampling and measurement used to determine SOC was not sufficiently sensitive to pick up changes. Total soil carbon and nitrogen turnover is slow and therefore less sensitive than lighter (active) organic fractions to management practices in tropical soils (Christensen, 1987). As both ecological and current practice involve adding similar quantities of organic matter to soil it is not surprising that difference in total SOC are not found. However measured differences in other soil properties may suggest differences in the quality rather than quantity of organic matter in soil. These findings do not represent a time sequence. Thus, they cannot confirm the reduction in SOM commonly postulated in conventional farming systems (Saunders, 1991; Bhuiyan, 1992; Ali, 1998). However, they do point to the fact that it is difficult to manage SOC in the farmers situation through application of moderately large amounts of manures or residues.

The total soil N content was significantly correlated to SOC, in both the conventional and ecological fields at Daulatpur ($r=0.89^{***}$ and $r=0.67^{*}$, respectively), at Gabtali ($r= 0.84^{***}$ and $r=0.87^{***}$, respectively) and at Shibganj ($r=0.76^{**}$ and $r=077^{**}$, respectively; data not shown). At all four sites and for both conventional and ecological fields, no significant relationship was found between total soil N and clay content. Differences in total soil N between ecological and conventional fields were not significant at any site, although total soil N was significantly higher at the Dhamrai and Daulatpur sites compared to the Gabtali and Shibganj sites. C:N ratio of soil provides an indication of the quality of organic matter. A low C:N ratio the soil suggests advanced decomposition of organic matter. A critical limit for the C:N ratio of 10:1 has been set by BARC as an indicator of SOM quality. The C:N ratios measured for all four sites were similar to the BARC critical limit of 10:1 (Table 2). The ecological management field had C:N ratios ranging from 9 to 11, whilst the conventional farming fields ranged from 7 to 12, with no significant difference between conventional and ecological farming practices. Strangely, BARC have given critical limits for soil parameters such as SOC and C:N ratio, which cannot be directly related to crop productivity and/or yields. Indeed their use in this context is highly questionable and incorrect, and leads one to suggest that BARC criteria and policy on soil fertility needs re-examination, re-evaluation and rewriting to reflect current advances in soil fertility research. Incorporating organic manures with a high C:N ratio may immobilise a proportion of the mineral N in soil, the proportion immobilised and the duration of immobilisation depending on the C:N ratio. Apparent N immobilisation was observed (based on crop colour) in fields under ecological management but this was not reflected in the soil C:N characteristics. This infers that the nature of the material added immediately prior to cultivation is the important determinant of N immobilisation in this situation. This is in contrast to the findings of Power and Doran (1984) who suggested that, one would expect the raising of SOM levels through incorporation of material with a wide C:N ratio, and an hence the increase in soil C:N ratio brought about by ecological farming techniques to decrease the levels of readily available N. The total P content of ecologically managed fields at Dhamrai, Daulatpur, Gabtali and Shibganj was not significantly different to their respective conventionally managed fields (Table 2). The total P content is higher than the BARC measured critical limit (BARC, 1997). There was no relationship found between total P and clay content.

Table 2: Physical and chemical properties of soils from all four sites.

Farming System	OC	TN	C:N	BD	CEC	K^+	Ca^{++}	Mg^{++}	BSP	P
	kg ha^{-1}			g cm^{-3}	$cmol^{(+)}kg^{-1}$	kg ha^{-1}			(%)	kg ha^{-1}
Dhamrai										
Conventional	18,000 ±4603	2200 ±94	8 ±2	1.07 ±0.01	18.19 ±0.37	99 ±4	1604 ±45	359 ±9	48 ±1	2900 ±91
Ecological	20,000 ±6258	2300 ±170	9 ±2	0.94 ±0.02	21.64 ±0.70	93 ±8	2103 ±140	385 ±12	60 ±3	3100 ±163
Probability	0.59	0.81	0.43	0.01	0.01	0.54	0.01	0.79	0.01	0.47
Daulatpur										
Conventional	17,000 ±5193	2300 ±125	7 ±2	1.29 ±0.01	21.65 ±0.67	110 ±7	1992 ±74	354 ±13	42 ±2	3100 ±140
Ecological	24,000 ±5822	2500 ±325	10 ±2	1.23 ±0.04	25.08 ±0.79	120 ±4	2391 ±245	479 ±34	44 ±4	3300 ±127
Probability	0.01	0.20	0.16	0.01	0.05	0.29	0.47	0.01	0.17	0.42
Gabtali										
Conventional	19,000 ±5888	1700 ±94	11 ±3	1.29 ±0.01	11.61 ±0.47	114 ±10	1693 ±82	369 ±20	67 ±3	2800 ±98
Ecological	16,000 ±5184	1800 ±147	9 ±3	1.22 ±0.03	13.10 ±1.52	128 ±20	1318 ±153	311 ±20	52 ±4	2700 ±140
Probability	0.68	0.84	0.11	0.01	0.56	0.41	0.05	0.67	0.05	0.33
Shibganj										
Conventional	20,000 ±3602	1700 ±73	12 ±2	1.28 ±0.01	13.89 ±0.46	146 ±11	1250 ±62	273 ±12	42 ±1	1800 ±40
Ecological	18,000 ±5676	1600 ±116	11 ±3	1.31 ±0.02	13.59 ±1.00	212 ±43	1645 ±201	271 ±50	51 ±4	1800 ±74
Probability	0.12	0.32	0.18	0.01	0.86	0.05	0.05	0.81	0.05	0.27

The cation exchange capacity determines the retention and availability of cationic macronutrients (K^+, Ca^{++} and Mg^{++}) necessary for crop production (Allison, 1973). The CEC is determined by the soils clay content and surface characteristics. Thus, logically the greatest CEC were measured in the Daulatpur soils (25.08 $cmol^+ kg^{-1}$) with the highest clay content. Comparatively lower CEC values were measured at Gabtali (11.61 to 13.10 $cmol^+ kg^{-1}$) and Shibganj sites (13.89 to 13.59 $cmol^+ kg^{-1}$; Table 2). Despite differences between sites, the CEC of all was medium to high (7.5 to 30.0 $cmol^+ kg^{-1}$; Table 9). The ecological farming systems had significantly higher CEC values at Dhamrai ($P<0.01$) and Daulatpur ($P<0.05$) compared to conventional fields. The CEC is strongly correlated with clay in conventional fields at Daulatpur ($r = 0.86^{***}$; data not shown). Thus, the CEC at Daulatpur reflects the greater clay content of the ecological practice fields as compared to the conventional fields.

It has been estimated that the organic matter content of mineral soils constitutes 30-60 % of the total exchange capacity of the soil (Allison, 1973), though VanDijk (1971) suggested that this could increase to 90 %. Increasing the soil organic matter therefore increases the CEC and the reservoir of available cations for crop production (Cooke, 1967). Studies on clay and organic matter content frequently tend to ignore the importance of cations in soil fertility. Within the CEC, and of the major cations, Ca^{++} was the most dominant base in the exchange complex for all soils (Table 8). The exchangeable Ca^{++} was significantly greater in soils under ecological farming at Dhamrai by 2103 kg ha^{-1} ($P<0.01$), at Daulatpur by 2391 kg ha^{-1} ($P<0.05$), and at Shibganj by 1645 kg ha^{-1} ($P<0.05$). Again at all sites these levels are higher than measured BARC critical limit (BARC, 1997).

The dominance of Ca^{++} exchange complex is reflected in the BSP values reported below. Conventional fields at Gabtali had the greatest BSP values. The next dominant base on the exchange complex was Mg^{++}, but this was only greater in ecological fields at Dhamrai and Daulatpur ($P<0.01$; Table 8). Again values were above the BARC critical limit (BARC, 1997). The measured K in soils was higher than BARC critical limit (BARC, 1997). However the only significant difference between ecological and current practice was measured at Shibganj ($P<0.05$). Again, presumably, a reflection of the greater clay content of the ecologically managed fields. The high percentage base saturation was reflected in the pH values reported earlier; exchangeable Ca^{++} and Mg^{++} buffered the soil pH to nearly neutral (Table 2). Measured pH was highly correlated with exchangeable bases and BSP except at Shibganj. This lack of correlation may reflect the different parent material at this site, as reported earlier. At Dhamrai ecological farming fields had on average significantly higher pH values (6.4; $P<0.01$), compared to conventional fields. Whereas, at Gabtali ecological farming fields had significantly lower pH values ($P<0.01$; Table 2). It should be noted that the lower BSP and exchangeable bases measured in ecological fields at Gabtali compared to current practice was reflected in soil pH reported earlier.

Overall, the fertility status of the soils studied was higher than the BARC critical limits, total P and the exchangeable bases in the fields studied were above the BARC critical limits and medium to high CEC values given BARC range. Moreover, at Dhamrai and Daulatpur, SOC and soil N content were also higher than the BARC critical limits (Table 2). It is common to hear from most farmers that their soils are not producing as much as they did in the past. All these indicate that fertility of Bangladeshi soils has declined considerably due to pressure on land use, inadequate amounts of manure applications and inappropriate soil management practices.

CONCLUSION

After 3-7 years under ecological management soils had significantly lower soil bulk density, a more granular structure and were more friable when compared to soils under conventional farming practice. Soil consistency in the dry and moist states was also different between both farming systems. Ecological farming had a better structure and consistency for crop root growth, than conventionally managed soil. These findings appear to confirm observations by farmers that fields under ecological farming are easier to cultivate and less hard. It does not however confirm that ecological management leads to improvements in soil physical and morphological properties, because farmers may have selected fields for ecological management, which were inherently fertile (or infertile), compared to fields selected for conventional farming. For instance at Gabtali fields were selected by the farmers for ecological farming where topsoil had been removed. The findings of this manuscript would be strengthened by elaborating with farmers, the management history of these fields and their rationale for selection of particular fields.

The total N, P, exchangeable K^{+}, Ca^{++} and Mg^{++} in the fields studied were significantly above the BARC critical limits and medium to high CEC values ranged BARC. However, individual measurements such as CEC do appear sensitive to management. Soil organic carbon was an insensitive measure, in this situation, of soil fertility. The reason for this is not clear, it may be that the method of sampling and measurement used to determine SOC was not sufficiently sensitive to pick up changes. Measured differences in other soil properties such as CEC may suggest differences in the quality rather than quantity of organic matter in soil.

From our study, observed that farmers use assessment of soil physical condition and colour to differentiate soils of differing fertility. This assessment appears justified based on the findings of this study. If a link can be made between farmers observations, measured soil properties and associated recommendations, these observations could form the basis of simple diagnostic indicators of soil fertility that do not require expensive and time consuming laboratory analysis.

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