Chapter 5: Sustaining Soil Quality

157. Soil performs a number of important services or functions, among which the following are of particular importance:

- Supporting the growth and diversity of plants and animals by providing a physical, chemical and biological environment for the exchange of water, nutrients, energy and air;
- Regulating the distribution of rain or irrigation water between infiltration and runoff, and regulating the flow and storage of water and solutes, including nitrogen, phosphorus, pesticides, and other nutrients and compounds dissolved in the water;
- Storing, moderating the release of, and cycling plant nutrients and other elements;
- Acting as a filter to protect water quality, air and other resources; and
- Supporting structures and protecting archeological treasures.

158. The term "soil quality" is used to describe the ability of soil to perform these functions. The USDA Natural Resources Conservation Service[93] defines soil quality as:

"*The capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation. Changes in the capacity of soil to function are reflected in soil properties that change in response to management or climate*."

159. Maintaining the functions of soil is thus central to the achievement of sustainable development. In exploring evidence for a degradation of the soil resource, it is important to identify first the soil function of interest and then to relate this to a measurable soil property or properties. An example of soil function is '*the ability of soil to provide raw materials for construction of dykes, roads and dwellings'*. The related soil property is the extent, in terms of both area and depth, of soils of particular clay content or type. From this example it is clear that both the function of soil and the related soil properties may be measured.

I. Challenges Facing Agriculture in Bangladesh

160. Agriculture accounts for some 23% of GDP and more than half of total employment, so the ability of soil to sustain agricultural production is an issue of national concern. Given the overriding importance of agriculture to Bangladesh, the soil function that has received the most attention to date is the capacity of the soil to '*sustain crop productivity*'. The terms soil productivity or soil fertility are used interchangeably to capture the relevant related soil properties. In addition to concerns that soil productivity is declining, there are reports of a degradation of soil that may affect other aspects of soil quality. This chapter outlines briefly the future challenges facing agriculture in Bangladesh, including the implications of climate change, and reviews agricultural productivity at the national and district levels, as well as evidence that a decline in soil productivity is occurring, before recommending ways to strengthen the strategy for monitoring of soil quality.

[93] 2001 – http://soils.usda.gov/sqi/files/sq_one_1.pdf

161. In Bangladesh a combination of factors create a challenging situation for agriculture, particularly for rice production. Domestic demand for rice is increasing, there is a limited flow of foreign exchange to pay for rice imports and the government strategy is to meet this demand through national production. Historically, increases in production were achieved through introducing higher yielding modern rice varieties to raise levels of yield in both the *Aman* and *Boro* crop, and by increasing the area of land cultivated, mainly by expanding the area under irrigated *Boro*. Opportunities for future expansion of the cropped area are severely constrained by a number of factors:

- Urbanization and industrialization are encroaching on the available land, competing for and contaminating water resources;
- More profitable agricultural options than rice production are available. Agricultural diversification is likely to compete for land (particularly irrigated higher lands used for *Boro* production); and,
- Sea level changes expected as a result of climate change will inevitably impact upon land use in lower lying areas, while in higher lands adaptation to water scarcity also associated with climate change will require adoption of crops with lower water requirements.

Given this context, any future increases in rice production will have to be achieved through increased yields of both *Aman* and *Boro* crops.

II. Trends in Agricultural Productivity

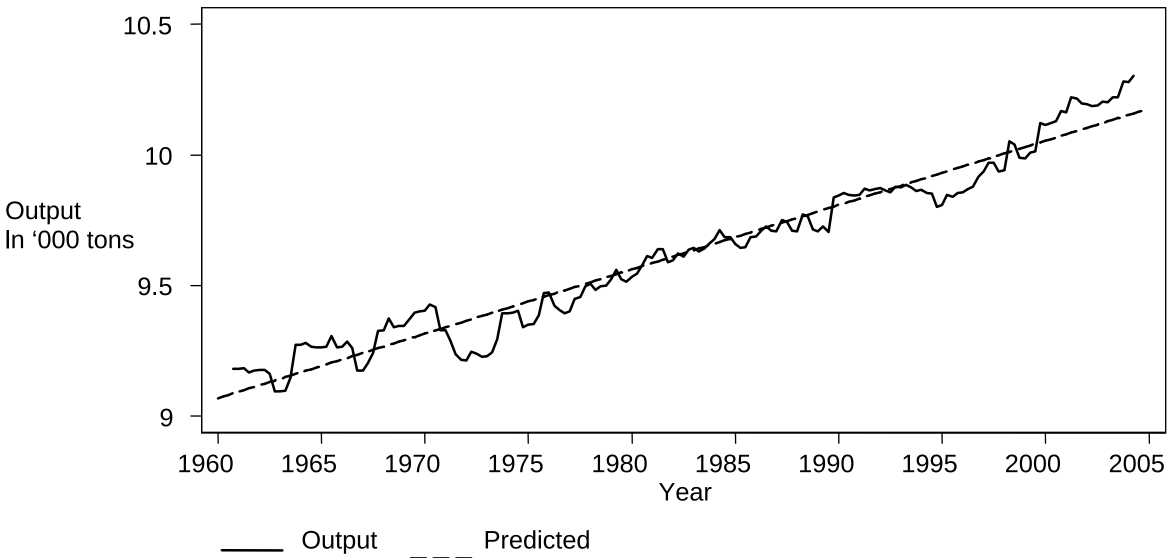
In the early to mid-1990s concerns were raised that production increases achieved over the previous three decades in rice-based cropping systems may have involved a trade-off against long-term sustainability[94]. Increases in crop production slowed and rice crop yields declined. A decline in soil quality (expressed as soil fertility or soil productivity) was inferred as the cause. These concerns are widely articulated in the literature and reflected in the National Strategy for Accelerated Poverty Reduction. This section revisits these trends.

162. Cereals production in Bangladesh has maintained a long run trend rate of growth over the last four decades of around 2.5% per year. Figure 5.1 shows the four-crop running average of grains production. Intensification of agricultural production associated with the introduction of improved, shorter duration rice and wheat varieties that were less photoperiod sensitive, together with the expansion of surface irrigation, led to a structural change in the cereals production system. Initially this occurred with an increase in wheat production and then, more significantly, of *Boro* rice production (Figure 5.2). A minor trend has been the decline, relatively small in absolute terms, of *Aus* production, and other rabi crops partly to make way in the cropping system for the rise of *Boro*. To get a clearer understanding of the trend in production, it is necessary to consider when particular factors such as the introduction of new technologies, or shocks such as natural and man-made disasters (such as floods and adverse price movements), influenced production.

[94] Asaduzzaman, 1995; Brandon, 1995; Pagiola, 1995, Scherr, 1999

163. Using a kinked exponential growth model[95], it is possible to identify trends and shocks in crop production, as shown in Figure 5.3. Between 1971 and 1972 gross crop production fell dramatically and is modeled as a discontinuity. This reflects the disasters of 1970-1972, including the cyclone of 1970 and the liberation war in 1971. In the period before this, a rate of growth was maintained and is modeled as a constant rate. From 1972 to 1977 a new faster rate of growth was maintained as cereals production recovered to its previous trend line. From 1978 until the present total cereals production is modeled as maintaining a constant rate of growth slightly faster than that maintained up to 1971, although there have been quite significant deviations from this trend, particularly in the mid-1980s and mid-1990's, at the points marked as slow-downs in Figure 5.3.

Figure 5.1: Growth of Total Cereals Output (ln '000 tons)



Note: Output is the crop wise moving average of the 4 crops (wheat, boro, aus and aman)
Predicted is the expected output from ln(output) = 9.07 + 0.0062*y (rsq = 0.95)
Which is a long run growth of 2.48% per annum since there are 4 crops per year

164. The underlying determinants of production levels however are not clear. Some have argued that production is determined by price[96], but while the relationship between price and production holds reasonably well up until the late 1990s, there has been a significant rise in production in the last 5 years, notwithstanding continuous low real rice prices. This may have been in part due to the Government's focus on rice production during this period, and may also reflect recovery from the 1998 floods. The effect of liberalizing markets in Bangladesh has been to establish a relative low parity price for rice, based on imports from India[97], and it is not unreasonable, therefore, to anticipate that rice production may now begin to slow.

[95] (Boyce, 1986, 1987)
[96] Ahmed (2001) does this with data up to 1996-7
[97] Previously Bangladesh imported from Thailand and other sources. In the1990s the private sector has developed trade with India as the most profitable source of staples imports. Obviously trends in Indian agriculture, prices etc., has an effect on these parity prices. It is not clear that India will remain a reliable source of imports for Bangladesh if the food situation were to deteriorate there, given the history of interventions in the grain trade by Indian governments.

Consequently, pressure on soil resources may well be reduced as a result of lower levels of agricultural protection.

Figure 5.2: Production of Major Cereals in Bangladesh 1960-2004

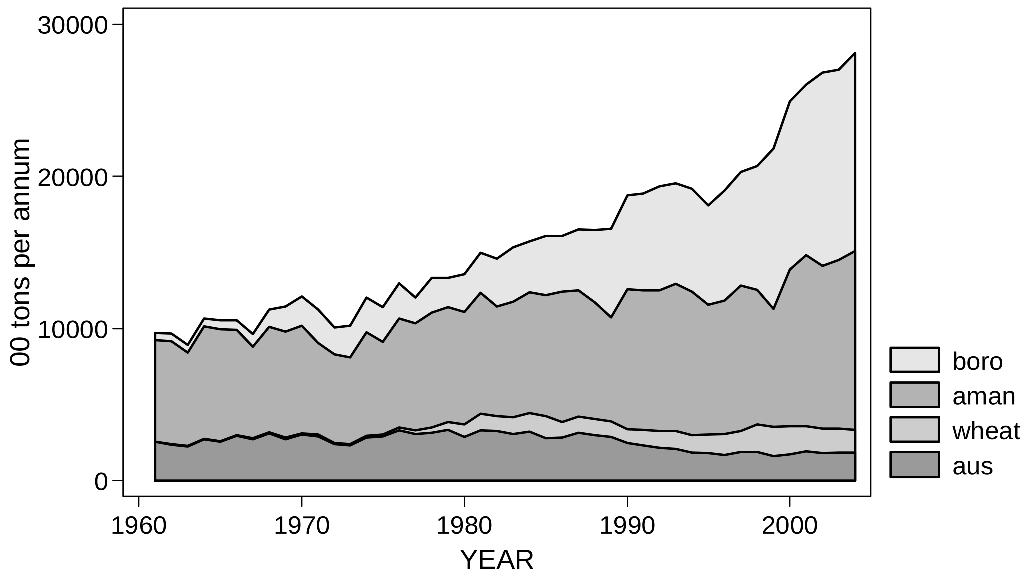
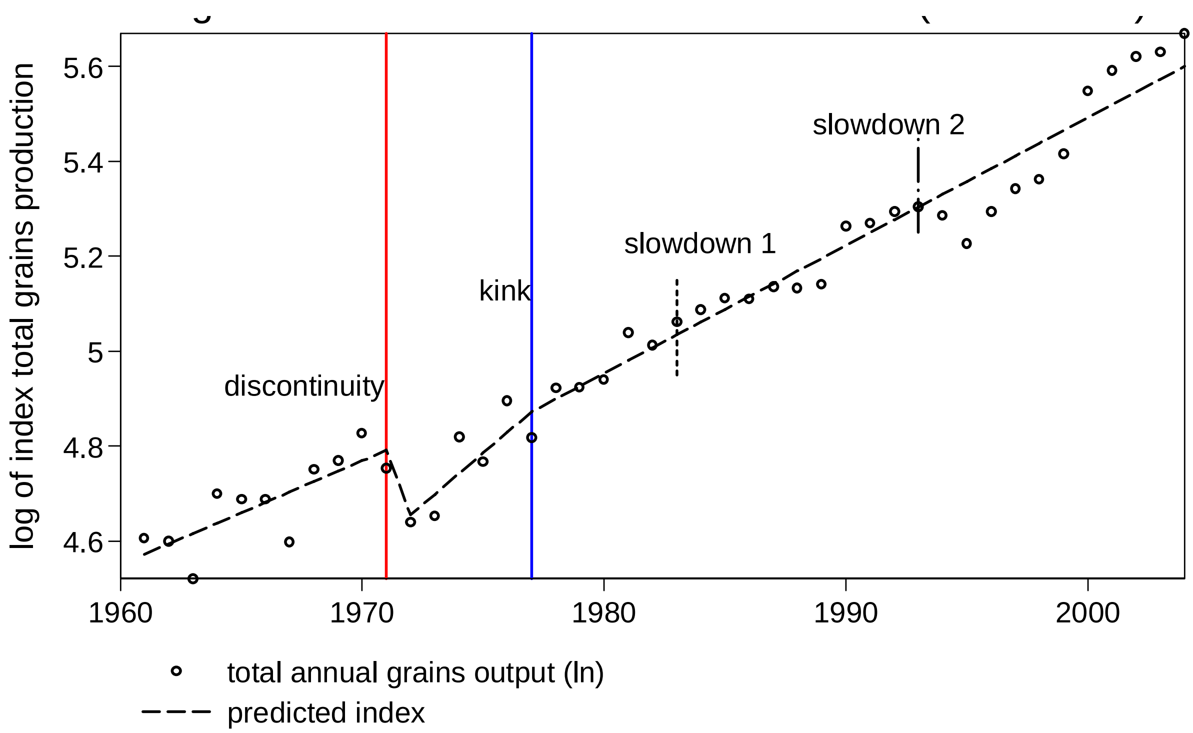


Figure 5.3: Index of Total Grains Production (1960 = 100)



III. Evidence of Declining Soil Productivity and Soil Quality

165. The growth trend in agricultural production and the influence of agricultural and food market developments on production were discussed above. As described earlier it is important to distinguish soil functions associated with soil quality. The following sections explore the evidence for a decline in soil productivity (i.e. the function of soil to sustain plant productivity), and then consider evidence for a wider decline in soil quality.

Evidence of a Decline in Soil Productivity: Yield and Total Factor Productivity

166. Long term rice–wheat experiments provide a useful starting point in this analysis. These experiments are generally established with the technical optimum in mind. Typically, such experiments provide a measure of yield (plant productivity) at specified levels of inputs and, in some cases, yield response to inputs over time. So, where inputs are constant, and evidence of pests and disease absent, a decline in crop production, measured as yield, may signal a decline in soil productivity. Long-term experiments constituted a major component of the evidence that yields were declining in the early 1990s. This evidence was typically drawn across a number of countries and agricultural situations, some of which differ from Bangladesh in both environmental characteristics and cropping pattern, and show no consistent yield impact. Dawe et al., (2000) analyzed long-term yield trends in 47 experiments in rice–rice and rice–wheat systems, and argue that yield decline is not very common, particularly at yield levels actually achieved by farmers. Duxbury et al., (2000) reviewed rice-wheat experiments on the Indo-Gangetic plains and showed that rice yields were declining in eight and wheat yields in three out of 11 experiments. However, Saleque et al. (2004b) found no evidence of a yield decline for the years 1990-1999 for a field experiment at the BRRI experimental farm at Gazipur.

167. Given that the *Boro* crop is dominated by HYV crops, and that management practices have remained constant with time[98], it is reasonable to expect that yield trends in the *Boro* crop yield in farmers' fields may reflect underlying soil productivity (and improvements in varieties). Pagiola (1995) analyzed yield trends at the district level and found that yields between 1979/80 and 1993/4 had shown the greatest decline in those districts which had been early adopters of HYVs. These observations were particularly worrying because they raised the prospect that a more widespread decline might occur with time.

168. It can now be seen that the analysis by Pagiola was influenced by the period in the early 1990s where yields and production were below trend. District level yield data for the period 1979/80 to 2002/03 suggests that the yield trends are stable or increasing. The only district where the yield trend is negative is the Chittagong Hill Tract, which is not a major rice producing area. In 12 out of 21 districts the increase is significant. For a number of districts, however, the yield trend is flat, which may indicate continued cause for concern, given the need to increase yields. While more detailed trend analysis of the sort presented earlier could be used to describe these data, in the absence of reliable explanatory information, the value of such interpretation is limited.

169. As described earlier, assessment of yield trends as a proxy for soil productivity assumes inputs over time are constant. Whilst this is reasonable as a first approximation,

[98] Ahmed, 2001

Total Factor Productivity (TFP) which provides a measure of output relative to inputs, provides a way to account for changes in management when interpreting production data. Data on total factor productivity for rice production in Bangladesh are limited, however. A key constraint is the lack of available data on fertilizer use at the district level, particularly since the liberalization of the fertilizer market. Given the lack of reliable data on input use, it is not currently possible to calculate TFP at the district level for Bangladesh. Ahmed (2001) who compiled information on TFP using data available at a national level in Bangladesh for the periods 1975/76-1986/87 and 1987/88-1997/98 found that TFP grew throughout this period by around 1% per year if constant rice prices are used. Using current prices[99], there is evidence that, whilst TFP continued to grow, the rate of annual growth in productivity slowed in the second decade (1987/8 – 1997/98). Ahmed attributed this slowing to a lower growth in rice prices compared to input costs.

Nutrient Balances

170. Nutrient balances are proposed as an indicator of likely future soil fertility issues. They are not a direct measure of either soil function or soil property. However, they can be relatively easily derived from data that would be used to calculate TFP. Negative balances over time indicate a trend to deplete soil resources. Visual symptoms in a crop of nutrient deficiency or positive crop responses to a particular nutrient input[100] confirm that soil resources are depleted, or in a form that is not available to the plant.

171. A national nutrient budget for Nitrogen (N), Phosphorus (P) and Potassium (K) was calculated using a partial budgeting approach that considered national data on crop yields (BBS data) and fertilizer input data from the MMIS.[101] This analysis suggested that the P budget was somewhat negative and has not changed over the last 20 years, while the K balance is much more negative. N inputs suggest a surplus application, but this reflects the fact that typically more than 50% of nitrogen fertilizer added to rice soils is lost. Once losses are accounted for, then the balance becomes negative. These data are somewhat in conflict with other evidence, however. Ahmed 2001 reports that the balance of N:P:K applied to rice was 50:30:20 and that the ratio had shifted to 72:15:12 by 1996/7.

172. Partial nutrient balances were assembled at the AEZ level using data from the SFFP demonstration database.[102] These data allowed comparison of farmers' practice and yields for a *Boro* – fallow – T *Aman* rotation. The findings were that the balance for nitrogen ranged between -50 and 0 kg ha^{-1} yr^{-1}, phosphorus was between -10 and +5 kg ha^{-1} yr^{-1} and the potassium balance was always very negative at -225 to -100 kg ha^{-1} yr^{-1}. Ripjma further reported that the balances were less negative in the Barind areas (AEZ 25, 26 & 27) in comparison with the Ganges Floodplains (AEZs 11,12 & 13). However, Ripjma cautioned that whilst the findings indicate trends and confirm the potential to identify areas of concern, the data did not reflect actual cropping patterns and intensities in all locations.

[99] Given that there is an expected relationship between output price (i.e. rice price) and input prices this is appropriate.
[100] This holds for macro-nutrients excepting N and all micro-nutrients
[101] (Ripjma, 2004).
[102] (Rijpma et al., 2004).

Crop Biophysical Indicators

173. The relationship between nutrient uptake and grain yield can be used to diagnose crop biophysical constraints. Again this is not a direct measure of either the function or related soil property, but may provide important diagnostic information. A limited data set shows the relationship between grain yield and N uptake obtained for the *Boro* rice crop at four locations (Dhamrai, Daulutpur, Gabtali and Shibgaj) during 1998 and 1999.[103] These results fall around the lower limit for accumulation established by Witt et al. (1999), suggesting that sink formation was limited by factors other than nitrogen. Simply put, the plant is not delivering the level of yield that would be expected given the measured level of N uptake by the crop.

174. The results suggest some factor other than N uptake limited yield. In this study, application of the macro-nutrients (P and K) and compost did not have any significant impact on yield. Other factors such as micro-nutrient deficiency, pests, disease, lack of water, low radiation may have limited yield. The data set is not sufficiently comprehensive to draw widespread conclusions, however the analysis does provide a useful example of how the aspects of crop performance can be used as an indicator of underlying soil productivity issues.

Evidence for a decline in Soil Quality: Quantitative measurements

175. The soils and environmental characteristics of Bangladesh have been extensively mapped and used to inform planning, land use and management decisions (see Box 5.1). The soil survey and analysis to date has focused on describing environmental characteristics and measuring soil chemical properties that may determine soil suitability for, and fertilizer requirements of, agricultural crops.

Box 5.1: Soil Mapping in Bangladesh

The first soil map of Bangladesh (then East Pakistan) recognized seven soil tracts combining physiographic, parent material and soil units. Reconnaissance soil surveys by the FAO-UNDP Soil Survey were undertaken from the early 1960s. This mapping was completed by the Soil Survey Directorate of the Government of Bangladesh (now the Soil Resources Development Institute, SRDI) in 1975 and led to the publication of the first soil map of Bangladesh at a 1:1 million scale. Further detailed analysis was carried out through the FAO/UNDP supported Agroecological Zones (AEZ) project study in the 1980s. The AEZ maps are at a scale of 1:250,000.

AEZs, while providing a useful characterization of the environment, remain broad units of characterization. Recognizing this, SRDI pursued the 'Upazila Nirdeshka' program to collect basic information on land, soil and water resources that would serve to identify resource management domains (RMD) as a spatial management unit that offers opportunities for the identification and application of resource management options to address specific land management issues. The Upazila Nirdeshka maps are completed at a scale of 1:50,000. SRDI have published 403 Upazila Nirdeshaka (previously called Thana Nirdeshka) and a BARC GIS Project has so far digitized and updated 300 of these maps (BARC 2004).

Research on soil fertility and fertilizer use at the farm level was also started in the 1960s with the establishment of the Soil Fertility and Soil Testing Institute of East Pakistan. The first fertilizer recommendation guide was published by BARC in 1979. These recommendations were revised and developed over time. By 1989 the guide was revised to establish cropping pattern-based generalized fertilizer recommendations for moderate yield goals for the main AEZs. Generalized fertilizer recommendations were developed for the major crops.

[103] (Hossain 2001).

176. Rahman et al. (undated report) compares soil properties that may affect soil productivity under different physiographic units sampled in 1967 and 1998. The results suggested a decrease in pH, indicating acidification, and a decrease in calcium, magnesium and potassium, with no consistent change in organic matter, N or P status. It should be noted that this survey appears to be based on a limited sample (24 observations) and no details of how methods were standardized or controlled between 1967 and 1998 were provided. Nor is evidence of a loss of soil function recorded.

177. A framework that identifies key soil functions, for the specific complex situation in Bangladesh, does not yet exist, and is beyond the scope of this chapter. Thus it is difficult to comprehensively review the wider evidence for a decline in soil quality. Well-recognized, localized, soil degradation problems exist in Bangladesh. Deforestation for example is leading to erosion in the Chittagong Hill Tracts and salinization is reported to have increased by 22% since 1973.[104] While important, and likely to affect a number of soil functions, these problems have limited geographic extent. A study by the FAO[105] suggested that in the late 1980s, the total degraded land in Bangladesh represented 7.4% of the total land area. When compared to other countries in the Asian Pacific region, this level of degradation was low, with only Myanmar and Tonga estimated as having lower levels of degradation. Emerging problems include the depletion of groundwater, and a build-up of arsenic in soil as a result of irrigation with water contaminated with naturally-occurring arsenic, although there it is not yet clear what concentration of arsenic in irrigation water would have a quantifiable impact on agricultural yields or human health.[106]

Qualitative Assessments

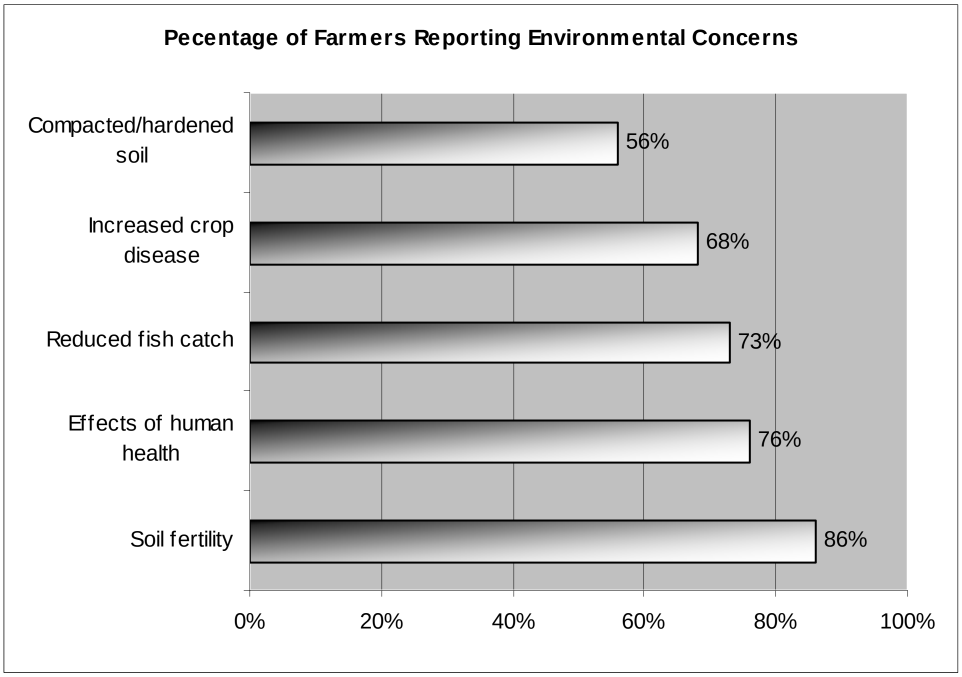
178. Farmers are aware of subtle changes in soil properties and associated functions. Saleque (2004a) found that farmer's assessment of soil fertility were consistent with measured soil properties. Hossain (2001) found that farmers in Bangladesh reported a beneficial change in soil properties associated with a change in management of organic matter inputs. With application of compost the soils were reported to be less hard. The change could not be substantiated through soil chemical measurements, including soil organic matter status, but was reflected in measures of soil physical behavior.

179. Assessments of soil quality, or of changes in quality, can draw upon qualitative data of different types, obtained in different ways. Gaunt et al. (2001) found a keen awareness amongst the farmers of the non-sustainability of parts of their farming systems, and of the need for better management of soil fertility and pests. The resource intensive approach taken by Gaunt, using participatory methods working through focus groups and drawing on a relatively small sample at distinct locations. Rahman (2004) used such an approach to design a questionnaire which was then used in a survey to interview a total of 406 households. In this study farmers were asked to respond to a set of twelve specific environmental indicators which had been identified in previous focus group discussions. As shown in Figure 5.4, soil fertility was ranked as the major problem (86% of those interviewed agreed), followed by

[104] (Muzib, 2004)
[105] Reviewed by Scherr (1999)
[106] World Bank, 2005

effects on human health (76%), reduced fish catch (73%), increased disease in crop (68%) and compacted/hardened soil (56%).

Figure 5.4: Environmental Concerns of Farmers



Source: Rahman, 2004.

180. Both these papers recognized a relationship between intensification of crop production and an associated reduction in fish production that lead to problems in achieving a balanced diet and associated health issues. These observations may indicate that at least in some locations the soil's function to protect water resources had declined, or a capacity had been exceeded.

181. Taken together these findings and those from elsewhere confirm the value of observations made by farmers and rural households. Although, as observed by Rahman (2004), awareness tends to be of visible impacts, and less obvious issues, such as the now well-publicized arsenic contamination of water, may go undetected by such qualitative measures.

Conclusions: No Clear Evidence of Declining Soil Productivity or Soil Quality, but some Causes for Concern

182. A framework for assessing soil quality in Bangladesh does not yet exist. Total cereals and rice production has maintained a long term increasing trend. Production and particularly fluctuations in production are influenced by a number of factors including price and natural events in addition to underlying soil productivity. There is insufficient evidence to support the assertion that agricultural production is declining as a result of a decline in soil productivity. However, there are causes for concern:

- Existing soil test protocols established to measure soil fertility and inform agricultural management decisions are too narrowly defined to monitor the functions of soil that are defined by soil quality;
- Sufficient data are not available to ascertain whether soil productivity has declined, but limited evidence from repeated soil sampling at the AEZ level may suggest decline in soil properties associated with soil productivity;
- Fertilizer inputs are imbalanced and nutrient mining is occurring, particularly for potassium;
- Limited crop physiological observations suggest poor rice crop performance;
- Qualitative evidence suggests deterioration of soil quality and impacts of intensification of rice production on human health and fish production;
- Scientists have expressed concerns that salinization, acidification and arsenic contamination are emerging soil quality problems.

IV. Implications of Climate Change

183. Agricultural production and soil quality are both influenced by the environmental impacts (externalities) associated with actions elsewhere, and likewise environmental externalities of agricultural production must be considered. These externalities create impacts and costs for society that are not captured by a field-based assessment and financial analysis of crop production, and may also have an impact upon future agricultural practice. The externalities associated with rice production include:

- Depletion of groundwater due to use for irrigation;
- Point source pollution, such as arsenic in some situations;
- Non-point sources pollution, derived from agricultural and other sources; and,
- The production of avoidable methane (CH_4) and nitrous oxide (N_2O) emissions.

While detailed review of these externalities is beyond the scope of this chapter, it is important to note that these externalities have negative impacts in the context of the definition of soil quality introduced above. The implications of climate change for agriculture in Bangladesh are considered briefly.

Adaptation to Climate Change

184. Climate change is likely to influence agriculture in Bangladesh. Sea level changes expected as a result of climate change will inevitably impact upon land use in lower lying areas as flooding and salinity increase, while in higher lands adaptation to water scarcity also associated with climate change will require adoption of crops with lower water requirements. As indicated earlier this may imply a slowing, or reversal of the expansion of the irrigated *Boro* rice area.

Mitigation of Climate Change

185. Agricultural systems produce greenhouse gasses. Carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) are important greenhouse gases emitted from agricultural systems. These gasses have different reactivity in the atmosphere, with CH_4 and N_20 approximately 30 and 320 times more reactive than CO_2 per unit in the atmosphere. Methane is produced under anaerobic conditions and N_2O is produced by biological action upon nitrate as oxygen becomes depleted in soil during wetting. Thus the level of CH_4 and N_20 emissions from a rice field depend on water and other management factors. If continuously flooded, rice fields become anaerobic and the levels of CH_4 emission are high[107], while aeration or drying reduces CH_4 emissions.

186. Emissions of N_2O loss are much less clearly understood. Studies have shown that N_2O emissions are low under irrigated conditions.[108] Although N_2O emissions are low during the period fields are flooded, N_2O emissions increase when the soil surface of rice fields dry or nitrogen fertilizer is applied in the floodwater. Research to date has, typically, looked at crop losses associated with crop management factors such within seasonal drying, fertilizer form and application, and other management activities affecting CH_4 and N_20 emissions. Such studies of rice field emissions consider only emissions during the period of crop growth and do not address N_2O emissions during times of non-rice cropping, particularly during land preparation for transplanting rice.[109]

187. Mineral Nitrogen (N) that accumulates as Nitrate (NO_3) under aerobic conditions between crops is lost upon irrigation. These losses of N are predominantly in gaseous forms, but the amount lost as N_2O is uncertain. The findings of Bronson et al. (1997) indicated that these transitional losses amounted to some 30% of mineral N that accumulates in soil prior to flooding at the time of land preparation. Given average levels of mineral N of 50 kg N ha^{-1} measured in soils prior to irrigation[110] this would equate to 23.6 kg N (equivalent to 7.3 t CO_2 ha^{-1}). Zheng et al. (2000) measured lower fluxes during the transition upon flooding the rice crop. Emissions were approximately 5 kg N (equivalent 2.4 t CO_2 ha^{-1}).

188. These transitional losses of N_20 can be avoided either through improved management of the fallow period and rice crop establishment phase or, where control over irrigation exists, by growing an alternate upland crop. Thus emissions from rice agriculture in Bangladesh could be reduced by:

- Diversifying of agricultural production;
- Management of the transition phases, together with improvements in the efficiency of rice production.

189. The potential for emissions avoidance of CH_4 and N_2O range from 4 – 11 t CO_2 per hectare where *Boro* rice is replaced by an upland crop. Emissions under the improved technologies scenario will depend on strategies adopted and whether transitional losses can

[107] Absolute levels depend on factors such as soil type, levels of organic matter incorporation, however IPCC (1996) use irrigation as the factor to estimate CH_4 emissions, reflecting its dominant control.
[108] (Freney et al. 1981)
[109] (Chen et al. 1996; Xing and Zhu, 1996)
[110] (Hossain, 2001)

be avoided, but importantly increases in the efficiency of rice production will reduce the emission intensity, that is the emissions of CH_4 and N_2O per ton of rice produced.

V. Sustaining Soil Quality: Recommendations and Areas for World Bank Support

Indicators of Soil Quality: Developing a Framework for Monitoring Soil Quality

190. Given the importance of the soil resource to sustainable development in Bangladesh, and the critical importance of increases in agricultural productivity, immediate actions should be taken to strengthen the monitoring of soil quality and productivity. A review of the current state of the art in monitoring of soil quality should be undertaken to enable Bangladesh to identify headline indicators of soil function and associated soil properties that it would be desirable to measure, both qualitatively and quantitatively. These indicators should be in line with international best practice, but sensitive to the complex situation in Bangladesh, and selected to inform ongoing efforts to improve agricultural production. Identification of these indicators should form part of the process of developing a framework for soil quality monitoring, incorporating a methodology for monitoring. Existing surveys should be reviewed against this framework to identify gaps and redundancies.

Total Factor Productivity as a Measure of Soil Productivity

191. Effective monitoring of soil productivity requires consideration of total factor productivity, which in turn means the collection of information to supplement soil quality data. Such information must include data at an appropriate level of aggregation on agricultural production and trends, prices and quantities of labor, fertilizer, pesticides, and other inputs, as well as socio-economic and environmental conditions.

Define Institutional Roles and Responsibilities for Monitoring Soil Quality

192. A variety of institutions have a role to play in monitoring soil quality. While SRDI is primarily responsible for soil monitoring and BARC provides coordination, a number of institutions including NARS, BRRI, BARI, and various universities support relevant research, and DAE, BBS and MMIS are important sources of data. To more effectively monitor soil quality, it is important to more formally establish institutional responsibilities, and to agree on mechanisms for the collation of data from these diverse sources.

193. Details of existing surveys in relevant GoB institutes and Ministries should be collated and reviewed for complementarities and overlap. Key surveys are the annual survey undertaken by BBS on crop production, irrigation, cropping pattern and land uses, SRDI Long term Soil Fertility Monitoring and Salinity Monitoring Surveys, and MMIS data on agricultural inputs.[111] Effective monitoring will require either revision of component surveys and co-ordination between institutions undertaking these surveys, or expansion of monitoring efforts within relevant organizations. A key to compatibility between surveys will be to agree an appropriate environmentally and politically relevant unit for future monitoring and

[111] The BBS survey provides data on the production of rice, and other important crops, which are obtained from a sample of 5,000 five-acre plots nationwide. The sample design and selection of clusters was finalized in 1963 and these data are reported and aggregated at the district level. Hoque and Sider (2004) indicate that 5% of the clusters are no longer operational and highlight the need to update and revisit the sample design to reflect changes both in land-use and the landscape.

underlying sample design. The potential to collate data at the Upazila level should be considered. Having defined a framework for monitoring soil quality, the design of the existing SRDI Long Term Soil Fertility Monitoring and Salinity Monitoring surveys should be reviewed to assess relevance, cost effectiveness and robustness of design, and the results to date should be published. A number of development partners, including the World Bank, are in a position to help strengthen the soil monitoring framework through ongoing and proposed technical assistance to the agriculture sector.

Leveraging Funds Available Through Carbon Emissions Trading

194. The Kyoto protocol established that avoided greenhouse emissions in developing countries could be offset against emissions by industrialized countries (those listed in Annex 1 of the protocol). Markets enable emissions reductions to be traded creating a source of income. To date, the strategy for carbon trading in Bangladesh has focused on reducing emissions from industry, energy and waste. An initial review suggests that an opportunity exists to monetize avoided greenhouse gas emissions associated with rice production through carbon emissions trading. Research support is needed to substantiate the extent of this opportunity, and technical assistance is required to help develop a pilot project. Such a pilot would aim to demonstrate how an income stream from carbon trading can provide support to promote crop diversification and the adoption of improved agricultural technologies. The Designated National Authority is open to the idea, and should be approached by the agriculture community, in particular BARC and MoA, to further develop this concept, with technical assistance from the World Bank as necessary.