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FINAL TECHNICAL REPORT

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Project title

Soil fertility and organic matter dynamics in floodplain rice ecosystems in Bangladesh.

Project leader

J.A.Rother

Organisation

Environmental Sciences Department,
Natural Resources Institute,
University of Greenwich.

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TABLE OF CONTENTS

Preface

This report is compiled from the work by project members of the four collaborating organisations:

1. Environmental Sciences Department, Natural Resources Institute, UK

J A Rother	Project Leader

2. PROSHIKA, Bangladesh.

Mobarak Hossain Khan Choudhury	Project Coordinator

PROSHIKA Senior management involved in planning activities:

Qazi Khazi Alam	(Director of Programmes)
Santosh C Sarkar	(Coordinator, Irrigation) Programme

3. Soil Science Department, Dhaka University, Bangladesh:

S F Elahi	Soil scientist; supervisor
Md Faruque Hossain	Ph.D. student
Nasrin Sultana	M.Sc. student

4. Soil Science Department, IACR-Rothamstead, UK:

John Gaunt	Co-leader, supervisor
Stephanie White	Post-Doctoral researcher

In addition to the staff named above, many field workers of the PROSHIKA Area Development Offices were involved in liaising with the farmers and collecting data and samples. Without their aid the project would not have been possible.

The project was centred on the on-farm research activities. The farmers who volunteered to work with us are listed in Appendix I.3.

Much of the detailed information data and conclusions used to generate the project Outputs are described in the 'Activities' section and the associated Appendices.

Executive summary

Purpose.

This was defined in the RD1 as: "Appropriate and sustainable methods to increase nutrient supply and satisfy crop nutritional demands developed and promoted".

The agro-ecosystem was floodplain rice farming systems, with particular emphasis on small-scale, diverse, low-input farming systems. The beneficiaries were resource-poor and small-scale farmers of Bangladesh; so, although the Goal has been redefined by DFID since the project started, the Purpose of the project is still appropriate in contributing to this Goal.

Activities.

We adopted three main approaches, which in turn would define the project outputs:

1. Quantify the major components of the nutrient fluxes
2. Identify and quantify the major loss processes
3. Develop measures of soil characteristics or processes which could be used as indicators

The data required to achieve this was obtained through the observation of farming activities with associated quantitative sampling and analyses. We compared two nutrient management systems- 'ecological' (organic inputs only)- ECO versus 'conventional' (farmers' normal practices, a mixture of organic and inorganic fertiliser inputs)- CONV. Researcher managed sub-plots were set up, in which N fertiliser was withheld, to determine soil N-supplying capacity. Four areas were chosen to cover a range of soils and agro-ecosystems.

Outputs

Only a small proportion of the nitrogen added as urea fertiliser was recovered by the Boro rice crop. This was in the region of 10-20% in the grain and 20-30% for grain plus straw. Boro rice was the major crop, in terms of investment in inputs and as a cash crop. As much of the fertiliser was applied early in the season, volatilisation would be the major loss mechanism. Most of the nitrogen remaining in the soil was lost through denitrification. The organic matter in the soil was a significant pool of N and might have mitigated the losses of N, provided that inputs were maintained..

A robust indicator of the transition from CONV to ECO was bulk density, a routine and simple measurement. Other indicators tested were soil organic matter fractions, and microbial biomass and activity. These were sensitive to time in crop cycle of sampling and, for microflora, to the conditions of storage and assay. However, some measures were of value, such as the anaerobic N-mineralisation assay (which revealed the significant organic N pool). The respiration quotient also has potential and may reveal more of the characteristics of the microbial communities.

Contribution of Outputs

The findings described above were broadly similar in all areas, yet there were significant regional and local differences. The use of organic matter differed widely, depending on availability and to some extent on history. Thus uptake of outputs will depend on local factors, but the tools developed here can be applied generally.

We could claim that the project itself is a contribution, as it involved the collaboration between an NGO and various kinds of academic (university) and research institutes.

Background

Introduction- the researchable constraints

Farmers have, since the beginnings of agriculture, modified their local environment in order to ensure security of food supply. Generally this has been achieved by maximising yields using locally available resources. Many factors contribute in determining the productivity of an area of land. These factors have usually been considered as constraints so the main research effort has been directed to removing or mitigating these constraints and so to increasing yields (Peoples *et al,* 1995). Recent technologies have developed which overcome other constraints and which reduce losses, for example use of pesticides, artificial fertilisers, reduction in post-harvest losses, high-yielding varieties, etc.

Rice farming occupies a significant proportion of farmland: about 75% of the world's rice is produced in Asia and is the staple crop of Bangladesh (Alexandratos, 1994). Bangladesh is a small country with an area of approximately 148,000 sq. km. The country is one of the most densely populated in the world. Although population growth has declined from 3.0% in the 1960's to 1.8% in the 1990's (Hossain & Shahabuddin, 1997) the population is still predicted to increase from 120 million in 1995 to 173 million in 2020. Of this growing national population an increasing proportion of the population will be based in urban areas. Agriculture occupies 60% of the labour force and contributes 40% of the GDP of Bangladesh. Policy changes, both national and international, have emphasised the importance of efficient use of locally available resources.

Past agricultural policy in Bangladesh has focused predominantly on rice production through the introduction of a package of technologies (modern varieties, fertilisers, pesticides). Although the Green Revolution provided a major increase in yields there has been concern over it's sustainability in the long term and of the environmental impacts. In addition, yields in farmers' fields are still generally lower than that achievable on demonstration or research plots (the 'yield gap'), so constraints still apply. However, considering the requirement of different types of food as specified by the Food and Agriculture Organisation and actual intake it is clear that in both rural and urban areas problems exist in providing a balanced diet, particularly amongst the poor.

Previous research

There is evidence of a long-term decline in yields (Cassman & Pingali, 1995) which has given rise to concern when it is considered that production will have to increase by 70% over the next 35 years (IRRI, 1993). The cause of the decline may be related to the decreasing concentrations of organic matter in the soil (Cassman & Harwood, 1995), or changes in its chemical composition (Cassman *et al,* 1995), which affects the capacity of the soil to supply nutrients. Continuous irrigation and rice cropping may also be a contributing factor to this decline in yields (Cassman *et al,* 1995), but a similar trend has been observed in rice-wheat systems (Nambiar, 1994; Pagiola, 1995).

However this is based on national statistics and has not been verified through specific field studies (ODA 1992). There is evidence of a long term decline in yields in other areas in Asia (Cassman & Pingali, 1995).

The cycling of organic matter is therefore a key aspect of nutrient cycling and in maintaining soil fertility. Research aimed at improvement in understanding how this works in the field needs to be undertaken before it can be applied to the judicious use and management of nutrients. This is particularly relevant to nitrogen, as most of it is present in organic forms (Kelley & Stevenson, 1995; Kundu & Ladha, 1995; Cassman *et al,* 1996) and is susceptible to many loss processes.

These changes in yields and in soil processes have been in progress for decades and have been accelerated by the widespread adoption of Green Revolution (GR) technologies, yet they have only recently become sufficiently apparent to cause concern. The impacts of further changes thus need to be monitored over a shorter time period (of a few years) to ensure that they are of benefit to farmers, yet at the same time to maintain the required increased productivity on a sustainable basis (i.e. without compromising future productivity or the 'health' of the environment). Indicators of sufficient sensitivity are needed, in addition to the usual economic ones (yields, costs of inputs, factor productivity, etc).

In assessing the effect of the introduction of deep tubewell irrigation (DTW) ODA (ODA 1992) concluded that:

- intensity of production had not substantially increased
- intensity of rice cropping had increased with associated impacts upon cropping sequences.
- introduction of high yielding varieties may have exacerbated existing problems due to nutrient imbalances
- there is a widespread awareness (farmers, extension, research) of the decrease in soil organic matter content and the need to improve this. Similarly use of balanced fertiliser application is now recognised as an important aspect of soil management in the future.
- Relative to the attention given to soil conditions, particularly fertility, other factors which may cause yield loss (pests and weeds). The inference being that there are no problems that occur regularly and with sufficient intensity as to alert researchers to study the problem and the required control measures.

Identification of demand

High-input farming technologies have their costs, both direct and indirect, and are susceptible to market forces beyond the control of farmers. The rapid gains in productivity made in the Green Revolution are unlikely to be continued as returns from further intensification diminish (Byerlee, 1992). A World Bank study has shown that there was a long-term downward trend in the yields of modern varieties at the district level in Bangladesh (Pagiola, 1995; Asaduzzaman, 1995; Brandon, 1995). This decline took place during the 1970s (Hossain and Shahabuddin, 1997) so may be associated with the process of adoption of these technologies by farmers who were still in the learning phase. Large-scale projects (DTW irrigation) and flood protection schemes lead to concentration on Boro rice at the expense of diversity (of other food and fodder crops) and to losses of sediment inputs, fisheries, changes in SOM, etc. It has been observed that farmers sometimes breach flood-control bunds in order to allow sediment, traditionally associated with a renewal of fertility, and also fish, to enter their fields.

The problems associated with high-input and large-scale solutions have led to a trend away from such schemes or policies towards more local solutions; policies which are also being adopted by international organisations and donor agencies. Low-input practices, however, have long been developed and promoted by NGOs and so they will have accumulated a fund of knowledge and experience. The evidence of benefits or yield gains however is generally empirical, based on observations of the end results of management practices on demonstration plots or farms (the holistic approach), rather than the result of rigorous scientific and statistical methods (the reductionist approach). This is not the role of most NGOs, who often do not have the technical facilities required, but it is the research approach used by NARs. There is potential for synergy, once initial distrust is overcome. These aspects have been highlighted in a programme development study (Kimmins *et al*, 1996).

The farmers themselves have expressed their concerns over declining returns on their investments in fertilisers and pesticides and also their fears of potential soil degradation. This information reaches the wider research and development community through village-based extension staff who report to their offices and headquarters. There is also reference to the decline in soil fertility in Bangladesh in the scientific literature (Mosheluddin *et al*, 1997)

PROSHIKA's own initiatives in promoting ecological farming are a reflection of their concerns over sustainable farming and the benefits to poor farmers. They have identified the requirement of a scientific basis in order to optimise their approach and to strengthen the content of their extension messages.

Their policy to the promotion of Ecological farming is not 'exclusive' in that farmers are not forbidden the use of the normal agrochemicals. Neither does it have BARC-style recommendations- it is more of an alternative point of view for the farmer which is different to the ones promoted by government extension services organisations and the agrochemicals dealers.

Project purpose

The Goal as stated in the project Log-frame is:
"Soil fertility enhanced or maintained"

This has been expanded in the current NRSP Log-frame (Programme Purpose) to focus on the needs of the poorest people:
"Benefits to poor people in target countries generated by application of new knowledge to natural resources management in high potential systems."

The project Purpose was defined in the RD1 as:

"Appropriate and sustainable methods to increase nutrient supply and satisfy crop nutritional demands developed and promoted".

The agro-ecosystem was floodplain rice farming systems, with particular emphasis on small-scale, diverse low-input farming systems. The beneficiaries were resource-poor and small-scale farmers of Bangladesh, so, although the Goal has been redefined, the Purpose of the project is still appropriate in contributing to this Goal.

Farming systems in Bangladesh are diverse and complex. This has implications for developing the means for sustainable production and for improving livlihoods. Plots and farms (the area owned or cropped by the household) are small, which constrains many options. These options (technologies and policies) need to be operable at a small scale, rather than as blanket recommendations, even if based on Thana-level maps soils maps or locally-based Department of Agricultural Extension (DAE) offices and advisors.

The project was based on floodplain rice farming systems, with particular emphasis on small-scale, diverse and low-input farming systems. The main comparison was between 'conventional' management versus an 'ecological' system of management promoted by PROSHIKA which had been running for at least 5 years before the start of the project. These were fields managed by the farmers, with observations and measurements made by the researchers.

How will the project address these constraints?

The main contributions of the project are:

1. A more detailed and scientifically validated data on the role of organic matter in soil fertility and nutrient dynamics in farmers' fields.
2. A nutrient budget, in which the various inputs and outputs will be quantified, the sources and sinks identified, and the potential impacts of changes in farming practices assessed.

Environmental indicators of soil ‘health’ and fertility, which complement the conventional ones (yield, incidence of pests, economic costs) were developed and employed to monitor changes in the soil.

The outputs of this project will enable the development of these findings. This will include long-term development, monitoring, and dissemination of farming practices in collaboration with NGOs and NARs through inputs into ICM programmes and projects.

Research activities

Introduction.

The activities planned at the start of the project are summarised below. The following sections deal, in turn, with: the characteristics of the soils and farming systems in Bangladesh; the features of the research areas; and finally the activities (Baseline soil sampling, monitoring of research plots, assembling nutrient budgets, and development of indicators).

The hypotheses underlying the design of the project were:

1. Soil organic matter is an essential component of soil fertility;
2. It is possible to improve nutrient supply to the crop through optimising nutrient management.

Secondary components or tools to test and develop these hypotheses are:

1. Nutrient budget, to determine quantitatively the major components (i.e. where interventions could best be made)
2. Indicators to monitor progress of these interventions, also to compare existing farming practices.

The 'experiments' to test these hypotheses were already in existence at the start of the project:

1. Fields converted to PROSHIKA ecological farming practice by farmers after motivation and basic training and managed by the farmers;

versus

2. 'Conventional' farming practices- generally with a mixture of organic and 'chemical' inputs and located in the same general area.

In addition, further plots (part of a field) were set up at the start of the project to assess indigenous nutrient supplying capacity of the soil and to assess fertiliser-nitrogen use efficiency; the researchers managed these. In addition, a further series of plots were established and managed by the researchers, in which only organic inputs were used as sources of nutrients (fertilisers). This was at the request of one of the collaborators (PROSHIKA) in order to check the feasibility of their ecological farming system when managed according to their 'best practices', and to monitor response (yields).

Conceptually the nutrient budget approach divides the farm into management units comprising of fields or livestock units, where the input and output flows for each unit can be identified and measured or estimated. Data of local yields, N offtakes, and common management practices are therefore of particular importance in establishing the appropriate nutrient flow structure for the model.

The indicators which were considered were those which were most likely to reflect changes in soil. These changes could be degradation (or other aspect of soil 'quality' or health) or a more direct indicator of fertility (or nutrient status/supply capacity). Further factors in selection were the feasibility of performing the measurement given the facilities likely to be available, the applicability to (flooded/irrigated) tropical soils (most of work on most indicators done on temperate soils), and interpretation of data/results into a form usable for INM.

Activity 1. Establish nutrient balance model and indicator measurements

This was a review process over the first year of the project, based on perusal of the literature, assessment of feasibility (with the facilities available) and laboratory testing of options. The outcomes of this initial sifting and review are discussed in the appropriate activities and in more detail in Appendix I.1.

Activity 2. To construct nutrient budgets.

Much of the effort was devoted to N, as this nutrient element was the major input (fertilisers: urea, compost) by farmers (whether ecological or conventional fields) and also is more susceptible to losses (through denitrification, leaching, volatilisation).

Activity 3. To establish and develop environmental indicator measurements.

Indicator measurements can be used to examine the status of a soil where the information is not available to compile a nutrient budget, or to confirm the findings from a nutrient budget. Further, there may be situations where a nutrient budget does not reveal risks of declining soil fertility. For example the yield decline reported at IRRI apparently occurred despite accumulation of total soil organic matter and in the absence of macro or micro nutrient deficiencies. Under such situations a nutrient balance will not reveal the cause of changing productivity.

The soils and agro-ecosystems of Bangladesh

In Bangladesh the fertility status of the soils is declining and the organic matter content of agriculturally important soils has been found generally to be low (Moslehuddin *et al.*, 1997). Approximately 90 % of Bangladesh soils contained between 0.5% -1.0 % organic matter (Islam, 1990). Areas of higher organic matter content coincided with the floodplain regions which were subject to annual inundation of water (Moslehuddin et al. 1997), the rate of decomposition under anaerobic conditions being far slower, allowing a build up of organic material in the soil (Patrick, 1982). Bangladesh soils have also been categorised as having a low nitrogen carrying capacity (Islam, 1985). This partly arises because the soils (approximately 80 % of Bangladesh) are formed from alluvial sediments (Saheed, 1984), but also because the organic matter is one of the most widely available nitrogen sources in Bangladesh and the lack of recycling of organic materials has led to a decrease in the soils nitrogen content. The reduction in recycling has resulted due to a fuel scarcity and both plant residues and manures are commonly used as fuel substitutes, lowering the available inputs to the soil (Moslehuddin, et al., 1997). Almost all the upland soils of Bangladesh are deficient in nitrogen, whilst deficiencies of phosphorous and potassium although not as severe can limit plant growth, reducing crop yield. Additionally the near continuous waterlogging of paddy soil reduces the availability of zinc and sulphur to rice crops. In Bangladesh the integration of organic farming and chemical farming is necessary to sustain and increase the soil fertility (Moslehuddin et al., 1997).

Research sites

Selection of sites and farming practices.

Several factors determined the selection of sites. In order to utilise the collaboration with PROSHIKA we have to work in areas where PROSHIKA have established Area Development Centre (ADC) offices. Given concerns regarding declining productivity it was important to have sites in areas that are intensively cultivated. It was also regarded as important to establish nutrient balances for systems on contrasting soil types and flooding regimes.

Locations (Fig 1)were selected in Dhaka, Manikganj and Bogra Zilas (former Districts). The characteristics of the soils and topography of each location (identified by the Thana names) are summarised in the table below. See Table 6 for the names of the villages, population nmbers, cropped areas, and rice production and demand.

Table 1. Characteristics of the research areas. Further details in Appendices I.2 and III.6, explanation of the AEZ (Brammer *et al*, 1988) in Appendix I.2.

Location	General Soil Type	Flood - level	Agro-ecological zone
Manikganj			
1. Dhamrai	Non-calcareous grey floodplain soil	MH - ML	Region 8d
2. Daulatpur	Non-calcareous grey floodplain soils	MH - L	Region 8
3. Koitta	Non-calcareous grey floodplain soil	MH	Region 8
Bogra			
1. Gabtali	Non-calcareous grey floodplain soil; Non-calcareous alluvium	H - MH	Region 4a
2. Shibgonj	Non-calcareous grey floodplain soils; shallow to deep grey terrace soils	H - MH	Region 25

L = lowland; H = highland; M = medium (low or highland)

Characterisation of selected sites:

Dhaka and Manikganj Zilas

The sites at Daulatpur are located on the lowlands and medium highlands within the Jamuna floodplain (close to the Ganges floodplain at the junction of the two rivers) and the Dhamrai and Koitta sites are on the western edge of the Mudhupur Tract.

Fig. 1. Locations of the four research areas in Bangladesh.

Daulatpur

This is more or less at the border between the Jamuna and Ganges floodplains. A low-lying basin (flooding depth up to 2 m) was fringed by higher land and 'made' land (i.e. homestead islands built in part from excavation of tanks and ponds). Irrigation from shallow tube wells, installed 10-15 years ago, is widely available in the basin area. About 90% of the area is irrigated and, at the time of the visit (22 April 1997), under Boro rice. Most of the rest, especially the slightly higher and non-irrigated land, was under wheat, which was being harvested, plus scattered fields of legumes (also harvested) and onions, with jute (recently sown, March 1997) close to the homestead islands. Little apparent input from biological nitrogen fixation (BNF) except in fields where legume crops were planted. These legumes (grass pea- *Lathyrus sativa* and black gram- *Vigna mungo*) were well nodulated. No *Azolla*, very little blue green algae (BGA); the dominant alga, occurring in abundance in many of the irrigated field, was *Hydrodyction*, a green alga commonly found in moderately eutrophic waters. However, it was observed that BGA, especially those growing on the soil surface, were much more abundant during the later period of the Boro crop. It should be noted that this was the case for all the sites visited during June-July 1997. Compost and manures were not extensively used (observations made during June 1997), principally due to constraints on supply.

Dhamrai

This area was characterised by high inputs through BNF (*Azolla* from within the field and material from elsewhere, BGA, and legume rotation). After using the 'Quick compost', which typically comprises of oilseed cake, rice bran, sawdust and poultry litter, farmers have relied upon inputs of BNF. Farmers were observed to incorporate weeds, *Azolla* and BGA by hand. There was comparatively little use of compost or manure (June 1997).

Bogra Zila

This region is characterised by its somewhat drier climate and higher lands. Where irrigation is available however, it has the highest cropping intensity. Potatoes, grown during the winter season, are a major cash crop, together with irrigated boro rice.

Gabtoli

In this area we saw a number of farmers in two command areas (one area using an RDA buried pipe irrigation system). The farmers were experiencing difficulties with the RDA pump. The soils in this area were lighter in texture, much less BNF was apparent with a greater reliance upon the use of organic manures. The availability of manure was a constraint to adoption although composts and manures were used extensively, in marked contrast to the Manikganj and Dhaka sites. One farmer (Rezaul Karim) has soils that have been under irrigation for different periods. The higher-lying land is very productive and is used for the cultivation of high-value crops for the local markets, principally vegetables.

Shibgonj

Again a somewhat lighter soil. Farmers are reliant on quick compost inputs on a seasonal basis. Manure includes Oilseed cake, household waste, some cow dung and water hyacinth (*Eichhornia crassipes*). Compost and manure were applied extensively, and at high rates (estimated at 5-10 tonnes ha^{-1}), during June prior to transplanting the aman rice crop. This area is not subjected to flooding, except during heavy rains in the monsoon when standing rainwater collects, thus the lower risks make investment in fertilisers and high-yielding varieties worthwhile.

Photo 1. Dhamrai (Dhaka Zila). From higher ground near villages, with jute, low land in the middle distance.

Photo 2. Gabtali (Bogra Zila). Looking over the 'bil', an area of permanent water.

Photo 3. Daulatpur (Manikganj Zila). View to north-west over the open area of lower-lying land in the middle distance. Note terracing to level the fields. Soil also removed to build 'made-up land for dwellings.

Photo 4. Gabtali (Bogra zila). BARC and BARC-N (N-withheld, paler green) plots.

Summary of experimental plan

The observed nutrient management systems (whole fields) were:

1. *Conv* (i.e. *Conventional*) Farmers' current practice
2. *Eco-90* PROSHIKA's recommended Eco-farming as practised by farmers

Treatments in the managed mini-plots were:

1. *BARC* Conventional practice using BARC recommended fertiliser rates
2. *BARC-N* Recommendation N withheld
3. *Eco-97* Eco-farming plots set up and managed by PROSHIKA.

There were generally 10 replicate fields for each of the 5 'treatments' in each of the four areas (total of 200). However, there were sometimes an insufficient number of farmer-established (ECO-90) fields in the area.

(Standardised names for each treatment, as defined above, shown in italics, and used in project documents).

Baseline soil sampling and analyses

At the beginning of the experiment each plot subjected to a baseline survey as specified by Tropical Soil Biology and Fertility (Anderson and Ingram, 1993). Parameters measured are listed in Appendix I.4. Composite soil samples were taken, composed of 5 samples distributed over the field. Soils were archived from all monitored plots (air dried and 2 mm sieved, stored in jars). Quality control used soil and plant reference material and blind samples. Further details on methods in Appendix III.6.

Table 2. Particle size fractionation of the baseline soil samples.

	Sand	**Silt**	**Clay**	**Texture**
		%		
Dhamrai				
Conventional	5	61	34	sic
Ecological	11	58	31	sicl
F test				ns
Daulatpur				
Conventional	16	41	44	sic
Ecological	4	35	61	c
F test				ns
Gabtali				
Conventional	11	57	32	sic
Ecological	15	55	31	sic
F test				ns
Shibganj				
Conventional	16	56	28	sic
Ecological	14	59	28	sic
F test				ns

c = clay, sic = silty clay, sicl = silty clay loam; ns=not significant

Table 3: Physical and chemical analysis of the four areas.

Treatment	CEC cmol+kg^{-1}	K Kg ha^{-1}	Ca kg ha^{-1}	Mg kg ha^{-1}	BSP	BD g/cm^{-3}	N kg ha^{-1}	C kg ha^{-1}	C:N	P kg ha^{-1}	pH
Dhamrai											
Conventional	18.18	99	1604	359	48	1.07	2234	29241	14	2940	6.1
Ecological	20.64	93	2103	385	60	0.94	2252	30737	14	3082	6.4
F value	**8.29****	**0.54^{ns}**	**18.55****	**1.79^{ns}**	**27.80****	**16.70****	**0.01^{ns}**	**0.59^{ns}**	**0.13^{ns}**	**0.47^{ns}**	**13.67****
Daulatpur											
Conventional	20.64	110	1992	354	42	1.3	2295	30177	14	3094	6.2
Ecological	25.08	120	2391	479	44	1.23	2453	42129	18	3334	6.1
F value	**6.10***	**0.29^{ns}**	**3.47^{ns}**	**11.03****	**0.17^{ns}**	**3.95***	**0.20^{ns}**	**45.86****	**6.76***	**0.42^{ns}**	**3.60^{ns}**
Gabtali											
Conventional	11.61	114	1693	369	67	1.29	1718	30373	19	2783	6.13
Ecological	13.1	128	1318	311	52	1.22	1759	27234	16	2662	5.7
F value	**1.56^{ns}**	**0.41^{ns}**	**4.28***	**2.00^{ns}**	**6.61****	**5.52***	**0.04^{ns}**	**0.68^{ns}**	**2.23^{ns}**	**0.33^{ns}**	**19.14****
Shibganj											
Conventional	13.86	145	1259	274	42	1.28	1706	33652	20	1797	6.06
Ecological	13.59	212	1645	271	51	1.31	1576	33294	22	1773	6.02
F value	**0.06ns**	**4.72***	**5.84***	**0.01ns**	**5.20***	**3.75***	**0.72ns**	**0.01ns**	**0.48ns**	**0.07ns**	**0.08ns**

* significant at 5% level

** significant at 1% level

ns non-significant

Table 4. Summary of bulk density (g cm^{-3}) of baseline soils from the four research areas, means (±SE) and F-values. (from Table 3 (above) and Appendix II.2 And III.6).

	Research areas			
Management	Dhamrai	Daulatpur	Gabtali	Shibganj
CONV	1.07 ±0.01	1.29 ±0.01	1.29 ±0.01	1.28 ±0.01
ECO-90	0.94 ±0.02	1.23 ±0.04	1.22 ±0.03	1.31 ±0.02
F value	4.72**	3.95**	5.52**	3.75**

** significant at 1%.

In three of the four areas, greater additions of organic matter led to a significant reduction in bulk density (Table 4). The exception is Shibganj, which is on the Level Barind Tract. This soil has a higher clay content than the others, and different parent material (Madhupur clay) and possibly different mineralogy. The fields at Dhamrai had been under ECO-90 for longer than any of the others (7 years at the start, the others varied from 3 to 5 years), and also had greater inputs of organic matter. This is reflected in the difference (0.14) compared to Daulatpur (same region; 0.06) and Gabtali (0.07).

Other significant changes, though not for all sites, were total organic carbon and some of the soil organic matter fractions used as indicators (see Appendix III.3). Soil buffering capacity (cation exchange capacity and exchangeable calcium) and reaction (pH) were also increased (Table 3; further discussion in Appendix III.6).

These soil characteristics are generally considered beneficial, in terms of ease of tillage, root penetration, nutrient reserves in the labile organic fractions, and retention of inorganic nutrients.

Monitoring of research plots and farmers' fields

Procedure for monitoring management and cropping patterns

Having decided the regions and sites in which the project was established, PROSHIKA identified farmers willing to work with the project. This was drawn from databases of farmers and by visits made by EDWs who are based at each ADC and who visit all the farmers involved in PROSHIKA schemes (not just eco-farming) within their areas. An example of the information available is given in Appendix I.3; these are farmers who are currently employing ecological farming. The objective was to establish the management practices of the participating farmers. This will enabled us to establish the nature and timing of inputs. This information formed the basis of the nutrient budget and site-specific sampling strategies.

The information collected included:

- Soil type and Agroecological zone
- Cropping history for sites (details as far back as possible)
- Knowledge of inputs / outputs
- Off-season management

Much of this information will come from the farmers during routine visits by project staff (the Economic Development Workers (EDWs) from the PROSHIKA ADC offices (which are local area offices serving a Thana) and through local workshops with the farmers. Although this information is largely descriptive it forms the basis of analysis of cropping patterns and resource utilisation, i.e. factors affecting farmers' decision making, which will consolidate predictions from the modelling exercises and aid in sifting out the best options for further development.

Information on inputs and outputs was recorded on standard data forms (see Appendix I.6). These forms served as a template for the database and as an *aide memoire* for the field staff. Each form was a complete record of a cropping season, from land preparation to harvest, for each field (i.e. a database record). Interaction with farmers was less formalised, with the discussions centring on current activities, but with the aim of ensuring accuracy and consistency.

To establish the yield gap due to difference between farmers actual nutrient use, recommended balanced nutrient input and eco-management the soil nitrogen supply capacity be modified. Plots were established within farmers' fields. In each area 10 replicate fields were selected for each of the five treatments. The sizes of the fields varied, but unusually small ones (less than 8-10 decimals (0.03-0.04 ha) were not selected. Originally, it was intended that fields would be divided into sub-plots only if the area was too large to manage effectively, or if it was to be a split-plot design for the BARC vs BARC -N (treatments 3 and 4,above). This did not turn out to be feasible where organic matter was to be added (treatment 5 in particular) due to the large amount that would be required and the short time available for preparation of the composts which are a component of PROSHIKA's eco-farming practice. Additionally, several farmers expressed their concerns over potential reductions in yield (treatment 2 especially) despite compensation being made available through PROSHIKA to make good any losses on (the basis of average yields for the area). For these reasons, and to maintain consistency, all researcher managed treatments were limited to a 12x12 m area, demarcated by a low bund, at one end or corner of the field. Samples were collected from a 10x10 m area at the centre, giving a 1 m buffer zone. The location of these plots was recorded using fixed markers.

Management and cropping patterns

A generalised cropping pattern is shown in Table 5. A complete record of the farmers' activities carried out in the observed plots (CONV and ECO-90) is given in Appendix II.1 (details of the plots, in Appendix I.3).

Table 5. Generalised cropping patterns of the research areas.

Doulatpur	Summer	Winter	Spring
	B.Aman	Mustard	Boro
	B.Aman	Fallow	Boro
	B.Aman	Grass pea (GM)	Boro
	B.Aman	Khesari	Boro
	Jute	Mustard	Boro
	Fallow	Mustard	Boro
	Fallow	Onion & Moula	Boro

Dhamri & Koitta	Summer	Winter	Spring
	B.Aman	Fallow	Boro
	B.Aman/ Aus	Fallow	Boro
	Aus	Fallow	Boro
	Jute	Fallow	Boro
	Jute	Mustard	Boro
	T.Aman	Wheat	Jute

Gabtoli	Summer	Winter	Spring
	T.Aman	Potato	Boro
	T.Aman	Potato	Boro & GM
	T.Aman	Potato	Jute
	T.Aman	Wheat	Jute
	T.Aman	Fallow	Boro
	Jute	Onion	Boro
	Jute	Potato	Boro
	Jute	Egg plant	Wheat

Shibgonj	Summer	Winter	Spring

T.Aman	Fallow	Boro
T.Aman	Mustard	Boro
Jute	Potato	Boro

The main rice crop, in terms of yields, is the Boro, which is grown under irrigation. The area under this crop, and cropping practice, has increased substantially in recent years, with the introduction of irrigation schemes (e.g. ODA (now DFID) Deep Tube well Project, Phase II, PROSHIKA's loan schemes and independent undertakings). A wide variety of crops are grown during the Rabi season (November to February). Potato is a particularly important cash crop in the Bogra sites. Aman rice is grown during the monsoon season, during which the Dhaka and Manikganj sites can become deeply flooded, up to a depth of 2.5 m. In 1998 there were major crop losses due to exceptional floods (the worst since 1988) and post-flood events such as damage to track, roads and other infrastructure, and also to cooler than average temperatures during the following Rabi season.

All the research areas produced a surplus of rice (Table 6), with at least 50% of the crop potentially available to the market and so a source of cash income. It is not surprising that the least populated areas (in this case as hectares of land to boro per head) had the greatest surplus; >88 at Dhamrai and 96% for Shibganj.

The Bogra sites had considerably greater areas of Aman, providing about half the annual rice crop. The significant factor here was the much lower risk of serious flooding, thus allowing farmers to invest more in inputs to increase yields than was the case at the Dhaka/Manikganj sites. This was clearly seen in the cropping calendar (Appendix II.1), where the floods of 1998 devastated the Aman crop and also disrupted preparations for the following ones once the water receded. The yields Aman rice were considerably greater at Bogra; c4.8 t/ha compared to c2.8 at the Dhaka/Manikganj sites. Boro yields were, however, little different between the areas, a reflection of the less variable conditions and the greater control of the cropping environment that the farmers have at their disposal, principally through irrigation and application of fertilisers. Further information on yields is given in the following sections (N-use efficiency, budgets). The amounts obtained from the household survey discussed above were broadly in line with the research plot data.

Photo 5. Checking the wet deposition trap (rain gauge): dry deposition trap cage in background. Shibganj, Bogra Zila.

Photo 6. Young farmers, with project record sheets for monitoring farming activities on the research plots.

Photo 7. Pit method of preparing compost. Shibganj, Bogra.

Photo 8. Yoke and baskets (Tukri) to carry manure and compost to field. Shibganj, Bogra.

Photo 9. Spreading FYM onto soil after wetting and first ploughing. Shibganj, Bogra.

Photo 10. Weeding, and incorporation Quick Compost at Koitta Farm. PROSHIKA's HRDC in background.

Table 6. Rice production and demand in the research villages.

Research location	Population	Land per head	Total production and crop area of (in tonnes/ha):						Total production		T
(village names)		(ha Boro cropped)	Aus		Aman		Boro		(tonnes p.a.)		de
			t/ha	ha	t/ha	ha	t/ha	ha			(t
Dhaka and Manikganj Zilas:-											
Daulatpur											
(Taluknagar)	450	0.152			148.6	51.4	441.3	68.4	589.9		
Dhamrai											
(Ghorakhanda)	763	0.041			57.1	21.0	190.4	31.6	247.5		
Bogra Zila:-											
Gabtoli											
(Chaksekandar)	551	0.049			128.5	26.7	173.4	27.1	301.9		
(Khidraperi)	1696	0.045	43.9	18.6	379.7	78.9	483.8	75.7	907.5		
Shibganj											
(Chakrasha & Dhewrapara)	285	0.396			502.7	113.0	668.7	113.0	1171.4		

Notes:

Site names (thanas) used in report in bold

Village names given in brackets.

Gabtoli split between 2 villages c 1 km apart; Shibganj 2 neighbouring villages.

Demand on basis of 161 kg/person/year (BBS, 1995).

Assembling the nutrient budgets

Quantitative measurements were made of many of the components of a field-based nutrient budget. These are detailed in Appendices III.4 and III.6 and the data in Appendices II.3 and II.4. Summary data for nitrogen balance for the Boro crops (1998 and 1999) are presented in Tables 7 to 10, and the data for the other elements (P and K) and for the other crops (Rabi and Aman) are in Appendix II.4 and summarised in table 11. Not all the fluxes were measured (see Appendix III.4 for details) and others were inferred. Biological nitrogen was not measured, since it is time consuming to obtain accurate values for a wide area over a whole season. There is also there is an extensive literature, including an earlier DFID-funded project in the Manikganj area (Whitton et al, 1984; project number R3630A; Rother *et al*, 1988, Rother & Whitton, 1989). In these tables a value of 10 kg N/ha was used (Rother & Whitton, 1989). Losses at the onset of irrigation, when the soil becomes anaerobic were calculated on the assumption that all the NO^{3-}-N in the soil prior to irrigation was lost through denitrification.

Nutrient budgets in the context of soil fertility management

The total offtake of grain and straw for the Boro crop ranged from 5 to 14 t/ha (Fig2). There was little variation either between areas or between CONV and ECO-90 in any one year, although the yields in 1999 were significantly greater than for 1998 in all areas. The amounts of fertilisers applied (see Fig 3 and below) were not significantly different, apart from Gabtali, where more urea-n was applied in 1999. The harvest index (grain yield/grain+straw yield) was generally around 50%, up to 70% (e.g. for Dhamrai, ECO-90, 1998).

The various components of the nutrient budget and their composition where relevant (e.g. for organic matter inputs) for the three main nutrient elements (N, P, K) for the Boro crops are shown in Figs 2 to 13. Grain and straw yields (as t dry matter/ha) for Boro 1998 and 1999 are shown in Fig 2, and inputs of inorganic fertilisers in Fig 3. The proportion of fertiliser N recovered by the crop is shown in Fig 4 (and discussed in the section 'Nitrogen Use Efficiency', below). The sequence of figures 5 to 8 illustrates the other inputs (organic matter, deposition) and components needed to calculate budgets for Boro 1998. Figures 9 to 13 do the same for Boro 1999. The bars are standard errors, where none are shown there were too few samples. In most cases farmers applied all the major inorganic nutrient elements (N, P and K). The ratios varied from year to year, but farmers in Bogra generally used more muriate of potash, i.e. KCl (MP in the fig), both as amounts and as a ratio of the other elements. The average ratio of N:P:K for the Dhaka and Manikganj sites was 100:14:16 and for Bogra it was 100:19:27.

The N content (as %) of organic matter inputs was variable (Appendix II.3) and depended upon the quality and availability of materials used to make the compost, or on other factors such as the straw content of the FYM, the method of preparation, and exposure to rain (leaching). Thus the amount of N applied to the field could be expected to be more variable than for urea N. Although this was the case, it was due to farmers' decisions as much as to the qualities of the material itself. For example, there were no inputs of OM in the CONV fields at Dhamrai in either year, and only small amounts at Doualtpur in 1999.

The P and K inputs through OM were substantial. Compared with the inorganic inputs, the proportions relative to N were:

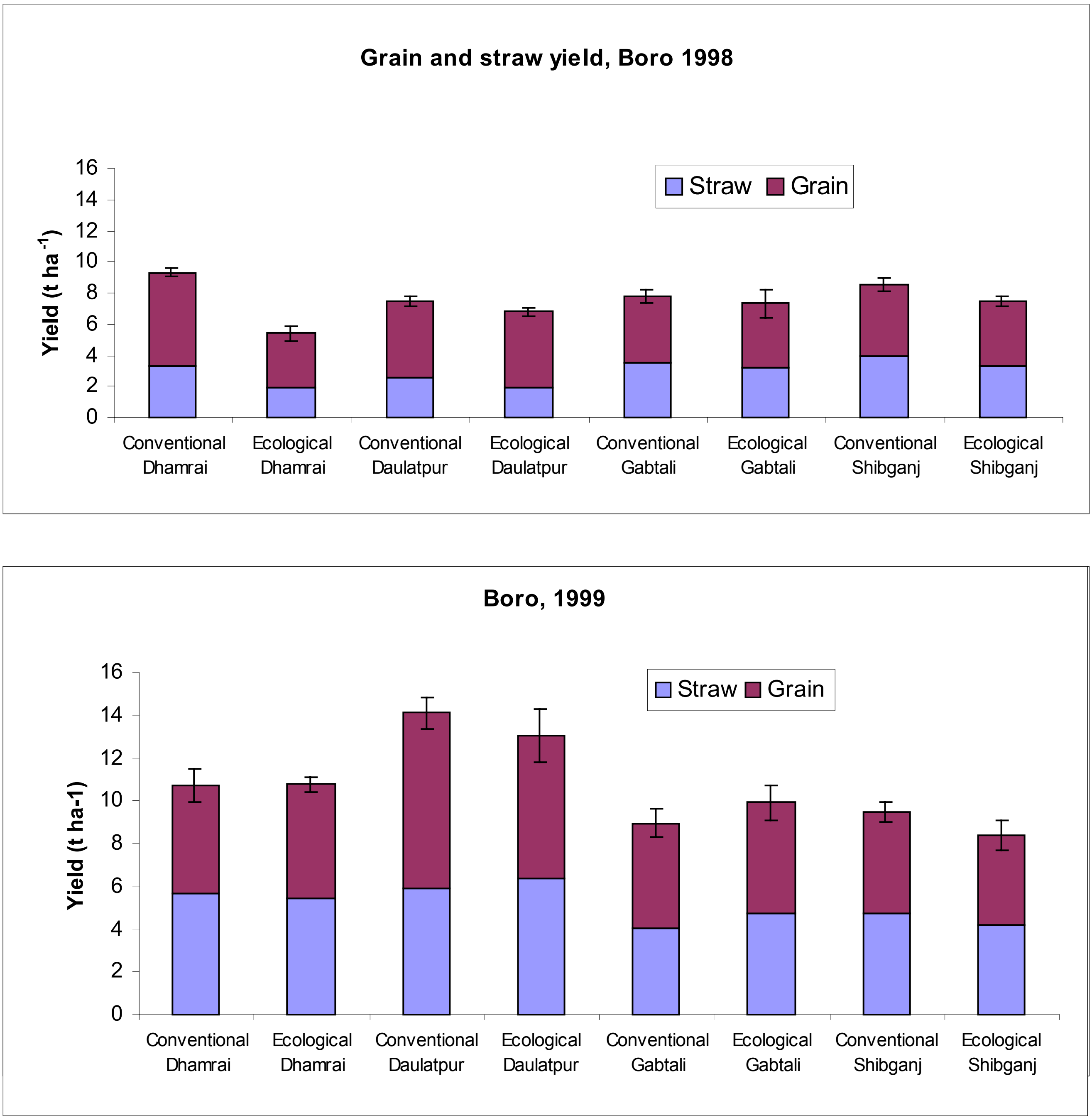
Element	Dhaka/Manikganj sites		Bogra sites	
Fields	CONV	ECO-90	CONV	ECO-90
N	100	100	100	100
P	62	72	56	59
K	117	96	110	79

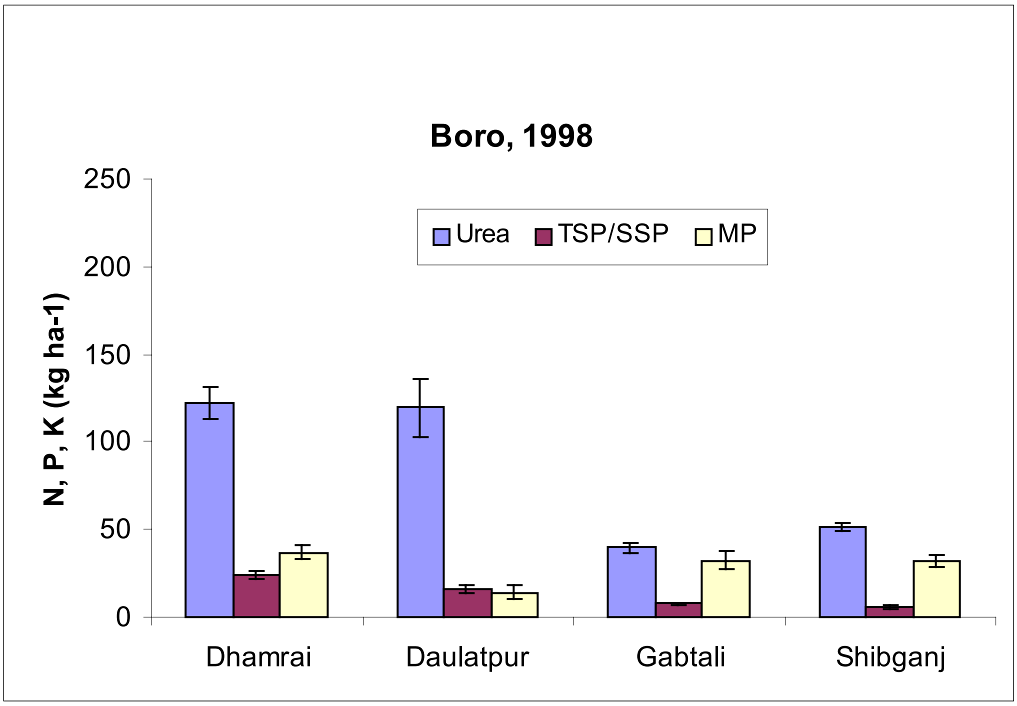
By far the greatest proportion of N entering the soil was that supplied by the farmer, either as urea, and/or as various forms of organic matter. The other inputs, from biological nitrogen fixation (BNF), rainfall, dry deposition, and irrigation water amounting to only 10-20% of the total at most. Of these minor inputs, BNF accounted for half (estimated at 10 kg N/ha).

In all cases there were substantial negative nitrogen balances. This applied to fields that were fertilised only with organic matter, as well as those that had urea only as the N input (apart from rainfall, etc). Fertiliser N loss was the main contributor. This loss was based on N-use efficiency calculations from N-withheld sub-plots (see below, also Cassman *et al*, 1996). Denitrification and leaching losses were also major, at c 20-30 kg N/ha for each.

Oftakes (grain and straw) amounted to 70-110 kg N/ha. This was a significant proportion of the fertiliser N inputs (which were c 100-200 kg N/ha) despite the low N-use efficiencies, suggesting that the indigenous soil N supply contribute significantly to yields. This supply could be maintained by some of the factors considered in the budget to be losses, for example the weeds. BNF from legume crops may also be more significant than estimated. Another source of N is from previous crops and from residual fertiliser N.

Fig 2. Grain and straw yields, Boro 1998 and 1999.





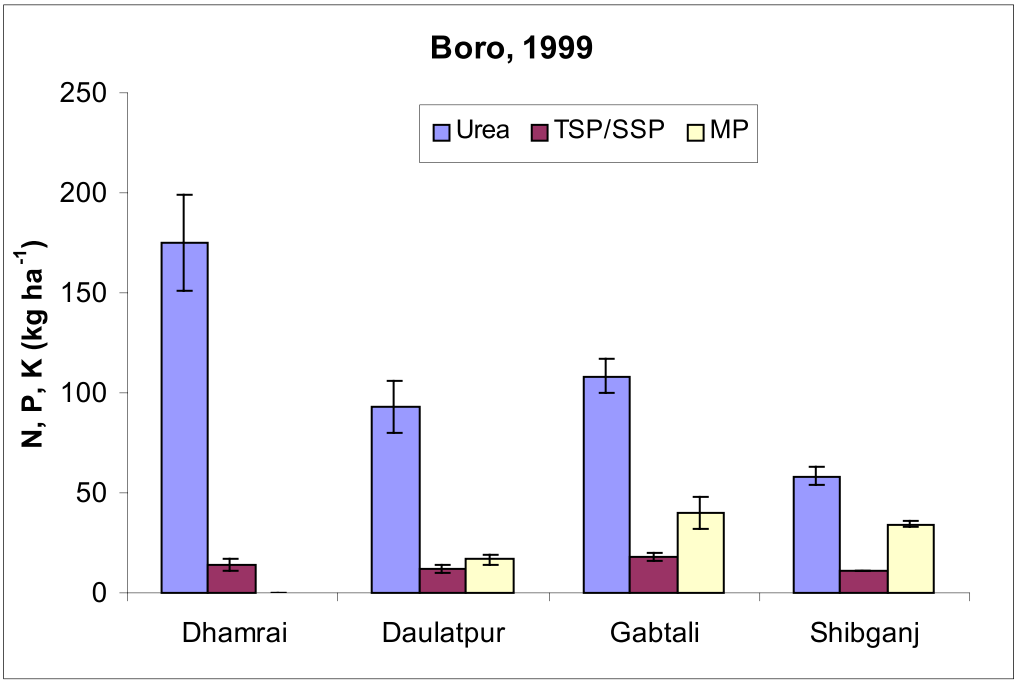
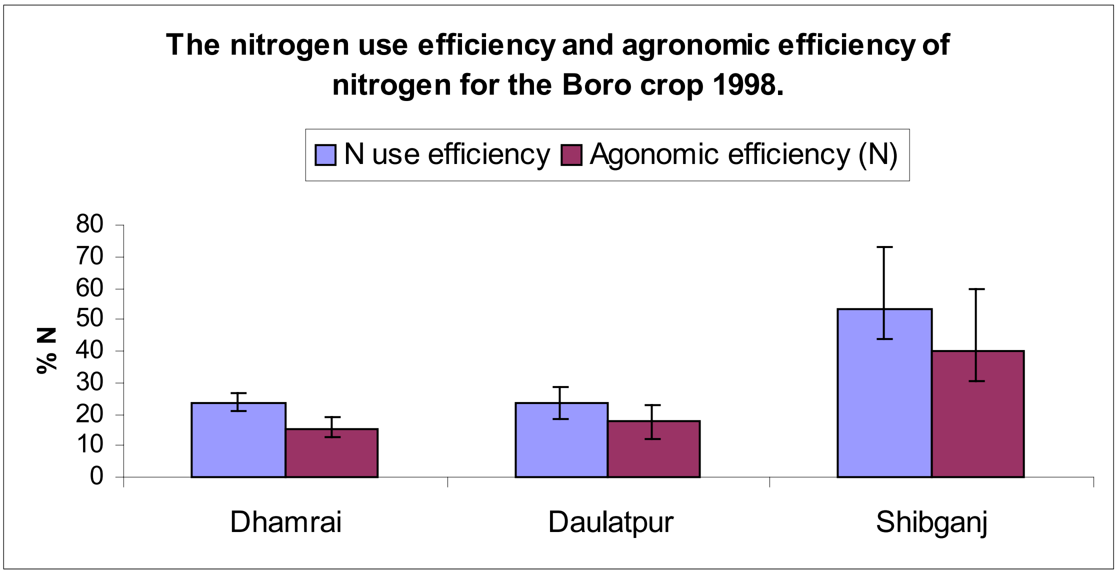


Fig 3. Chemical fertiliser inputs into conventionally managed fields for the Boro crops of 1998 and 1999.



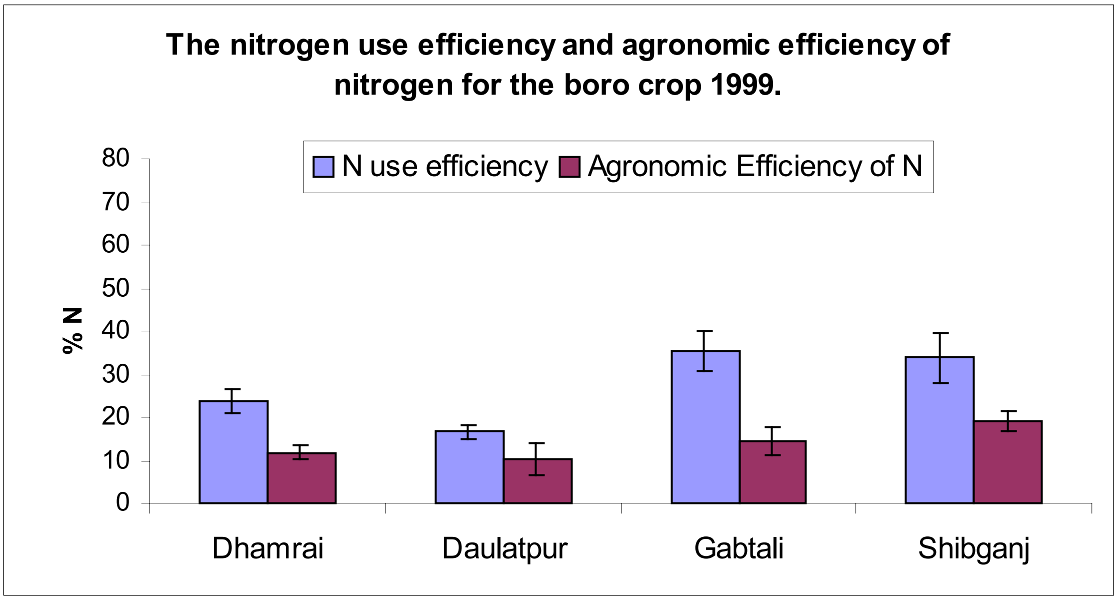


Fig 4. Agronomic and N-use efficiencies, Boro 1998 and 1999.
(see also Table 13 for BARC sub-plots data).

Table 7: **Dhamrai-** N budgets for Boro cropping seasons 1998 and 1999.

	1998				**1999**			
	Con	SE	Eco	SE	Con	SE	Eco	SE
INPUTS-								
Chemical Fertiliser	**123**	±9			**175**	±24		
Organic Manure			**44**	±0.03	**35**	±1	**37**	±2
Atmos. N Deposition-								
Dry Deposition	**<1**		**<1**		**1**	±0.01	**1**	±0.01
Wet Deposition	**4**	±0.05	**±4**	±0.06	**7**	±0.05	**6**	±0.06
Irri. Water (Pump)	**5**	±0.09	**±5**	±0.01	**5**	0.09	**6**	±0.01
Biological N Fixation	**10**		**10**		**10**		**10**	
Total Inputs	**142**		**63**		**233**		**60**	
OUTPUTS-								
Grain	**-69**	±2	**-40**	±5	**-68**	±5	**-78**	±4
Straw	**-22**	±1	**-12**	±1	**-54**	±5	**-32**	±2
Weeds	**-24**	±3	**-19**	±3	**-25**	±2	**-23**	±1
Loss upon irrigation (gaseous N)	**-32**	±2	**-26**	±1	**-24**	±1	**-15**	±6
Leaching					**-22**	±2	**-23**	±2
Fertiliser N loss	**-97**	±7			**-154**	±21		
Total N Outputs	**-244**		**-97**		**-347**		**-171**	
Balance	**-102**		**-34**		**-114**		**-111**	

Abbreviations for all nutrient balance tables: Con = Conventional, Eco = Ecological, SE = Standard Error, Atmos. = Atmospheric, Irri. = Irrigation

Table 8: **Daulatpur**-N Budgets for Boro Cropping Seasons 1998 and 1999.

	1998				**1999**			
	Con	SE	Eco	SE	Con	SE	Eco	SE
INPUTS-								
Chemical Fertiliser	**119**	±17			**92**	±16		
Organic Manure	**29**	±5	**68**	±15	**5**	±1	**5**	±1
Atmos. N Deposition-								
Dry Deposition	**<1**		**<1**		**1**		**1**	
Wet Deposition	**4**	±0.06	**4**	±0.07	**7**	±0.06	**7**	±0.07
Irri. Water (Pump)	**4**	±0.01	**3**	±0.01	**5**	±0.01	**5**	±0.01
Biological N Fixation	**10**		**10**		**10**		**10**	
Total Inputs	**166**		**85**		**120**		**28**	
OUTPUTS-								
Grain	**-54**	±3	**-56**	±1	**-75**	±6	**-59**	±11
Straw	**-16**	±2	**-10**	±1	**-34**	±2	**-32**	±2
Weeds	**-26**	±1	**-22**	±1	**-27**	±3	**-22**	±1
Loss upon irrigation (gaseous N)	**-45**	±4	**-43**	±7	**-23**	±4	**-17**	±3
Leaching					**-27**	±2	**-26**	±2
Fertiliser N loss	**-98**	±14			**83**	±14		
Total N Outputs	**-239**		**-131**		**-269**		**-156**	
Balance	**-73**		**-46**		**-149**		**-128**	

Table 9: **Gabtali**-N Budgets for Boro Cropping Seasons 1998 and 1999.

	1998				1999			
	Con	SE	Eco	SE	Con	SE	Eco	SE
INPUTS-								
Chemical Fertiliser	**39**	±3			**108**	±9		
Organic Manure	**71**	±9	**103**	±9	**12**	±1	**15**	±2
Atmos. N Deposition-								
Dry Deposition	**<1**		**<1**		**1**		**1**	
Wet Deposition	**4**	±0.06	**4**	±0.06	**6**	±0.06	**6**	±0.06
Irri. Water (Pump)	**8**	±0.02	**7**	±0.17	**9**	±0.02	**8**	±0.17
Biological N Fixation	**10**		**10**		**10**		**10**	
Total Inputs	**132**		**124**		**146**		**40**	
OUTPUTS-								
Grain	**-52**	±3	**-51**	±6	**-68**	±5	**-69**	±4
Straw	**-26**	±3	**-21**	±3	**-38**	±8	**-41**	±5
Weeds	**-18**	±1	**-22**	±4	**-17**	±1	**-26**	±3
Loss upon irrigation (gaseous N)	**-34**	±4	**-36**	±5	**-30**	±12	**-25**	±4
Leaching					**-19**	±1	**-20**	±2
Fertiliser N loss	**-36**	±3			**-92**	±7		
Total N Outputs	**-166**		**-130**		**-264**		**-181**	
Balance	**-34**		**-6**		**-118**		**-141**	

Table 10: **Shibganj**-N Budgets for Boro Cropping Seasons 1998 and 1999.

	1998				1999			
	Con	SE	Eco	SE	Con	SE	Eco	SE
INPUTS-								
Chemical Fertiliser	**51**	±2			**58**	±5		
Organic Manure	**69**	±18	**65**	±6	**36**	±7	**86**	±10
Atmos. N Deposition-								
Dry Deposition	**<1**		**<1**		**1**		**1**	
Wet Deposition	**3**	±0.06	**3**	±0.06	**5**	±0.06	**5**	±0.06
Irri. Water (Pump)	**8**	±0.03	**7**	±0.18	**9**	±0.03	**8**	±0.18
Biological N Fixation	**10**		**10**		**10**		**10**	
Total Inputs	**141**		**85**		**119**		**110**	
OUTPUTS-								
Grain	**-54**	±3	**-46**	±4	**-57**	±3	**-53**	±6
Straw	**-25**	±3	**-20**	±1	**-33**	±3	**-36**	±7
Weeds	**-27**	±7	**-13**	±2	**-24**	±2	**-28**	±3
Loss upon irrigation (gaseous N)	**-39**	±9	**-36**	±2	**-23**	±4	**-35**	±7
Leaching					**-18**	±1	**-18**	±1
Fertiliser N loss	**-42**	±1			**-47**	±4		
Total N Outputs	**-187**		**-115**		**-202**		**-170**	
Balance	**-46**		**-30**		**-83**		**-60**	

Table 11. Summary table of nutrient budgets (kgN/ha) for Boro, 1998 and 1999.

Nitrogen

	1998		1999	
Dhamrai:	CONV	ECO-90	CONV	ECO-90
Inputs	142	63	233	60
Outputs	-244	-97	-347	-171
Balance	*-102*	*-34*	*-114*	*-111*
Daulatpur:				
Inputs	166	85	120	28
Outputs	-239	-131	-269	-156
Balance	*-73*	*-46*	*-149*	*-128*
Gabtali:				
Inputs	132	124	146	40
Outputs	-166	-130	-264	-181
Balance	*-34*	*-6*	*-118*	*-141*
Shibganj:				
Inputs	141	85	119	110
Outputs	-187	-115	-202	-170
Balance	*-46*	*-30*	*-83*	*-60*

Phosphorus

	1998		1999	
Dhamrai:	CONV	ECO-90	CONV	ECO-90
Inputs	33	16	50	38
Outputs	-34	-22	-30	-32
Balance	*-1*	*-6*	***+20***	***+6***
Daulatpur:	33	37	20	7
Inputs	-31	-34	-42	-34
Outputs	**+2**	**+3**	-22	-27
Balance				
Gabtali:				
Inputs	56	61	43	31
Outputs	-27	-28	-28	-31
Balance	***+29***	***+33***	***+15***	*0*
Shibganj:				
Inputs	34	30	39	60
Outputs	-38	-31	-33	32
Balance	*+7*	*-1*	***+6***	***+28***

Potassium

	1998		1999	
Dhamrai:	CONV	ECO-90	CONV	ECO-90
Inputs	54	43	71	76
Outputs	-55	-36	-139	-133
Balance	*-1*	***+17***	*-68*	*-57*
Daulatpur:				
Inputs	51	65	25	9
Outputs	-54	-35	-157	-130
Balance	*-3*	***+30***	*-132*	*-121*
Gabtali:				
Inputs	87	59	187	109
Outputs	-65	-55	-107	-126
Balance	***+22***	***+4***	***+80***	*-17*
Shibganj:				
Inputs	62	39	62	58
Outputs	-59	-50	-120	-113
Balance	***+3***	*-11*	*-58*	*-55*

In contrast to N, the P and K budgets were often positive (Table 11, above). These elements are not subject to as many loss processes (particularly denitrification) and are supplied through the chemical weathering of soil minerals. Alternatively, there is no process of 'biological fixation' (although microorganisms are involved of mineralisation of P-bearing minerals and fertilisers such as rock phosphate and also in the cycling of all mineral nutrients). As noted above, organic matter inputs were a major source of P and K.

Nitrogen balance

It is not surprising that the major N input is through chemical fertilisers, almost wholly as urea (Tables 7 to 10). Organic matter inputs were used sparingly at Dhamrai and Daulatpur, a factor being competing uses (sold as fuel within the densely-populated Dhaka region) limiting its availability. In contrast, inputs of urea were lower and of organic fertilisers greater at the Bogra sites, in particular at Shibganj. (see photo 8 for FYM carrying basket). The ECO-90 plots at Gabtali had particularly low inputs in 1999. Table 12 (below) summarises the N balances for all the seasons for which data were available. The greatest deficits were for the Boro rice. Aman rice crops also had net N losses, of 20-40 kg N/ha at Bogra (Gabtali and Shibganj). No data was available for Dhamrai or Daulatpur, due to floods (1998) and to the fact that the fieldwork started after the 1997 crop was underway.

Rabi crops in all areas had positive N balances, which would counteract the losses of other crops. It is not yet possible to put a quantitative value on this as this would require a systems or farm-level analysis.

Table 12. Summary table of nitrogen budgets for duration of field observations arranged in chronological sequence (summer 1997 to summer 1999), for two management systems.

DHAKA & MANIKGANJ ZILAS.

		Dhamrai		**Daulatpur**	
Season		CONV	ECO-90	CONV	ECO-90
Transplanted	Input				
Aman (rice)	Output				
1997	**Balance**	**No data**			
Rabi	Input	49		142	
(potato, mustard)	Output	-14		-12	
1998	**Balance**	***+34***		***+130***	
Boro	Input	142	63	166	85
(rice)	Output	-244	-97	-239	-131
1998	**Balance**	**-102**	**-34**	**-73**	**-46**
Transplanted	Input				
Aman (rice)	Output				
1998	**Balance**	**No data due to severe floods**			
Rabi	Input				
(potato, mustard)	Output				
1998	**Balance**	**No data due to after-effects of severe floods**			
Boro	Input	233	60	120	28
(rice)	Output	-347	-171	-269	-156
1998	**Balance**	**-114**	**-111**	**-149**	**-128**

BOGRA Zila.

		Gabtali		**Shibganj**	
Season		CONV	ECO-90	CONV	ECO-90
Transplanted	Input	149	40	100	49
Aman (rice)	Output	-183	-79	-112	-63
1997	**Balance**	**-34**	**-39**	**-12**	**-14**
Rabi	Input	108	50	257	45
(potato, mustard)	Output	-71	-88	97	-73
1998	**Balance**	***+37***	**-38**	***+136***	**-27**
Boro	Input	132	124	141	85
(rice)	Output	-166	-130	-187	-115
1998	**Balance**	**-34**	**-6**	**-46**	**-30**
Transplanted	Input	110	49	96	68
Aman (rice)	Output	-129	-78	-117	-55
1998	**Balance**	**-19**	**-29**	**-21**	***+13***
Rabi	Input	160	35	316	1
(potato, mustard)	Output	-75	-80	-48	-35
1998	**Balance**	***+85***	**-45**	**+262**	**-34**
Boro	Input	146	40	119	110
(rice)	Output	-264	-181	-02	-170
1998	**Balance**	**-118**	**-41**	**-83**	**-60**

Nitrogen use efficiency

This was essentially the difference in yield between the plots which had the BARC recommended amounts of nitrogen applied and the plots from which nitrogen was withheld. See also Appendix III.3 for further discussion on the principles and interpretation. Two indices were calculated: kg grain N per kg fertiliser N (Agronomic efficiency of N; abb. AE(N)) and kg grain plus straw N per kg fertiliser N (N-use efficiency; abb. N-use).

A summary of the data for the BARC subplot, N-withheld experiment is presented in Table 13. In all areas the fertiliser N recovered in the grain was in the region of 10 to 27%. While this may not be exceptionally low when compared to other rice farming systems, it clearly indicates substantial inefficiencies or loss. If the straw is included, the situation improves somewhat (16 to 36%) but only if the assumption is made that the N taken off in the straw is returned as compost or FYM rather than being used as fuel.

Good yields were obtained in the BARC plots with relatively small regional differences. Yields at Dhamrai were consistently higher, even in the BARC-N plots, suggesting better soil fertility. The BARC-N plots supported yields of 2.8 to 5.8 t/ha, quite appreciable and possibly due to the residual affects of fertilisers applied in previous years. The long-term yields where no inputs apart from biological nitrogen fixation, sediments, crop residues, etc, are made would only be c 1-2 t/ha.(Greenland, 1998).

Similar calculations were made for the CONV fields (Fig 4 and Appendix II.5), i.e. differences between CONV and BARC N-withheld plots. However, this was not a paired-plot design, (unlike the BARC vs BARC-N sub-plots) due to the practicalities of the layout of the fields. The conclusions were broadly the same; low AE(N) and N-use efficiency.

Mineralisable nitrogen

At the start of the Boro season there was about 50 kg N/ha in the soil as nitrate and ammonia (Fig 10), mostly as nitrate. On flooding it was assumed that all the nitrate was lost (based on the literature) through denitrification. In addition to this inorganic N, there are organic fractions available for mineralisation. An anaerobic incubation procedure was used to measure this (Fig 14), in which soils were sealed in bottles and incubated for a week at a constant temperature, after which the increase in ammonium-nitrogen was determined. A range of 20 to 70 kgN/ha/week was mineralised under the assay conditions. It is not known at what point (in weeks of incubation) the curve levells off, but this process was clearly an important source of N, albeit recycling what was already present in the soil.

Table 13. Summary data of yields, indigenous N supply (from the BARC- N withheld plots; 'BARC-N'), offtakes, and proportion of fertiliser taken up by the crop (difference between BARC and BARC-N), in the grain and in grain plus straw combined. Boro crop, 1998 and 1999. N fertiliser added as urea. See Appendix II.5 for original data and statistics.

Treatment and	Dhamrai		Daulatpur		Gabtoli		Shibganj	
Measurements	1998	1999	1998	1999	1998	1999	1998	1999
Kg N/ha (BARC)	100	99	99	101	104	100	100	100
Yield, t grain/ha:								
BARC	6.15	5.83	4.45	4.59	4.16	4.67	4.13	4.76
BARC -N	4.27	5.14	3.03	4.14	3.10	3.83	2.80	4.18
Difference:	**1.88**	**0.69**	**1.42**	**0.45**	**1.06**	**0.84**	**1.33**	**0.58**
% N of grain:								
BARC	1.17	1.15	1.18	0.85	1.06	1.36	1.11	1.26
BARC-N	1.05	1.12	1.10	0.83	1.02	1.29	0.98	1.20
Yield, kg N/ha								
BARC	71.9	67.0	52.5	45.1	44.1	63.5	45.8	60.0
BARC-N	44.8	57.6	33.3	34.4	31.6	49.4	27.4	50.2
Difference	**27.1**	**9.4**	**19.2**	**10.7**	**12.5**	**14.1**	**18.4**	**9.8**
Agronomic efficiency (AE-N) = kg grain N per kg fertiliser N:								
AE-N	**0.271**	**0.095**	**0.194**	**0.106**	**0.120**	**0.141**	**0.184**	**0.098**
N offtake, grain + straw, kg/ha								
BARC	96	136	74	72	71	129	68	114
BARC-N	64	112	45	56	47	93	37	80
Difference	**32**	**24**	**19**	**16**	**24**	**36**	**31**	**34**
N-use efficiency (N-use) = kg grain N plus kg straw N per kg fertiliser N:								
N-use	**0.320**	**0.243**	**0.292**	**0.158**	**0.231**	**0.360**	**0.310**	**0.340**

Fig 14. Pools of microbial nitrogen measured by anaerobic incubation.

Indicators

The indicators developed were to reflect the impacts of management practices on underlying processes related to soil fertility, e.g. soil organic matter turnover and mineralization. These techniques were based on measurement of pools of i) soil organic matter that are sensitive to changes in management and ii) methods to characterise microbial communities. These were based on techniques which can be used in Bangladesh with limited facilities.

General properties of indicators

No single indicator would be suitable and, given limited resources, many which could be developed for the purposes of the research component of the project would not be appropriate for the monitoring and development component. The qualities we would look for are:

1. validity of the measurement;
2. sensitive to changes in the organic matter fractions that are to be used as SOM indicators (discussed above);
3. if laboratory based, not too sensitive to disruption caused by sampling;
4. usable *in situ* (in the field).

Soil organic matter

The total soil organic matter (SOM) content of soils is generally rather high and small changes are difficult to measure relative to this large background. However, such small changes may be critical in terms of fertility. Thus indicators of SOM aim to identify smaller pools of organic matter that contribute directly through their mineralisation or turnover to soil fertility. Accumulation of organic matter due to increased inputs that can be decomposed readily by microorganisms will lead to an increase in the biomass C per unit soil organic C. Depletion of soil organic matter or inputs of organic matter which cannot be decomposed will result in a decrease in the biomass C per unit soil organic C. Other potential indicators include measurement of labile C by using an oxidation procedure or the use of density separation to quantify. In this project we compared the use of density separation and microbial biomass C (see next section).

The soils were collected at the end of the 1997 Boro season (May-June 1997) as part of the baseline soil survey. The density separation procedure fractionated the organic matter into a free light fraction (FLF) and an inter-aggregate light fraction (IALF), amongst others (denser fractions). The FLF is considered to be the more labile fraction as it is not protected form mineralisation by being enclosed within aggregates. It is also relatively recent in origin, so has not become humified or sequestered in clay minerals. Generally the differences in the FLF carbon were small or not significant (Fig 15). The amounts of FLF-C were not greatly or consistently different to the IALF. An exception was ECO-90 at Dhamrai, where larger amounts of OM were added to the fields over the previous seven years than at the other sites. During this time the IALF would have accumulated, even though the FLF was little different to the other areas. Since the samples were collected at the end of the season it is likely that much of the labile SOM had been mineralised.

The pattern for N content of these fractions was very similar to that for C. Some of the differences between the N content of fractions were greater (e.g. Shibganj) than for C.

Since these fractions are labile, they are by definition sensitive to the time of sampling. Thus their use as indicators would depend on further research into the understanding of the dynamics and what drives this, and then to devise an appropriate protocol. (See Appendic III.3 for further discussion).

Fig 15. Quantity of C and N in the free light and interaggregate fractions.

Soil microbial biomass and activity

Microbial biomass and respiration.

The underlying hypothesis of these indicators is that changes in soil fertility (and SOM content) reflect management induced changes in the ability of the soil microbial communities ability to decompose organic matter inputs.

Soil microbial biomass (SMB) is a pool of labile organic matter and is directly involved in its mineralisation and turnover or cycling, the relationship between total soil C and biomass C can be used as an indicator.

The basal respiration of microorganisms (BR) in soils (i.e. without the addition of carbonaceous substrates immediately before or during the assay) is also a reflection of the SMB and of the amount of respirable organic matter in the soil.

Substrate-induced respiration (i.e. when a substrate, generally glucose has been added in an amount sufficient to satisfy the full respiratory requirement of the SMB), has been used as a measure of the 'active' microbial biomass and the potential rate of C mineralisation when C substrate is not limiting.

Microbial communities.

There were a number of candidates, such as:

a) 'biomarkers', where organic compounds specific to particular groups of organisms are analysed,
b) substrate utilisation assays (or community response profiles, CRP; Degens & Harris, 1997; Degens, 1999), in which a soil sample, or isolates from the soil, are incubated in a range of substrates, the pattern of use (measured by simple colour changes) giving some indication of functional groups and taxa and
c) metabolic and enzyme activity (nitrogen fixation, methane production and oxidation, dehydrogenase).

These three methods require access to good (and reliable) laboratory facilities. Further, there is little information yet on using (interpreting) any of these in tropical soils and, despite the promise of these methods, they would have required a considerable investment in order to make them useful (in delivering the project outputs). Hence, it was decided to use the tried and tested measures of SMB and BR (see ii, above).

Several methods were tested over the first 18 months of the project. These were:

1. Soil microbial biomass (SMB), as carbon or nitrogen. A chloroform-fumigation and extraction method, developed and tested at IRRI for flooded rice field soils (Gaunt *et al.,* 1995), was used routinely.
2. Soil basal respiration (BR) measured (as CO_2 output) using an infra-red gas analyser (IRGA). This instrument was battery powered so could be used in the field. Gives either an instantaneous (spot readings) measure of respiration, or an integrated value ofer a period of time, depending on the experimental setup used.
3. BR measured by absorbing the CO_2 in an alkali (NaOH)- the classical method. Can be used anywhere, as little equipment, none requiring power, is required. However, we used this mainly for laboratory based experiments and incubations. This method is less sensitive than the IRGA and required 24 hours or so for sufficient CO_2 to be absorbed to be measurable, so integrated only.

4. Substrate-induced respiration (SIR), as a measure of the potential activity (as C mineralisation) of the SMB. A single substrate (glucose) was added in a quantity sufficient to saturate the requirement at the maximum rate of respiration of the SMB and CO_2 output measured (by both IRGA and CO_2 absorption) over a short period of incubation (not more than 4-6 hours, depending on soil, SMB, etc). The assumption is that the SMB does not increase during the course of the incubation assay.
5. Respiration response to a range of substrates (added singly). Basically a SIR, but with many different substrates, giving a profile of the catabolic capability or pattern of the soil microbial community. Referred to as catabolic response profiles (CRP) by Degens (1997). This is a potentially interesting approach but currently the interpretation of the different 'patterns' is limited mostly to observing differences (e.g. through pollution, or a chronosequence of development, etc). So, although academically challenging, it was decided not to pursue this approach in this project. A further problem was that nearly all the work was done on temperate soils and virtually none on waterlogged or anaerobic ones.

The methods and indicator measures selected were SMB-C and N (1) and BR (routinely 3, some 2). In the process of measuring SMB data for extractable C (EC) were obtained (from the unfumigated controls). Inorganic N in the SMB samples was also measured as an indicator of mineralisation.

From the SMB and BR data the respiratory quotient (qCO_2) can be calculated, BR/SMB-C, an indicator of the respiratory efficiency of the SMB. This has been suggested as an indicator of stress brought about by changes in the soil, for example by pollution or disturbance. It could also be affected by availability of substrates- a higher qCO_2 if abundant and no need to conserve or be 'efficient'. An alternative factor is the successional process, from an disturbed environment with fewer species of pioneers (k-strategists) through to a climax one where a wide diversity of microorganisms are in competition (R strategists).

Table 14. Soil microbial activity. Basal respiration (BR) and substrate-induced respiration (SIR) as μg CO_2-C g^{-1} dry soil h^{-1}) and metabolic quotient (qCO_2) of fresh soils. Soils collected from Gabtali June 1998, at end of Boro hervest.

	Management:					
	Conv			Eco-90		
activity	mean	SD	CV	mean	SD	CV
SMB-C	208	57.5	0.277	133	58.8	0.441
BR	0.622	0.296		0.977	0.346	
qCO_2 (BR/SMB)	0.00320			0.00845		
SIR	2.126	0.523	0.246	4.247	1.565	0.368
BR/SIR	0.272			0.223		

The differences in microbial biomass and respiration between ECO-90 and CONV were generally small in relation to the variability, especially for fresh soils (Table 14). The same was true for substrate-induced respiration. There did not seem to be a major difference in the capacity of the soil microflora to utilise readily available substrates between ECO-90 and CONV. There were, however, indications that there were differences in the microbial communities (Fig 16). This was on the basis of difference of the differing patterns of response to a range of organic substrates (CRP) although insufficient work has been done in order to interpret the data.

In example above (Table 14), the qCO_2 showed greater differences although there were insufficient data for calculation of errors. However, given the variability of the other parameters (which were typical for this kind of measurement) the 20-3-fold difference may be significant.

Sampling and handling will have a major impact on microbial populations and activity. Several tests were carried out, such as the effects of storage and pre-incubation, and these are described in Appendix III.7. It can be stated that whatever the methods used, there will be changes, especially as the soils were wet or waterlogged (and thus likely to be anaerobic) for much of the year. The most rapid changes occur in the period immediately after sampling; which can be a matter of minutes or hours (anaerobic metabolism) to days. The best option, given the limited facilities, was to make measurements after a period of storage to reduce variation. We found that populations decreased rapidly after collecting the soil in the field, but that after two weeks stored at 4 °C, or after air-drying for 1-2 weeks, biomass and respiration had stabilised. Storage for longer than six weeks was not desirable. As the populations had changed and the data cannot be used as a measure of activity (e.g. mineralisation) in the field. They may serve as indicators, or as a measure of mineralisable N (see Fig 14, above) or organic matter (Appendix III.7).

One objective was to test microbial biomass and activity parameters as an indicator of labile SOM fractions. This was done using the Baseline soils collected in 1997 and stored air-dry for a year before the experiment. Single and multiple regression analysis of the data showed that the best correlations for the most sites were for MBC vs BR/TC/EC (TC = total C, EC = extractable C, i.e. the unfumigated control). Pairs of variables were not always or consistently correlated, apart from MBC vs EC. The best fit was between anaerobic mineralisation of N (see fig 14) vs MBN/TN (MBN = microbial biomass N; TN = total N).

Fig 16. Catabolic response profiles (microbial responses as SIR to a range of substrates).

Outputs

Introduction

The outputs originally committed to in the PMF were:

1.1 A report assessing the current state of knowledge of the importance of: organic matter in maintaining soil fertility, particularly in relation to small-scale farming systems; and environmental indicator measurements.

1.2 A prototype nutrient budget (computer software model).

2.1 An inception report detailing sites, (history, management) experimental design, analytical and assay methods.

2.2 Farming system based nutrient budgets: summary budgets for 20-50 sites; detailed budgets for at least two key management practices contrasted.

3\. Environmental indicators to monitor changes in soil organic matter dynamics and activities of microbial communities.

4\. Options to improve soil fertility and establish methodologies for management and monitoring.

Nutrient budgets: a comparison of two farming systems

In large part, the poor agronomic efficiency of applied N achieved by conventional fields resulted from mismatch N applied to that required by the crop. This suggests that there is scope for considerable improvement of AE(N) through more effective nutrient management. Several field studies have demonstrated an increase in AE(N) from eliminating or reducing the amount of N applied in the crop establishment and early vegetative growth (De Datta *et al.,* 1988; Cassman *et al.,* 1994; Peng *et al.,* 1996b). These tactics increase the congruence between crop N demand and N supply because soil N mineralisation is greatest after flooding (Dei and Yamasaki, 1979). Monitoring of plant N status to determine the need for topdressing is one option for improving the congruence between N supply and crop demand (Peng *et al.,* 1996b).

A key question is why farmers did not respond to differences in the indigenous N supply (INS) by adjusting the rate of applied N accordingly. Year to year fluctuations in the indigenous N supply would make it difficult for farmers and extension researchers/scientists to obtain consistent results from experimentation with different N fertilisation tactics. The grain yield from N-withheld (BARC-N) sub-plots might provide farmers with a practical surrogate parameter for the indigenous N supply once the relationship between grain yield and N uptake has been defined. Although this relationship significantly differ somewhat from year to year. Monitoring grain yield in BARC-N fields over time would also provide information about crop management effects on indigenous N supply, which might help farmers' optimise the N contribution from indigenous resources. Detailed discussion of the reasons for such large fluctuations in the indigenous N supply are beyond the scope of this report. The measured range would account for only a small portion of the differences in the indigenous N supply in farmers' fields. Instead, we suspect the observed variation in the indigenous N supply among lowland rice fields reflects differences in soil conditions and management during the fallow period. The degree of soil drying, residue management and subsequent effect on N mineralisation and retention of available N in the root zone are considered key factors (Cassman *et al.,* 1995; Gaunt *et al.,* 1995; Kundu and Ladha, 1995).

The results provide initial evidence that farmers are not applying fertiliser at optimal rates. Some apply too much N fertiliser, others are too little in relation to INS of their fields, resulting in low %AE(N) or grain yield. According to the farmers, one reason for the lack of congruence between INS and their N fertiliser rates is that while they know which fields have greater or native soil fertility, they have not had the means to quantify that. N-withheld plots provide a laborious but direct measure of plant-available N and so appear to be a useful index for researchers. However, these may not be useful for measuring INS when plant N uptake or grain yield is limited by pest or poor weather instead of available soil N (Olk *et al.,* 1999). In this study, however, widespread pest damage in the N-withheld plots was not observed.

Indicators of changes in soils

Soil organic matter fractions

Total soil carbon changes slowly, as the greatest part is in a form that is resistant to breakdown by microoraganisms. Only a small proportion is in the 'active' or labile fraction. This is in the range 1-5%, depending on what is included, as there is a spectrum from recalcitrant humified compounds to carbohydrates. It is the labile fraction, or 'fast' pool that is significant in satisfying plant nutrient requirements (in addition to inorganic fertilisers), but it is the large 'slow' pool that holds the long-term reserves. We found that this was particularly relevant in the case of N, where there were large short-term losses which may have been made good by mineralisation from these pools. The reasonably good yields from the plots where the N was withheld for a short time (1-2 years) indicates that this may be so.

We examined IALF and FLF in soils collected at the end of the Boro crop. The more labile of these fractions (FLF) was lower than the IALF. There was little difference between ECO and CONV apart from one site, which had a lot of organic matter, added over seven years. Samples collected within the first few weeks would have been of interest. The method is laborious and relatively costly, and so frequent sampling would not be practical in this case (except as a research project).

Soil microbial biomass and activity

The microbial biomass is both a pool of nutrients in the organic form, and the primary engine driving soil fertility- the cycle mineralisation and immobilisation. The research findings discussed above show that, although a potentially powerful and revealing tool (in terms of science), its application as an indicator is not straightforward. Like other labile organic fractions, it would be expected to change markedly over the season. Sampling later during the growth of the crop might be the best option if fresh soils are required. Then the readily usable substrates from decomposing crop residues would have been immobilised (Witt, 1997) and thus population dynamics would fluctuate less widely. This was observed to be the case for methanogens, as measured by methane emissions from soil; about 4-6 weeks would be required from flooding, depending on the amount of crop residues incorporated (unpublished data).

A further complicating factor is the effect of sampling and treatment. Provided that these factors are tested and that the variations and their causes are known, it is possible to develop an assay protocol which is usable over a wide range of conditions. The microbial biomass N and anaerobic N mineralisation assay were closely correlated for most sites, so these are candidates. Ratios (e.g. qCO_2) may be less susceptible to short term fluctuations in their components.

Establishment of field trials

The recovery of yields on conversion from inorganic fertiliser inputs to organic ones takes some time- generally 3-4 years in temperate farming systems. PROSHIKA considers that its ecological farming programme can recover profitability within 1-2 years, primarily through the reduction of costs of inputs. It was clearly the case that much of the investment in N inputs (whether inorganic or organic) could be considered to be wasted.

It was appreciated from the outset that some kind of long-term programme of quantitatively and (soil) scientifically monitoring farmers' fields under ECO and CONV was needed. As it happened, the ECO-90 fields supplied this need. PROSHIKA motivated us (the project) to set up additional sub-plots (ECO-90 in project terminology) as a means of promotion and development.

Contribution of outputs

Introduction

The project has generated some outputs which were not specified, at least in detail, in the project memorandum. However, the contributions of all significant outputs are discussed below. The outputs have been divided into two types:

Institutional:

1. The collaborative linkages between three main kinds of organisations- the NGO (PROSHIKA), a university (Dhaka University) and research institutes based in the UK (IACR-Rothamstead and NRI).
2. Farmer participatory research. There has already been significant feedback from farmers whose fields we are using, and others were keen to collaborate.
3. Development of research capacity (technical, training, and the working relationships between organisations).

Technical or research:

1. Nitrogen use efficiency of the Boro rice crop
2. Major loss processes of nitrogen
3. Other components of the nitrogen cycle as regards the crop (especially inputs other than fertilisers)
4. Indicators of changes in soils

Institutional contribution

Collaborative linkages

The project started in December 1997 with a team, and a group if organisations, that have not previously worked together. The project actually got underway in February 1998, when the first team meetings and field visits were held in Bangladesh. The learning curve was thus initially steep, as the project infrastructure and organisation were honed.

A crucial factor in this process, and a major contribution to the overall success of the project, was the secondment of a member of PROSHIKA's staff as a 'Project Coordinator'. This key role linked the team members working in the field, and in laboratories in Bangladesh and the UK (Fig. 17), and it also assumed the overall management of activities in Bangladesh.

Research projects in the universities of Bangladesh tend to be based around the requirements of higher degree studies. Further, there are limitations in equipment, but more particularly, the means for extended or extensive field work. Through collaboration with locally-based organisations with an extensive network at the village level these constraints can be reduced. Thus Dhaka University provided soil science expertise and the field work programme could be carried out as planned with the transport facilities and field workers of PROSHIKA.

Fig 17. Linkages within project.

The UK based collaborators provided inputs at several levels. The most significant were the technical and scientific advisory roles at the inception and initiation phases, and during the initial field work period. Specialist laboratory and analytical facilities were provides, as was training in the form of supervision of higher-degree students working on the project.

Given the demand for further research and for development of the project outputs articulated by PROSHIKA, it is probable that the experience of the current team of HQ managerial staff, the project coordinator, and the field staff (the EDWs) would be a valuable resource. The links built with Dhaka University and the expertise developed are also an asset.

Farmer participation

The farmers identified by PROSHIKA at the start of the project were willing collaborators. Once the fieldwork and the experimental plots were under way other farmers expressed interest, on the assumption that the research will benefit them through increasing production. There were concerns from some farmers in situations where the researchers' interventions could reduce yields, such as the N withheld sub-plots. These sub-plots were relatively small and so the farmers could be compensated for the difference in yield compared to the local average without causing perturbations in the local economy. The situation did not arise where the farmers compensated the project where the yields in the experiments were greater. Thus, where significant changes in management are required to test a hypothesis, the smaller the area affected the better.

Research and technical contribution

Nutrient dynamics in rice fields.

This project provided detailed and scientifically validated data. Nutrient budget were constructed, in which the various inputs and outputs will be quantified, the sources and sinks identified, and the potential impacts of changes in farming practices assessed. This can be used to develop predictive models which could then be used as tools in the identification of constraints in existing farming practices and to devise modifications and new practices which could then be tested in the field by farmers. By examining both conventional and organic ‘ecological farming’ practices we can rationalise, and consider strategies for improved nutrient management as part if an ICM package.

The main outcomes of the field monitoring programme, strengthened by the evidence from the researcher-managed sub-plots, were the inefficient use of N and the high rate of turnover (flux). Large amounts of N were incorporated in the weed biomass. The budgets should not be seen as 'water-tight' since a proportion of the 'loss' as straw from the Boro crop will be returned to the farming system. Quantifying in any detail this system-level budget was outside the scope of the project and would be a major task in its own right. However, the outputs would go some way to reducing the task.

Specific points include (see also Strategy: the Next Steps, below):

1. Low nitrogen use efficiency of the Boro rice crop
   Was found to be only 10-20% of the fertiliser (urea)-N applied in terms of grain yield, 20-30% for grain and straw. This applied for both management systems (CONV and ECO-90). This may be because most of the fertiliser inputs are made early in the cropping cycle.

2. Major losses of nitrogen
   The N budgeting exercise revealed that losses from processes other than crop offtakes were a major proportion of the total turnover.
   This is probably not greatly different to published data; the significant aspect (together with N-loss, below) was that the data were for farmer-managed fields.

3. Significance or organic matter pools, particularly of N.

Indicators of changes in soils

The purpose of this project was not to undertake research into the complex interactions between SOM, microorganisms and the managed environment (agroecosystem) but to determine whether these could be developed as indicators useable by farmers and extension workers, particularly as an early warning system of impacts (beneficial or adverse) of changes. The aim would be to detect changes within about 2 years of a change in farming practice.

Soil organic matter fractions did show differences, but generally were statistically significant where large amounts of organic matter were added to the soil regularly over a period of some years (≥5). This observation, however, was based on a one set of samples (the Baseline soil survey) and it is known that both the amounts and constituents (chemical form) of organic matter can change rapidly over the cropping season. It is suggested, therefore, that given the cost of this kind of work its usefulness lays in use as a research tool for investigating organic matter dynamics than as an indicator for extension workers to use.

The same conclusion could be reached for the soil microbial indicators. However, it is relatively easy to measure some aspects, such as biomass and basal respiration, with simple equipment. Thus, since the labile fractions of SOM and SMB (which is in any case a part of the labile SOM) are closely related, the SMB could act both as an indicator and as a measure of labile SOM.

The most practical and reliable indicator was one of the parameters measured as a routine in soil surveys: bulk density. It has the advantages of simplicity and of being less sensitive to seasonal fluctuations than the others we tried. Yet, it was able to discriminate between ECO-90 and CONV in three of the four areas, even where the conversion to ECO was relatively recent (3-5 years).

Strategy- the 'next steps'

In the second project workshop (Appendix III.2) three working groups were formed to discuss various aspects of the project. One group discussed the current project research plan whereas the other two looked at:

- Developing tools for ICM, and
- Dissemination of tools and outputs.

A number of recommendations were made, in the context of this project of research activities in soil fertility and ICM. These included:

1. An integrated approach is required, drawing on technologies derived from indigenous knowledge and research.
2. This requires a participatory approach, also necessary to achieve uptake

Photo 11. Changes I- power tillers replacing bullocks and country plough.

Photo 12. Changes II- conversion of farmland into brickfields; soil into buildings. Peri-urban Dhaka.

3. Scientific research projects generally produce a lot of data and complex interpretations; this needs to be condensed into simple messages and 'rule of thumb' interpretations. This is the heuristic approach (Heong, 1999).
4. An understanding of farmers' perceptions is required- of soil health, fertility, their values and abstract features. Adaptation of soil scientists' quantitative approach to the terminology used by farmers needed.
5. Involvement of all stakeholders- farmers, local extension and development workers, HQ staff, researchers- from the start. This presupposes continuing input and exchange- discussion, training (familiarisation), communication- over some time, not encapsulated into specific projects.
6. Groups should not be excluded, either through economic reasons, or through cultural ones. Not all farmers are in a position to adopt desirable practices, but the network should still be there and they have an opportunity to hear a different perspective (this applies particularly to Ecological farming).
7. Broadcast mass media is often effective. Other publicity would include attractive billboards to advertise research and testing activities and fields.
8. There were several others (e.g. gender issues, alternative means of generating income, the scientific means of identifying constraints), but the overall view was that an integrated approach should be followed and that solutions would come from initiatives developed locally rather than from blanket recommendations.

A discussion of some points from the project outputs:

Addition of organic matter, as crop residues and manures, often improves soil characteristics, a fact well known and appreciated by farmers. Ways of optimising quality (as C:N and N:lignin ratios) in terms of synchronising mineralisation with crop requirements is the key. This would apply regardless of the abundance of organic matter, but availability of materials will affect options. A starting point would be the 'Quick Compost' developed by PROSHIKA. This is a mixture of oilcake, rice bran and FYM in the ratio 1:2:4 and composted for two weeks. FYM is a varied mixture of cowdung, household wastes, and poultry litter if available.

Farmers often try out new ideas or make a succession of small changes to their farming practices. The use N-withheld mini-plots, or other management, as a comparison may be effective in aiding their appraisal of the effectiveness of the changes. Alternatively, a corner of the field could be left under the old management as a form of control experiment.

The ECO-90 fields should continue to be monitored, but on a less intensive basis now that the key variables are better known.

The most practical indicator to monitor these changes is bulk density. It ia also a reflection of the workability of the soil and was correlated with other parameters of an improvement in soil fertility. Calibration would have to be on a local basis, depending on soil type, but it seemed to be applicable over wide areas. This calibration affects other indicators as well, such as leaf colour charts.

One tool or output that was developed for use by the project was a GIS. This was instigated at the end of 1998 with the objective of integrating the spatial data (e.g. distribution of research plots) with other information (management, irrigation systems, topography). Although this information was already available in various forms it was considered necessary to start to develop the GIS as a tool for continued development of the other outputs.

In the light of concerns over sustainability and perhaps as a result of policies to shift towards a decentralised and localised approach, relying on inputs from farmers and a bottom-up research strategy, there is an increasing concern to consider low-input practices. These have long been developed and promoted by NGOs and so they will have accumulated a fund of knowledge and experience.

The evidence of benefits or yield gains however is based on the evidence of observations of the end results of management practices on demonstration plots and farms. PROSHIKA is an NGO in Bangladesh, advocating ‘Eco-farming’ in the context of their broader social programmes.

A limitation was the quantitative data was on a per field basis whereas the farming system operates on a farm and village community scale. This scaling will have to be built into the budgets and models but it depends on how details or broad-ranging these are to be. For instance, it may be necessary to devise some means of incorporating government policies on subsidies and market prices of fertiliser, fuel and crops. At the project level we will work on the ‘farm’ (household) as the unit.

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Appendices

List of appendices:-

I. Activities

II. Outputs

III. Dissemination

IV Miscellaneous

I. Activities

I. 1. Summary of literature- organic farming, nutrient budgets, indicators

Organic farming

The fundamental axiom of organic farming is “healthy soil produces healthy plants”. This is difficult to define, but practices which maintain high levels of soil organic matter and a diverse soil micro- and macrobiota provide an environment, which, through some as yet unknown process, improves plant health (Merrill, 1983). A lower incidence of pests has been observed when maize was grown in organically farmed soil (Phelan et al, 1995). Even ten years on the mechanism is not fully understood, in this case it is attributed to some form of buffering rather than on the form or supply of plant nutrients. This buffering has been attributed to amelioration of pH, soil moisture and nutrient supply, etc, but may operate at a higher level- the susceptibility of plants to attack by pests (Phelan et al, 1995). Improvements in soil structure, water-holding capacity, cation exchange capacity and nutrient retention has often been observed (Prasad & Goswami, 1992).

Although organic farming practices can be as effective as conventional ones there are greater difficulties predicting and supplying plant-available nutrients. Organic matter is decomposed and mineralised by microorganisms- an extra link in the nutrient supply chain (Hendrix *et al,* 1992). Factors which affect the composition and activity of microorganisms will thus affect the health of the soil. Pankhurst *et al* (1995) found that some components of the microflora were more affected than others by a change in practice. Mycorrhizal fungi, protozoa, pepsidase and cellulose decomposition were better indicators then total microorganism biomass, mineralisation of nitrogen or phosphatase. This data was collected from a long-term arable field trial in South Australia so cannot be assumed to hold in other agroecosystems. This is an aspect that needs investigation, in view of the fundamental role of microorganisms in all aspects of the cycling of nutrients.

Although required for the elucidation of organic matter-nutrient dynamics it is not certain whether indicators can be devised for monitoring changes in the microbiota without the aid of relatively sophisticated biotechnology. The activities of the microbial community is so interwoven that it is difficult to unravel (Sims, 1990) and thus separate the direct from indirect effects. The technology changes rapidly so this could (already) have changed; one of the project activities is to research this.

Crop residues and farmyard manure are valuable resources with many alternative and competing uses. In low-lying seasonally-flooded areas (beels), or in tanks and drainage canals, the biomass of aquatic plants can be appreciable, up to 0.5 tonnes/ha in deepwater rice fields; the total biomass of rice plants was 10-12 tonnes/ha at that time (Rother & Whitton, 1988). The concentration of the major nutrients and essential trace elements however was much higher and would be an effective means of improving soil fertility. It should be noted that aquatic plants are also efficient accumulators of heavy metals, which would have to be checked if their use is promoted for agriculture in the peri-urban interface. Continuous cropping and application of chemical fertilisers has led to trace element (Zn, Mo, S) deficiencies in large areas of Bangladesh (Byerlee, 1992; Rashid, 1994). The efficient ‘harvesting’ of aquatic plants could help to mitigate although there will be conflicts and limitations due to competing demands, alternative uses and labour costs. This may have an impacts on present or planned projects in other production systems, for example Land-Water Interface and Peri-Urban.

Indicators

The performance of these options, and also of the current trials, needs to be assessed in relation to current farming practices and to agricultural development already in progress (e.g. the dissemination of improved modern varieties, fertilisers and pesticides). Yields of grain and cost-benefit analyses have long been used but are generally limited to those factors (i.e. inputs of fertilisers, pesticides, etc.) which are currently perceived by policy makers and NARs to be relevant. With the growing concern over sustainability, soil health and the importance of organic matter other measures of performance need to be developed. In this project we will develop two main kinds of indicators, selected in view of their potential as monitors of the impact of changes in farming practices:-

- soil organic matter (SOM) fractions
- microbial biomass and activity.

The variables to be measured for each of the two indicators were chosen on the basis of their importance in determining the nutrient supplying capacity of the soil, nutrient reservoirs, cycling of nutrients and thus their key role in maintaining soil fertility. Secondary factors can also be important, for example the improvement of soil workability when compost is used.

There is a requirement for quantifiable indicators capable of assessing impacts of different agroecosystems and management practices on the environment. This is partly due to the heightened awareness of the unsustainability of intensive agricultural systems, which are able to bypass many natural biological activities in the soil. For example, the use of fertilizer reduces the role played by the soil microbial biomass in supplying nutrients to the plants (Swift and Woomer, 1993). Cultivation also increases the natural rate of microbial processes, carbon mineralization being double that under a natural system (Tiessen et al., 1994). This causes concern because of the increased dependence of cropping systems on inorganic nutrient sources and the probable deterioration of the soils physical condition (Sparling, 1991). Additionally, environmental conditions greatly effect the inherent potential fertility of a soil. Soils from an Amazonian rain forest were found to support agriculture economical and unsupplemented for up to 3 years following slash and burn, as compared to 65 years for a temperate prairie and 6 years for a tropical semi-arid thorn forest (Tiessen et al., 1994). Therefore tropical soil management has to take into account the faster turnover rate of organic matter and other nutrients.

Indicators which evaluate and monitor the environment should ideally be easy to measure and sensitive to changes at the desired level of accuracy (Gaunt *et al*., 1995). Additionally they should be able to clearly assess the availability of the resource and the rate of its use, so as with cropping systems, they indicate the sustainablilty of the management practices in that system (Swift and Woomer, 1993). To gain a comprehensive understanding of the parameters involved in soil fertility and the sustainability of systems a number of indices may be required (Swift and Woomer, 1993).

Soil organic matter indicators

Soil organic matter is central to many indicator ideas, being a source and a sink of nutrients, a renewable resource and having a large effect on soil fertility. A number of investigations fractionating soil organic matter into different components found that the light density fraction was more sensitive to management changes and therefore could be used to monitor changes in soil fertility (Hassink, 1995 and Imhof *et al.*, 1995). Similarly there are attempts to correspond measurable organic matter fractions to soil nutrient dynamics, it has been found that the labile organic matter component, being highly enriched in organic carbon and more rapidly decomposed as compared to the whole soil, probably supplies many of the soils nutrients (Dalal and Mayer, 1986 and Dalal and Mayer, 1987). Other indicator ideas include measuring the maximum rates of decomposition and mineralization which could provide a baseline for assessing the microbial communities and their functions in the environment (Gaunt et al., 1995). Swift and Woomer (1993) outlined a number of indicators centered mostly around organic matter;

1. the ratio of microbial biomass: total soil organic matter (TSOM);
2. labile soil organic matter (LSOM);
3. LSOM :TSOM;
4. nitrogen mineralization capacity;
5. the quality and quantity of organic inputs;
6. the contribution of cation exchange capacity;
7. indicator species of soil fauna and flora for example earthworms.

Of those outlined, the first five indicators deal generally with the organic matter inputs, and the rate of mineralization together with the overall change in the soil organic matter content. The microbial biomass and labile soil organic matter being more sensitive to management changes and inputs than the measurement of total soil organic matter. Whereas the quality and quantity of organic inputs ultimately effects the rate of decomposition and subsequent availability of any nutrients, such measurements include the C:N ratio of the plant material, the protein binding capacity, (lignin + polyphenol) :N ratio (Handayanto *et al.*, 1994).

The last two indicators give a chemical and biological indication respectively of the fertility status of the soil. Biological indicators sometimes are also used to measure the health status of a soil, a fertile soil being able to support a larger and more varied community of flora and fauna.

Soil microbial biomass and activity as indicators

The importance of microorganisms (bacteria, fungi, protozoa and algae) in soil processes has been recognised from the earliest days of soil science (***). The progress of research into their roles has, however, been hindered by the technical difficulties involved in investigation of the dynamics of complex and interacting ecosystems on a microscopic scale. Much of the research effort has been directed to the behaviour of whole systems or communities in response to various factors. Examples include the cycling of nutrients, in particular of nitrogen, their role in the global carbon cycle, and the inpacts of pollution. Some groups with specific nutrient requairements or matebolic pathways, such as the nitrifying and nitrogen fixing bacteria, are more amenable to investigation than the ‘generalists’ so the distribution of data within the broad group of the microorganisms is very patchy.

Requirements of an effective indicator

These will vary depending on the questions (hypotheses), the facilities available and above all on the objectives of the project in relation to the beneficiaries, i.e. the uses to which the indicators will be put. In this project the problems of selecting and employing an indicator of soil health/fertility are compounded by the normal seasonal fluctuations in the environment, with annual flooding (June to October), irrigation during the dry season, non-irrigated areas, and areas which are not flooded or only occasionally so, for example by heavy rainfall (see Farming Systems). Ideally an indicator should be:

1. sensitive to the changes to be measured;
2. easily measurable with the resources available;
3. the measurements should be replicable;
4. usable over a wide range of conditions (soils, farming systems);

Types of microbial indicator

Microbial indicators can be grouped into three main classes:

1. biomass,
2. activity,
3. diversity.

Within each class there are numerous methods, some of which are generally considered to be ‘standard’ through widespread use, for example the chloroform fumigation and extraction method for microbial biomass C, N and P. The divisions between the classes are not watertight; an estimate of biomass may be based on physiological activity such as rate of respiration, diversity includes functional diversity as well as taxonomic. In all cases, however, the type of assay used, and the method employed to measure it, must be tested by comparison with a range of other methods and soils as well as with previous findings. The objective it to check that the data are reliable and representative for the conditions of the experiment (soil type, physico-chemical conditions). Many of these measurements were restricted to measures of total microbial activity, respiration being the most commonly used, or to laborious techniques requiring culture and isolation of single taxa, or of time-consuming visual counts by microscopy. Breakdown of specific organic compounds has been used as a measure of specific groups of microorganisms, as has the analysis of certain marker compounds (termed ‘biomarkers’ e.g. phospholipid fatty acids (PLFA), muramic acid) thought to be specific to groups of orgnaisms.

Pankhurst *et al* (1995) investigated a number of organisms and their properties and how they were affected, if at all, by farming practices. These were conventional versus no-tillage, stubble managed (retained or removed), rotation and N-fertilisation in long-term trial plots in South Australia. Total bacteria, fungi and actinomycetes, determined by serial dilutiuons of soil samples and plating (counts of colony-forming units) onto agar were not greatly affected so therefore had limited potential as bio-indicators. The same was true for numbers of cellulose decomposing bacteria and fungi, soil phosphatase and sulphatase avtivity, and N mineralisation. Good indicators were microbial biomass C, numbers of protozoa (which graze on the bacteria, so it is not a truly independent measure), the soil meso-fauna (collembola and earthworm populations), mycorrhizal fungi, the rate of cellulose decomposition, and protozoa. Thus different measures of the same component, such as cellulose decomposition, can be either ‘good’ or ‘poor’ bio-indicators. Not all, however, were equally good under all management regimes. Although a rather different agro-ecosystem, the lessons to be drawn are that no one indicator can be universally applied, that relatively simple ones can be effective, that a range of approaches are needed even for the same indicator and, above all, that everything must be tested and validated.

Biomass

‘Mass’ suggests the weight of the population; this is often the case, if indirectly, for example when C or another element is measured. However numbers; of cells, filaments, or other organismal units; is often used as a measure of biomass. Even within a unit of measurement there are many ways of assay. Carbon can be measured by fumigation with chloroform ($CHCl_3$) followed by several kinds of analysis of C, for example direct extraction and analysis, assessment through stimulation of microbial respiration or various isotope analyses.

Diversity

A potentially useful system to characterise microbial communities is that developed and marketed by Biolog™, Inc (Bochner, 1989). It is essentially the same as the substrate utilisation assays discussed in the previous section. The method was originally developed to meet the needs of clinical microbiologists for a rapid method of identifying bacteria. Subsamples from an actively growing population of a single strain of bacterium (i.e. a pure culture) is inoculated into a range of C substrates contained in the wells of a micro-titre plate. If the substrate is utilised (oxidised) the colour of a tetrazolium salt, an indicator of redox potential, is changed from colourless to purple. The plates are examined after 4 and 24 hours. The 96-well microtitre plates are supplied by the manufacturer complete with 95dehydrated substrates and one control (blank) arranged in a consistent format. The carbon sources are predominantly carbohydrates, carboxylic acids and amino acids, with some amides, polymers, aromatic and phosphorylated chemicals; list in Garland & Mills (1991). Thus the pattern of coloured wells, the 'metabolic fingerprint', can be read, manually or automatically, and compared to a database of known species and their diagnostic patterns. As supplied the system can identify 434 species of aerobic Gram negative bacteria. When tested against 39 reference taxa from the American Type Culture Collection and 45 Gram negative isolates from water samples Klingler *et al* (1992) found that 98% were identified correctly to genus level and 76% to species level, although identification of some strains of *Enterobacter*, *Klebsiella* and *Serratia* was less reliable.

It has since been adapted for other groups of microorganisms but requires that a database is constructed; no trivial undertaking as the most useful substrates have to be determined and the various patterns of response determined for isolates of each species. It is, therefore, a versitile system which can be adapted to a wide range of conditions and can be customised to suit individual requirements, for example using home-made plates, reading and data comparisons done by eye rather than needing to purchase and maintain costly equipment.

A more recent development has been to use the Biolog ™ system to characterise mixed soil microbial communities (Tunlid & White, 1992; Winding, 1994), rhizosphere (Garland, 1996) and activated (i.e. aerobic) sludge (Guckert *et al*, 1996). A comparison of a range of soils produced consistently different patterns determined by linkage cluster analysis (Winding, 1994). Differentiation between habitats and spatial gradients within estuarine and terrestrial sites were revealed by ordinations produced from principal components analysis (Garland & Mills, 1991). The factors that affect reproducibility and accuracy when used with mixed and 'raw' samples would need to be determined for each case. Soil samples collected from the field which will contain cells in various states from actively growing to resting and dormant stages, to moribund cells. Thus the conditions of the assay will greatly affect the end result. This would be acceptable for comparative purposes (provided that the impact of experimental variation is not too great), but would not reveal what was actually going on in the soil. The length of incubation, for example, would need to be standardised. Generally periods of 24 to 96 hours are used, but, as the inoculum grows, different groups of bacteria start to become active and utilise a different range of substrates thus giving a different profile.

I. 2. Criteria for selection of sites and fields

Agroecological regions and sub-regions were produced as an output of the Land Resources Appraisal of Bangladesh, undertaken by the FAO/UNDP Agricultural Development Adviser Project. The country was mapped at a scale of 1:750,000. The survey technique used a combination of aerial survey and ground truthing. The local soil classification is based on General Soil Types. A General Soil Type classifies together soils with broadly similar characteristics, providing an overview of soil conditions. These units have been related to FAO and USDA classifications (Brammer *et al* 1988). At this scale the minimum area that it is possible to show separately on the map is about 2 km wide. Several soils can occur within this unit and are mapped together as a soil association.

The Agroecological map (see next page for copy) was built up using the following information:

- physiography (information on landforms and soil parent material)
- soils (using soil associations described above)
- depth and duration of seasonal flooding
- length of rainfed kharif and rabi growing periods
- length of the pre-kharif period of unreliable rainfall
- length of cool winter period
- frequency and occurrence of extremely high (>40^{o}C) summer temperatures

A map of the 34 Agroecological regions of the FAO/UNDP and their definitions are provided (Fig ***, from Brammer *et al*, 1988). These correspond with the physiographic units recognised within Bangladesh.

A major limitation to the value of this exercise is the scale at which it was conducted. As recognised in the FAO/UNDP report 2 mm on the map represents 1.5 km on the ground. Thus a square with 2mm sides covers a land area of about 3 average villages and approximately 1500 fields. Thus the purposes for which the survey can be used are limited to broad scale planning activities.

The Bangladesh Agricultural Research Council (BARC) produced a fertiliser recommendation guide (Karim *et al* 1989) that provided general fertiliser recommendations based on agroecological region and provided a summary of nutrient requirements by crops as the basis of site specific recommendations where soil analysis was available. This guide is currently being revised and a new edition, with significant changes, is expected this year (1998).

An ongoing programme by the Bangladesh Soil Resources Development Institute (SRDI) is conducting soil surveys at a scale which is of relevance to the farming community. Soils are sampled at the Thana level. This information is compiled using a GIS system, and is the basis of local agricultural recommendations in Bengali (the information is stored in English). These reports underpin the current extension program.

Several factors determined the selection of sites. In order to utilise the collaboration with PROSHIKA we have to work in areas where PROSHIKA have established ADC offices. Given concerns regarding declining productivity it was important to have sites in areas that are intensively cultivated. It was also regarded as important to establish nutrient balances for systems on contrasting soil types and flooding regimes.

Agroecological Regions of Bangladesh (Brammer *et al*, 1988). See next page for key.

Key to agroecological regions.

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I. 3. Research plots and fields- areas, plot numbers, farmers, history

I. 4. Parameters for Baseline soils analyses

Site Description
Present and past land use, topography and position on slope & in command area
Climate
Mean monthly precipitation
Mean monthly maximum air temperature
Mean monthly minimum air temperature
Soil Classification
FAO Agroecological zone - Soil association
Bangladesh Soil group ≅ USDA Soil Family
Soil Characterisation (0cm - plough pan)
Depth to plough pan
Bulk density
pH
Total N & P
Exchangeable AL^{3+}
Exchangeable K^+, Ca^{2+} and Mg^{2+}
ECEC (where pH <6.0)
CEC (where pH ≥ 6.0)
Bicarbonate extractable P
Resin extractable P
Organic P
Micronutrients
Mechanical Analysis
Field capacity
Soil microbial biomass
Nitrogen mineralisation index (anaerobic incubation)
Physical fractionation of SOM

I. 5. Parameters measured quantitatively in intensive for monitoring research plots

Input

Chemical Fertiliser	Type, timing, amount and method of incorporation. Sample to be collected for analysis.
Crop residues	Fresh weight of the material incorporated must be measured. A representative sub-sample must be taken for analysis. Fresh weight of sub-sample is recorded. Sample is air dried and re-weighed. Stored in paper bags for transfer to Dhaka. Nutrient composition (N, P, K, S + micronutrients) to be analysed. Moisture content determined. Biochemical analysis - Lignin (+ polyphenolics?)
Animal manure	Sampling as above.
Liquors	Record volume added, keep sub sample over ice.
Grazing animals	Record stocking density (urine input to be calculated from data available from the literature or livestock projects).
Atmospheric deposition (wet & dry)	Using deposition traps.
Inputs in irrigation (and flood) water	Analysis of water from tube wells plus measurement of flow rate and duration will give total nutrient input. Uptake by crop much more difficult- temporarily enclose a section of field and measuring changes in water chemistry will only indicate net effects (losses, crop uptake, mineralisation from soil).
Inputs from sediments	Sediment traps (trays): gross rate of deposition so includes resuspension. Suspended particulate matter in floodwater. Similar difficulties in quantifying inputs as with water.
Soil N supply	Estimated from the -N plots, anaerobic incubation.

Outputs

Crop components	Harvesting method: 5 quadrats (2 m^2) sampling + field estimate A representative sub-sample must be taken for analysis. Fresh weight of sub-sample is recorded. Sample is air dried and re-weighed). Stored in paper bags for transfer to Dhaka. Moisture content determined.
Livestock	Estimate of units per field (proportional if grazed in several areas).
Denitrification Loss	Measure NO_3 immediately before flooding (after periods of drying) assume all is lost by denitrification upon flooding.
Leaching loss	Assume no losses from puddled crop. Calculate water balance and measure solution NO_3 during non-rice crops.
Ammonia volatilisation	May be important in early phases of rice growth. Use established relation NH_4, pH and windspeed.
Transfer in irrigation water and sediments	See above (Inputs).

I. 6. Data sheets (for EDWs)

FIELD DATA SHEET

Name of Recorder:	
Date:	**Season:**

Management system: (Tick one)

ECO-97	ECO-90	BARC	BARC-N	Conventional

Farmer:	**ADC:**	**Plot no.:**	**Area:**
Crop:	**Cultivar:**		
Date of sowing:		**Date of transplanting:**	

Planting density:

Broadcast:	**cups/field**	
Transplanted:	**Seedlings/hill**	**Hills:**

Land preparation:

Previous crop:		**Fate of residues:**
Ploughed: times	**Dates:**	**Laddering:**

Fertilizers:

Element	**Fertilizer**	**Amount**	**Date(s) of application**
N			
P			
K			
S			
Trace elements			

Green manures & organic fertilizers:

Type of material	as (local name)	Rate	Applied on (date)	Method and source	Sample Nr.
Compost					
Slurry					
Manure					
Crop residue					
Sesbania					
Other legume					
Aquatic plant					
Others					

Land management:

Irrigation	**From (dates)**	**to (dates)**	**At**	**hours/day**	**Sample Nr.**
Weeding	**On (dates)**	**Yield:**			**Sample Nr.**
Use of weed		**% removed from field**		**% incor-porated**	**Sample Nr.**
Pesticides/herbicides applied on (dates)					**Sample Nr.**

Environmental factors

Flooding started: **Date**	**Ended:** **Date**	**Max. depth:**	**Sample Nr.**	
Rainfall:	**- mm during season**		**Sample Nr.**	

Date of harvest	

Yield	**Sample Nr.**	
Use of crop **- % sold.**	**- % household consumption**	

Amount of residues		**Sample Nr.**	
Use of residues	**- % ploughed in.**	**Sample Nr.**	
	- % removed (compost)		
	- % sold, for use as ____________		

II. *Outputs*

II. 1. Cropping calendar and farming systems

II. 2. Baseline soils data

II. 3. Nutrient budgets: Boro 1998 and 1999

II.4. Agronomic efficiency and N-use efficiency

II. 5. Nutrient budgets, Aman and Rabi crops

III. Dissemination

1. Project Workshop, March1998:
   Inception Workshop. 174-183
2. Project Workshop, April 1999:
   Mid-term Review and Planning Workshop. 184-203
3. Low-input ecological rice farming in Bangladesh. S K White *et al.*; BSSS Meeting, Edinburgh. 204-206
4. Nutrient budgets- can farmers use them? S K White *et al.*; 10th N Workshop, Copenhagen (was submitted to Plant and Soil, now to be resubmitted) 207-218
5. Comparisons between ecological and conventional rice farming practices in Bangladesh. S F Elahi *et al.*; ISCO Conference. 219-226
6. Transfer Report (M.Phil/Ph.D); M F Hossain, Dhaka University & Wye College, London: *A comparison between ecological and conventional rice farming systems in Bangladesh.* 227-246
7. M.Sc. thesis (draft); Nasrin Sultana, Dhaka Univ. *Soil microbial biomass dynamics under ecological and conventional farming systems in Bangladesh.* 247-294

III. 1. Project Workshop, March 1998 Inception Workshop

III. 2. Project Workshop, April 1999 Mid-term Review and Planning Workshop

III. 3. Low-input ecological rice farming in Bangladesh. S K White *et al.*; BSSS Meeting, Edinburgh

III. 4. Nutrient budgets- can farmers use them? S K White *et al.*; 10th N Workshop, Copenhagen (submitted: *Plant and Soil*)

III. 5. Comparisons between ecological and conventional rice farming practices in Bangladesh. S F Elahi *et al.*; ISCO Conference

III. 6. Transfer Report. M F Hossain, Dhaka University & Wye College, London: *A comparison between ecological and conventional rice farming systems in Bangladesh*.

III. 7. M.Sc. thesis (draft); Nasrin Sultana, Dhaka University. *Soil microbial biomass dynamics under ecological and conventional farming systems in Bangladesh*

IV. Miscellaneous

Copy of Mauza map with plots marked 296

Digitised maps slowing location of plots, tube wells irrigation channels, dwellings, etc. Note that many of the fields would have been subdivided since the areas were surveyed. Approximate boundaries of research area boxed. 297-304

Details of one part shown on p 300.

IV. 1. GIS map outputs

IV. 2. The Future

Although the project has come to an end, and so the researcher-managed plots will no longer be maintained (as they have served their purpose), it is hoped that the ecological managed plots (set up by the project in 1997) and fields (set up by the farmers) will continue to be managed as before. This would provide a valuable resource for further research as well as acting as demonstration and test (of feasibility) plots.

In addition to the farm sites in the in the project research areas we have also been offered the following sites on research stations by the Rural Development Authority (RDA), BRRI and BARI.

PROSHIKA are establishing a field experiment together with RDA at their headquarters in Bogra. The experiment has a 5 year duration and could be used for our experimental purposes. At BRRI three long term experiments will be used to test some of the findings of this project and for development of some of the soil organic matter indicators. Initially we will test the sensitivity of different SOM fractions and microbial biomass to long term management.

Long-term experiments at BRRI:-

Experiment 1: Long term study on the integrated use of organic materials and inorganic fertilizers for wetland irrigated soil. Started in 1983.

Experiment 2: Long term study on the requirement of N, P, K, S and Zn fertilization for wetland rice. Started in 1983.

Experiment 3: Study on the consequences of continuous wetland rice cropping. Started in 1971.

BRRI scientists (Soil Chemistry Department) have offered to collaborate in this work and will also supply data from the start of these experiments. Details of the experiments are given in Appendix II.

BARI have offered to establish new field experiments.