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ABSTRACT

The present paper provides a detailed analysis of agricultural land use changes in Bangladesh over a 59 year period (1948-2006) and examines its effects on crop diversity, productivity, food availability and the environment. The following key results emerged from the analysis: (i) land use intensity has increased significantly mainly as a result of widespread adoption of a rice-based Green Revolution technology package from the early 1960s; (ii) contrary to expectation, crop diversity has actually increased; (iii) land productivity has increased significantly, but productivity of fertilizers and pesticides declined significantly, thereby raising doubts on sustaining agricultural growth; (iv) food availability has improved and a reversal in the dietary energy imbalance in recent years was observed despite high population growth rate; and (v) the production environment suffered with widespread soil nutrient depletion experienced in many agro-ecological regions. Policy implication points towards embracing crop diversification as a desired strategy for agricultural growth in Bangladesh as it holds the potential to improve resource economy, productivity and efficiency in farming.

Key words: Agricultural land use change, productivity, crop diversity, food availability, environment, trend analysis, Bangladesh.

1. Introduction

Land use change is becoming important nowadays because of its close relationship with global climate change and global food security (Tong et al., 2003). In general, land use change can be strongly affected by factors such as land use policies, population growth, urbanization, agricultural product prices and world trade. Also, food security returned as the most important development agenda given unprecedented foodgrain shortages and hike in food prices worldwide (Allen 2008) although it was previously maintained that the global food supply is sufficient to meet food needs of the world's population and is expected to continue well into the next century (Islam, 1995). However, despite such food abundance, world hunger is increasing and the number of hungry people is estimated at 923 million in 2007, increasing from 848 million in 2003-05 (FAO, 2008). Furthermore, 65% of the 832 million chronically hungry people live in only seven countries: India, China, the Democratic Republic of the Congo, Bangladesh, Indonesia, Pakistan and Ethiopia (FAO, 2008). Also, Bangladesh is one of the countries affected most by high food prices (FAO, 2008) indicating its vulnerability in achieving food security.

Agricultural development policy is one of the most important factors affecting land use change in Bangladesh, which has one of the lowest land-person ratio of only 0.12 ha (FAO, 2001). Agriculture is the major source of livelihood in Bangladesh accounting for 23.5% of national income and employs 62% of the labour force (MoA, 2008). The dominant sector is the field crop agriculture accounting for more than 60% of agricultural value added. Among the field crops, rice is the major staple crop, occupying 70% of the gross cropped area (BBS, 2002). If supporting activities, such as, transport, storage and marketing of agricultural products are taken into account, then the share of agricultural sector GDP is likely to be over 60% of total (Alauddin and Tisdell, 1991). Historically, being a food deficit country, Bangladesh has pursued a policy of rapid technological progress in agriculture.

Consequently, over the past four decades, the major thrust of national policies was directed towards transforming agriculture through rapid technological progress to keep up with the increasing population. Development programs were undertaken to diffuse high yielding varieties (HYV) of rice and wheat with corresponding support in the provision of modern inputs, such as, chemical fertilizers, pesticides, irrigation equipments and infrastructures, institutional credit, product procurement, storage and marketing facilities. As a result farmers concentrated on producing modern varieties of rice all year round covering three production seasons (*Aus* – pre-monsoon, *Aman* – monsoon, and *Boro* – dry winter seasons), particularly in areas that are endowed with supplemental irrigation facilities. This raised concern regarding the loss of crop diversity consequently leading to an unsustainable agricultural system. For example, Husain et al., (2001) noted that "the intensive monoculture of rice led to displacement of land under low productive non-rice crops such as pulses, oilseeds, spices and vegetables, leading to erosion of crop diversity, thereby, endangering sustainability of crop-based agricultural production system". Mahmud et al., (1994) noted that "the area under non-cereal crops has continuously fallen since late 1970s, mainly due to the expansion of irrigation facilities, which led to fierce competition for land between modern *Boro* season rice and the non-cereals".

However, systematic analysis of the agricultural land use change in Bangladesh covering a longer period has not been attempted since early 1990s. The existing trend analyses of production growth (with implicit agricultural land use change) cover mainly the period 1973–1991 (e.g., BASR, 1989; Khalil, 1991; Mahmud et al., 1994) except Boyce (1985. 1987) and Alauddin and Tisdell, (1991) which cover 1948–1984. Also, only one attempt has been made to link the diffusion of Green Revolution (GR) technology to foodgrain availability (i.e., Alauddin and Tisdell, 1991).

Given this backdrop, the objectives of this study are to: (a) analyze agricultural land use change and trends in crop diversity in Bangladesh covering a 59 year period (1948–2006); (b) examine the trends in productivity of all major crop groups as well as key inputs; (c) examine the trends in foodgrain availability per capita per year as well as daily per capita dietary energy balance (DEB) as proxy measures to assess the goal of achieving self-sufficiency in food production; and (d) examine the effects of such agricultural land use change on the production environment, particularly on the soil fertility status.

The paper is divided into 4 sections. Section 2 describes the methodology used including sources of data. Section 3 presents the results. The final section concludes.

2. Methods

2.1 Data sources

The principal data on Bangladesh agricultural sector is taken from the latest available issue of Agricultural Handbook of Bangladesh 2007 published by the Ministry of Agriculture (MoA, 2008), a special issue of Statistical Yearbook of Bangladesh which reports land area, production and yield of all major crops covering the period 1948-1972 (BBS, 1975), various issues of the Statistical Yearbook of Bangladesh covering the period 1975 to 2002 published annually by the Bangladesh Bureau of Statistics (BBS, various issues), agricultural databases covering the period 1948 to 1990 compiled and published by Hamid (1991, 1993), and various issues of Economic Trends from 1990 to 2007 published monthly by the Bangladesh Bank (BB, various issues).

It is worth mentioning that analysis of agricultural production in Bangladesh encounters formidable problem of data quality (Alauddin and Tisdell, 1991) leading to misleading picture of the level and trend in output series (Pray, 1980). Boyce (1985, 1987) identified a number of systematic errors in the official crop acreage and yield series and prepared a revised series of agricultural output and yield for the period 1949–1980. It is important to note that Boyce (1985) only revised data of Aus and Aman rice crops, but not Boro or wheat crops (Boyce, 1987). Alauddin and Tisdell (1991) provided an estimate of both official and Boyce's revised data of foodgrain in Bangladesh for the period 1948-1982 (Table 12.1, p.250-251). They concluded that although official data slightly underestimates foodgrain area and production in the 1950s and overestimates in the 1960s, results do not appear to differ substantially from the official estimates when total period is considered (1948-1982) and, therefore, "raises further doubts about the validity of the revised series" (Alauddin and Tisdell, 1991, p252). Therefore, based on the evidence presented above, we have decided to use the official data source in our study.

2.2 Trend analysis classified by stages of Green Revolution diffusion

Average annual compound growth rates were computed in order to determine the rate of change of the variable of interest. The growth rates were computed using semi-logarithmic trend function: $lnY = \alpha + \beta T$, where Y is the target variable, T is time, ln is natural logarithm, and β is the growth rate.

We have presented all growth rates classified by stages of GR diffusion to examine whether the thrust in government policies to promote GR technologies has paid-off or not (Table 2). The period 1948–59 depicts the first decade when undivided India was partitioned into two independent nations: India (the present day India) and Pakistan in 1948. Pakistan in turn was composed of West Pakistan (the present day Pakistan) and East Pakistan which later became Bangladesh in 1971. Therefore, this period perhaps carried the effects of aftermath from a massive shift in identity along with subsequent relocation of masses of population to and from these two newly formed nations. Therefore, one may expect some adverse effect on the smooth functioning of the agricultural sector, although this cannot be clearly distinguished from the records. Nevertheless, little growth is expected during this period. The period 1960–75 depicts introductory stage of the GR technologies that received priority through import of HYV rice seeds in the late 1960s to support accelerated food production program sponsored by the Ford Foundation (Darlymple, 1986 cited in Hossain, 1989). Soon after independence of Bangladesh in December 1971, the government accorded highest priority to promote GR technologies leading to a rapid expansion of HYV rice seeds at a rate of 242,800 ha per year, consequently reaching one-third of total rice area by 1985 (Hossain, 1989). Hence this period 1976–1985 can be deemed as the take-off stage of the GR (Rahman, 2007). The remaining 21 year period (1986–2006) depicts the mature stage of the GR when stagnation in the adoption of this technology package started to set in during the late 1980s (Rahman, 2007).

2.3 Derivation of agricultural land use change

We have analyzed the changes in areas planted and production of eight major crop groups (aggregated from a total of 47 individual crops) at the national level covering a 59 year period from 1948 to 2006. The crops included in the analyses are: (i) foodgrain which includes local varieties of rice and HYV rice grown in each of the three seasons (*Aus* = pre-monsoon; *Aman* = monsoon; and *Boro* = dry winter), wheat, maize, barley, and other minor cereals; (ii) cash crops which include jute, cotton, sugarcane, tobacco, tea and betel leaves; (iii) pulses which include gram, mungbean, lentil, khesari, blackgram, and other pulses; (iv) oilseeds which include mustard, sesame, linseed, groundnut, coconut, and other oilseeds; (v) spices which include onion, chilli, garlic, ginger, and other spices; (vi) potatoes which include potatoes and sweet potatoes; (vii) vegetables which include eggplant, tomatoes, cauliflower, cabbage, radish, and other summer and winter vegetables; and (viii) fruits which include mango, banana, pineapple, papaya, jackfruit, litchi, guava, and melon.

2.4 Analysis of crop diversity

To analyze crop diversity, we have employed two indices, one adapted from the ecological indices of spatial diversity in species (Shannon index) and the other from the marketing industry index of market concentration (Herfindahl index) (Table 1). Each index represents a unique diversity concept. Evenness, which combines both richness (i.e., number of species/crops) and relative abundance concept, is measured by a Shannon index (Benin et al. 2004), and the concentration of crop type is measured by a Herfindahl index (Bradshaw, 2004; Rahman, 2009a; Rahman, 2009b).

[Insert Table 1 here]

2.5 Analysis of productivity

Information was also collected on major inputs of fertilizers, pesticides, area under irrigation and distribution of HYV seeds for cereals (rice and wheat) covering the period 1973–2005. The types of fertilizers included are: Urea, Triple Super Phosphate, Single Super Phosphate, Muriate of Potash, Diammonium Phosphate, Sulfur and Zinc. However, analyses of fertilizer use are expressed in actual nutrient contents of *N, P, K, S,* and *Zn*. Pesticides include information on the amount of active ingredients in insecticides, herbicides and fungicides.

We have also analyzed partial measures of crop productivity with respect to land, i.e., trends in crop yield per ha, as well as growth in fertilizers and pesticides as well as their use rate per unit of land area, area under irrigation and the distribution of HYV cereal seeds. Next, to examine sustainability of Bangladesh agricultural sector, we have examined three indices of partial productivity with respect to three key inputs: land, fertilizers and pesticides. Since we do not have specific time-series data on the amounts of fertilizers and pesticides used in each crop, we have analyzed productivity of these two inputs with respect to aggregate Gross Value Added (GVA) from agricultural production (expressed in Bangladeshi taka[1]) measured at constant 1984-85 prices, which implies net/real increase in productivity of the agricultural sector per se. Hence, land productivity is measured as GVA per hectare of net sown area per year ('000 Tk/ha/year), fertilizer productivity is measured as GVA per kg of

[1] Exchange rate 1 USD = Tk. 61.39 in 2005 (BB, various issues).

nutrients per year (Tk/kg/year), and pesticide productivity is measured as GVA per 100 ml/gm of active ingredients of pesticides per year (Tk/100 ml/year).

2.6 Analysis of food availability

One of the principal objectives of Bangladeshi agricultural land use policy is to improve food availability. We have utilized three proxy measures to examine the level and trends in food availability. These are: (i) foodgrain (i.e., all cereals) availability per capita per year, (ii) GVA in agriculture (measured at constant 1984-85 prices) per capita per year (Tk/capita/year), and (iii) daily per capita dietary energy balance (DEB) (Kcal/capita/day), which is a standard measure of national food availability, and gives sufficiency of a country's dietary energy supply (DES) for meeting the dietary energy requirement (DER) (Smith et al., 2000). In order to determine energy availability from food crops, we have used the standard calorie availability per 100 gm of individual crop weighted by its share of edible portion. The information on calorie availability and the share of edible portion of each crop was taken from the Household Income and Expenditure Survey (HIES) conducted by BBS (BBS, 2006).

2.7 Analysis of the effects on the environment

Detailed analysis of the effects of land use change on the physical production environment over time is not feasible due to unavailability of such data. Therefore, secondary evidences on the effects of intensive land use practices and the effect of major cropping patterns on the soil nutrient balance based on the researches conducted by the MoA and/or Bangladesh Agricultural Research Institute (BARI) were examined and supplemented with additional insights provided from available published materials mainly based on farm-level cross-sectional surveys on the topics.

3. Results

Results were presented in the form of trend diagrams (Figures 1 through 8) and growth regressions (Table 2). A key feature of Table 2 is that about 76% of the 251 estimated growth rate coefficients are significantly different from zero at 10% level at least, implying that Bangladesh has experienced significant changes in agricultural land use and its associated effects over time.

3.1 Trends in agricultural land use change and crop diversity

Figure 1 presents the trends in agricultural land use change in Bangladesh over the 59 year period under consideration (1948–2006) and Panel A of Table 2 presents the growth rates of selected indicators of land use change. The overall land area has increased by 4% from 14.28 million ha in 1948 to 14.84 million ha in 2006 owing to reclamation of new lands rising from the river beds (known as *char* lands). The net sown area available for agriculture recorded an overall decline of -0.1% perhaps due to diversion of land for non-agricultural land uses (e.g., housing, road and industrial infrastructures). However, due to improvements in irrigation, the gross cropped area (GCA), which takes into account land area sown twice or three times in a year, has steadily increased during the early and take-off stages of GR (1960-1985), as expected, but then stagnated during the mature stage of GR (1986-2006) finally reaching 14.10 million ha in 2006. In other words, land use overtime became very intensive in Bangladesh as reflected by consistently rising cropping intensity from 127.9% in 1949 to 176.9% in 2005 with an overall estimated growth rate of 0.7% per annum. The main reason for such an increase is the development of irrigation which enabled farmers to grow three crops of rice in a year.

An interesting feature to note in Figure 1 is that the increased share of HYV rice area could not compensate for the consistent decline in local rice area, thereby leading to an overall decline in the share of total rice area in GCA at an annual rate of -0.2%. The area under non-cereals fluctuated and also declined overtime. The share of other cereals, dominated by HYV wheat, recorded a consistent rise in GCA. This finding clearly contradicts with the findings of Husain et al., (2001) and Mahmud et al., (2004), who claimed that monoculture of HYV rice has been seriously hampering crop diversity. The trend in the computed indices of crop diversity presented in Figure 2 with their growth rates in Panel B of Table 2 provides conclusive proof. The Shannon index shows that crop evenness grew at an annual rate of 0.6% increasing from 0.81 in 1948 to 1.07 in 1998 and reached 0.94 in 2006. The Herfindahl index also tells the same story that crop concentration has actually declined annually by -0.4% from 0.69 in 1948 to 0.54 in 1999 and reached 0.62 in 2006. The implication is that, overall crop diversity has been increasing (with some fluctuation) in Bangladesh instead of falling as many suggest[2] (e.g., Husain et al., 2001; Mahmud et al., 2004; Alauddin and Tisdell, 1991). Rahman (2009b), based on an analysis of the level of crop diversification between two Agricultural Censuses of 1960 and 1996, also noted that the level of crop diversity (measured by Herfindahl index) has actually increased by 4.5% over a 36 year period from 0.59 in 1960 to 0.54 in 1996.

Figure 3 presents additional information on agricultural land use change with estimated annual growth rates of major crop groups presented in Panel C of Table 2. It is clear from Figure 3 that except jute area, all other non-cereal areas experienced positive growth rates overall. Among the cereals, wheat area experienced a varied rate of growth. The wheat area was only 0.03 million ha in 1948 which increased to a peak of 0.88 million ha in 1999 and then fell sharply to 0.48 million ha in 2006. Wheat area and production experienced a crisis at a global scale during mid-2000 and Bangladesh was not an exception. As a result, the average annual growth rate has been estimated at 5.4% only. Among these non-cereals, only jute area declined annually at a rate of -0.9% mainly due to a lack of demand for fibre products owing to the availability of cheap synthetic alternatives worldwide. The fall in jute area was sharp during the mature stage of GR (1986-2006). Also, pulses and oilseeds faced

[2] The Herfindahl index is an index of crop concentration. Therefore, a negative sign of the index implies positive relationship with diversity and vice-versa.

the same fate during this period. Vegetables and potatoes recorded impressive growth in area during this period estimated at 2.5% and 4.1%, respectively, although they constitute less land area in absolute terms. The area under vegetables and potatoes covered only 0.19 million ha and 0.34 million ha in 2006. Potatoes gained importance because it substitutes starch intake from rice and is relatively cheaper. For example, sweet potato in the northern region of Bangladesh is considered as food for the poor. The rise in vegetable production can partly be attributed to the drive of many non-governmental organizations promoting kitchen gardening by engaging rural women clienteles. Bangladesh has been exporting vegetables since early 2000 and the trend is on the rise. According to the Export Promotion Bureau of Bangladesh, a total of Tk 4,232.9 million (USD 61.8 million) was earned by exporting different varieties of vegetables against the target of Tk 2,800 million (USD 40.86 million) in the year 2007-08. It was Tk 2,498.1 million (USD 36.31 million) in the year 2006-07 (New Nation, 2008).

3.2 Trends in productivity and input use

Once land use change has been analyzed, we next examine the trends in productivity (i.e., yield levels of major crops) and use of modern inputs. Figure 4 presents the trends in the use of modern inputs in Bangladesh agriculture and Panel D in Table 2 presents the growth rates. It is clear from Figure 4 that the growth in input use has been explosive, particularly fertilizers and pesticides, which became an integral part of the modern day agriculture. Fertilizer consumption was only 0.18 million tons of nutrients in 1973, which increased by 11 times to 1.70 million tons of nutrients in 2006. Fertilizer use in Bangladesh is dominated by nitrogen fertilizers (70% of total use), although use of zinc and sulfur started from 1981 and has been increasing gradually. Pesticide use was only 3.13 thousand tons of active ingredients in 1977 which increased by 5.5 folds to 17.39 thousand tons of active ingredients in 2002. The expansion of irrigation facilities has been impressive, initially boosted through governmental support and later by market forces following agricultural reform since 1990s.

The proportion of irrigated area in GCA was only 11.0% in 1973 which increased to 37.5% in 2006, recording a steady increase at a rate of 4.4% per annum. Growth in the distribution of HYV seeds for cereals (i.e., rice and wheat) is also impressive. The government has distributed 5.48 thousand tons of HYV cereal seeds in 1974 which increased at an annual rate of 5.9% to 45.62 thousand tons in 2006, although the actual level is far lower than the required amount needed to sustain continued expansion of HYV technology.

Figure 5 presents the trends in yield rates of major crops as well as use rates of two major inputs, fertilizers and pesticides and their growth rates are presented in Panels E and F in Table 2. The striking feature in Figure 5 is the performance of HYV rice. The yield of HYV rice actually fell at an annual rate of -1.0% during the early and take-off stages of GR (1960-1985) and then reversed the pattern during the mature stage of GR (1986-2006) growing at an annual rate of 1.4%. The reasons for such a decline in yield include lower than recommended dose of fertilizers (upto 40-70% below requirement), expansion to less suitable lands (e.g., to coastal, central and north eastern regions), and depletion of soil fertility (Rahman, 2007). The overall level of rice yield (HYV and local varieties) increased at 1.7% per annum due to the fact that yield rate of HYV rice is still twice the yield rate of local rice. For example, yield of HYV rice was 2.31 ton/ha which was 2.7 times the local rice yield of 0.87 ton/ha in 1973. However, although the yield level of HYV rice increased to 2.92 ton/ha in 2006, it was only 1.9 times higher than the yield of local rice of 1.42 ton/ha because farmers perform screening of local rice varieties of rice and also use modern inputs. Yield rate of wheat also grew at an annual rate of 3.0% per year increasing from 0.58 ton/ha in 1948 to 1.53 ton/ha in 2006. The growth in yield rates of non-cereals is lower ranging from only 0.3% for pulses to 1.9% for spices, implying little or no technological progress for these crops. In fact, for the non-cereals, modern technology is only well established in potato cultivation (Mahmud et al., 1994). Although, a total of 131 improved varieties of various non-cereal crops have been developed and released by BARI, two-thirds of these are released only from 2006 (Rahman, 2009b), which explains the lack of yield growth of the non-cereals.

On the other hand, rates of fertilizer and pesticide use exploded over the years. Fertilizer use rate was only 14.25 kg of nutrients per ha in 1973 which increased to a staggering 127.18 kg of nutrients per ha in 2006 recording an annual growth rate of 6.3%. The growth in pesticide use is even higher. Pesticide use was only 0.26 kg of active ingredients per ha in 1977 which increased to 1.23 kg of active ingredients per ha in 2002, recording an annual growth rate of 8.5%. The implication is that proportionately higher doses of modern inputs (i.e., fertilizers and pesticides) were necessary to keep modest positive growth in crop productivity, which may soon become unsustainable if the trend continues.

Finally, we report our three partial productivity measures of land, fertilizers and pesticides presented in Figure 6 and growth rates in Panel G of Table 2. It is clear from Figure 6 that overall land productivity is consistently rising at an annual rate of 2% with twice the rate during the mature stage of GR diffusion, as expected. However, when productivity of other two key inputs of fertilizers and pesticides were examined, the scenario is not very encouraging. Productivity from these two inputs was consistently declining over the years, and the rate of decline was very high for pesticides at -6.5% per year. The rate of decline in fertilizer productivity has been lower during the mature stage of GR estimated at -3.8% per annum. There may be multiple reasons for such a decline in productivity of inputs, which include loss of soil fertility, expansion to poor quality land, and/or genetic impurity of the crops (particularly HYV seeds) used (Rahman, 2007). These findings raise serious doubt on the sustainability of modern agricultural technology for the future.

3.3 Prospects in achieving self-sufficiency in food production

The final element of analysis was to examine whether Bangladesh has succeeded in its goal towards achieving self-sufficiency in food production for its fast rising population.

Figure 7 presents the trends in population growth and per capita food availability during the period 1948-2006 with growth rates presented in Panel H of Table 2. It is clear from Figure 7 that foodgrain availability per capita fluctuated and did not grew during the early and take-off stage of GR (1960-1985) but then recorded a steady growth of 1.7% per year during the mature stage of GR diffusion (1986-2006), although population grew at an overall rate of 2.1% per year throughout. In other words, growth in foodgrain production was able to more than offset the growth in the population base, particularly during the mature stage of GR diffusion, which is very encouraging indeed. The foodgrain availability per capita per year has fluctuated from 171.5 kg in 1948 to 163.4 kg in 1985 and then increased to 200.3 kg in 2006. However, real growth in agricultural production per person (i.e., agricultural GVA measured as Tk/capita/year) demonstrated an impressive growth of 2% per annum during the mature stage of GR, but the overall contribution was negative (-0.2% per annum) due to persistent decline during early and take-off stages of GR (1960-1985). The principal reason may be due to a very high rate of population growth of 2.3% during the early phase, which tend to offset net return from the agricultural sector.

Bangladesh is not only a food deficit country, but also deficient in nutrition. According to FAO (2006), the Average Daily Energy Requirement (ADER) for South Asian population is 2,110 Kcal per capita and the Minimum Daily Energy Requirement (MDER) for Bangladeshi population is 1,750 Kcal (FAO, 2008a). The MDER is the threshold level below which the person would be classified as malnourished. Figure 8 presents the trends in Daily Energy Supply (DES) of various food crops and the Daily Energy Balance (DEB) per capita with respect to ADER and MDER. The horizontal bar denoting 0 at the secondary Y axis is the balance threshold of DEB. Any line below the horizontal bar reflects dietary imbalance. The picture on DES from food crops is quite mixed (Panel I, Table 2). The mature stage of GR is the period when positive growth rates of 1.2% per annum was observed in

DES, mainly powered by growth in foodgrain, while energy derived from non-cereals as a whole declined at an annual rate of -0.7%. However, growth in energy derived from spices, potatoes and vegetables were impressive during this period.

In terms of actual measure, DES was 2,086 Kcal/capita/day in 1948, which remained remarkably close at 2,093 Kcal in 1985 (despite a sharp rise in population at an annual rate of 2.3% per annum during this period) and then finally increased to 2,451 Kcal/capita/day in 2006, which is very encouraging. The figures are comparable to recent FAO estimates[3]. For example, FAO estimates of DES for Bangladesh is 2,230 Kcal/capita/day during 2003-05 (FAO, 2008) with cereals contributing 80% of DES, roots and tubers 2%, oil and fats 7% and animal protein 3%, respectively. Our figure for the same triennium periods is 2,446 Kcal/capita/day with cereals contributing 82% of DES, roots and tubers 3% and oils 3%, respectively[4]. However, when we examine the DEB with respect to ADER, the extent of deficit in nutrition becomes more than clear. Bangladesh has been deficit in meeting the ADER until 1985 with occasional boost during the 1960s. It is only during the mature stage of GR diffusion, when a reversal in dietary imbalance was observed, with dips in mid-1990s. However, when DEB with respect to MDER is considered, one could see overall positive DEB with large fluctuations during the early and take-off stages of GR (1960–1985). Therefore, results from Figures 7 and 8 together provides a clear indication that Bangladesh has improved food availability for its population in recent years, which is consistent with the anecdotal claims made by ruling political parties since year 2000.

[3] FAO's DES is defined as "food available for human consumption, expressed in kilocalories (kcal) per capita per day". At the country level, it is calculated as the food remaining for human use after the deduction of all non-food consumption (exports, animal feed, industrial use, seed and wastage).

[4] It should be noted that we did not include energy derived from animal protein sources.

3.4 Impacts on the production environment

Serious loss of soil fertility has become a concern in Bangladesh. It is believed that more than 65% of the total agricultural land is suffering from declining soil fertility and about 85% of the net area suitable for cultivation has organic matter content below the minimum requirement (TFR, 1991). Soil analysis of 460 samples from 43 profiles from the same locations between 1967 and 1995 revealed a decline in fertility (Ali et al., 1997) although this decline in soil fertility has not been explicitly linked to GR technology. Baanante et al., (1993) noted that food crop production in Bangladesh takes up an estimated 0.93 million tons of nutrients (N, P, K and S) from the soil annually. The MoA (2008) reported that 11 out of a total of 30 agro-ecological zones[5] of Bangladesh have lost soil fertility between 10–70% due to intensified crop cultivation over a 30 year period from 1968 to 1998 (Table 3). Barind Tract and Old Brahmaputra Floodplain areas seem to be the hardest hit areas in terms of soil fertility decline (Table 3).

Table 4 presents the ranking of the cropping system according to the rate of soil-fertility decline. It is clear from Table 4 that the most intensive cultivation system spurred by the diffusion of GR technology, i.e., three rice crops a year (Boro rice–Transplanted Aus rice–Transplanted Aman rice) ranks first and depletes approximately 333 kg of N, P, K per ha per year, which is alarming. However, adding 'green manure' in the system and keeping two crops of rice dramatically reduces the depletion rate to 121 kg of nutrients/ha/year. The least amount of soil nutrient depletion of 112 kg of nutrients/ha/year is associated with the system comprising of Wheat–Mungbean–Transplanted Aman. The results are not surprising although depressing. Widespread adoption of GR technology was identified as a cause of significant

[5] The Land Resources Appraisal of 1988 classified Bangladesh into 30 distinct agro-ecological region*s* (88 including sub-regions) based on information relevant for land use and assessment of agricultural potential (UNDP/FAO, 1988).

soil degradation and declining crop yields in India (Singh, 2000). Pimentel (1996) indicated that extensive use of fertilizers and pesticides to support the GR has caused serious public health and environmental damages worldwide, particularly in developing countries. Furthermore, it has been noted that continued, intensive production of rice has led to yield reductions in some countries in Asia, explained in part by soil nutrient exhaustion (Doberman et al., 2002). Selected farm-level evidence also tells the same story. Rahman (2003) noted that farmers are well aware of the adverse environmental impacts of modern agricultural technology and reduction in soil fertility has been ranked as the number one adverse effect of GR technology diffusion.

4. Conclusion

The present paper attempted to provide a detailed analysis of the agricultural land use changes at the national level in Bangladesh over a 59 year period (1948-2006) and an examination of its effects on productivity, crop diversity, food availability and the environment. Results revealed that agricultural land use in Bangladesh became intense facilitated by increased provision of irrigation infrastructure and modern inputs of fertilizers, pesticides, and HYV seeds of cereals to diffuse a rice-based GR technology package throughout the country. Although we see consistent growth in land productivity, productivity of the other two key inputs of fertilizers and pesticides has been falling consistently, thereby, raising doubts on sustaining future agricultural growth based on GR technology alone. However, contrary to the widespread apprehension that Bangladesh is fast losing its crop diversity owing to HYV rice monoculture, results showed that crop diversity has actually increased significantly overtime as reflected by the Shannon index of species/crop evenness. It is encouraging to note that Bangladesh has shown success in raising its foodgrain availability per capita and was able to outstrip the influence of high population growth. However, the real gain in returns derived from the agricultural growth could not outstrip the influence of population growth but managed to restrict the overall decline at a minimal rate. It is only during the mature stage of GR (1986-2006) that the returns from agricultural growth reversed its sign and managed to grow at an annual rate of 2% per annum, which is quite encouraging. Although we see a reversal in the dietary imbalance during the mature stage of GR diffusion, the main contributor to this growth in DES was the foodgrain sector (82% of total DES).

Given the results from the aforementioned analyses, we can conclude that the GR technology has delivered its expected outcomes, i.e., improved per capita food availability and contributed positively towards achieving the goal of self-sufficiency in food production. However, concentration of food energy availability from cereals as opposed to non-cereals is a source of concern for dietary health of the Bangladeshi population. However, it is encouraging to note rising trends in the production of selected non-cereal crops of spices, potatoes and vegetables during the mature stage of GR, which could pave the way for a diversified agricultural system that is relatively more sustainable. Thus, Bangladesh needs to widen its technology base and go beyond the diffusion of HYV rice and should diversify its land use towards producing non-cereals (Rahman, 2007). Rahman (2009b) based on farm-level survey data, demonstrated strong evidence of economies of diversification amongst various crop enterprise combinations, significantly lower use rates of all inputs in diversified farms, and significant technical efficiency gains from diversification. He concluded that crop diversification should be the desired strategy for agricultural growth in Bangladesh. The government has also realized the importance of promoting crop diversification as a strategy to increase production of nutritional crops as well as to encourage export of vegetables and fruits (PC, 1998). The Fifth Five Year Plan (1997–2002) earmarked spending of Tk 1,900 million (US$ 41.8 million), accounting for 8.9% of the total agricultural allocation, to promote crop diversification (PC, 1998), which is a step in the right direction. Nevertheless, challenges remain in order to effectively implement such a policy shift away from only promoting GR diffusion as it would require adjustments in dietary habits, social preferences, as well as market and other support services.

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Table 1. Crop diversity indices

Index	Concept	Construction	Explanation	Interpretation
Shannon	Evenness or equitability (both richness and relative abundance)	$D_S = -\sum \alpha_j * \ln \alpha_j,\ D_S \geq 0$	α_j = area share occupied by the *jth* crop in *A*. *A* = total area planted to all crops	Higher value of index denotes higher diversity
Herfindahl	Concentration	$D_H = \sum \alpha_j^2,\ 0 \leq D_H \leq 1$	α_j = area share occupied by the *jth* crop in *A*.	A zero value denotes perfect diversification and a value of 1 denotes perfect specialization

Source: After Benin et al. (2004); Bradshaw (2004); and Rahman (2009a).

Table 2. Growth rate estimates by stages of Green Revolution diffusion.

Panel	Variables	Average annual compound growth rates				
		Pre-GR	**Early GR**	**Take-off GR**	**Mature GR**	**All stages**
		1948-59	**1960-75**	**1976-1985**	**1986-2006**	**1948-2006**
A	**Land use change**					
	Net sown area (NSA)	0.002	0.000	0.004***	-0.003**	-0.001***
	Gross cropped area (GCA)	0.004	0.012***	0.014***	0.000	0.007***
	Cropping intensity	-0.002	0.007***	0.003**	0.005***	0.007***
	Share of HYV rice area in GCA	--	0.280*	0.069***	0.046***	0.058***
	Share of local rice area in GCA	0.000	-0.013***	-0.028***	-0.044***	-0.023***
	Share of total rice area in GCA	0.000	-0.003**	-0.009***	0.001**	-0.002***
	Share of other cereals in GCA	0.000	0.056***	0.131***	0.006	0.047***
	Share of non-cereals in GCA	0.001	0.003	-0.000	-0.001	-0.002***
B	**Crop diversity**					
	Herfindahl index of crop concentration	-0.001	0.021	-0.017***	0.002**	-0.004***
	Shannon index of crop evenness	0.000	-0.028	0.024***	-0.002*	0.006***
C	**Trends in cropped area**					
	Local rice	0.003	-0.012**	-0.015***	-0.044***	-0.015***
	HYV rice	--	0.289*	0.082***	0.045***	0.062***
	Total rice	0.003	0.009***	0.005*	0.002*	0.005***
	Wheat and other cereals	0.004	0.068***	0.144***	0.005***	0.054***
	Jute	-0.042*	0.012	0.002	-0.030***	-0.009***
	Pulses	-0.029***	0.045**	0.080**	-0.037***	0.018***
	Oilseeds	0.008	0.004	0.036*	-0.022***	0.014***
	Spices	0.027***	0.036***	-0.005*	0.041***	0.021***
	Potatoes	0.102***	0.058***	0.012**	0.041***	0.033***
	Vegetables	-0.011*	-0.005*	0.024***	0.025***	0.003***
	Fruits	0.002	0.029***	0.013***	0.002	0.004***
D	**Trends in modern inputs**					
	Fertilizer nutrients	--	0.372*	0.093***	0.051***	0.067***

Panel	Variables	Average annual compound growth rates				
		Pre-GR	Early GR	Take-off GR	Mature GR	All stages
		1948-59	1960-75	1976-1985	1986-2006	1948-2006
	Pesticides (active ingredients)	--	--	0.017	0.085***	0.089***
	HYV seeds for cereals	--	--	0.222***	0.037***	0.059***
	Irrigation area	--	0.089***	0.042***	0.043***	0.044***
E	**Trends in crop productivity**					
	Local rice yield	--	0.001	0.010*	0.014***	0.014***
	HYV rice yield	--	0.005	-0.003	0.014***	0.005***
	Total rice yield	-0.001	0.006	0.018***	0.028***	0.017***
	Wheat and other cereals yield	0.017	0.020**	0.055***	0.020***	0.029***
	Jute yield	0.043**	-0.024**	0.006	0.013***	0.005***
	Pulses yield	0.004	-0.008	0.003	0.008***	0.003**
	Oilseeds yield	0.008*	0.045***	0.030***	0.008***	0.015***
	Spices yield	0.082**	0.017	0.002	0.006***	0.019***
	Potatoes yield	--	0.035***	0.009**	0.022***	0.014***
	Vegetables yield	0.002	0.020***	0.002	0.010***	0.008***
	Fruits yield	0.050**	-0.010*	-0.008***	0.023*	0.006***
F	**Trends in input use rates**					
	Fertilizer use rates	--	--	0.070***	0.054***	0.068***
	Pesticide use rates	--	--	0.001	0.085***	0.085***
G	**Productivity of key inputs**					
	Land productivity	0.006	0.003	0.017***	0.038***	0.020***
	Fertilizer productivity	--	--	-0.071***	-0.023***	-0.054***
	Pesticide productivity	--	--	0.005	-0.064***	-0.065***
H	**Trends in food availability**					
	Population	0.026***	0.023***	0.023***	0.012***	0.021***
	Foodgrain availability per capita per year	-0.026***	-0.008*	0.009***	0.017***	0.004***
	GVA (at constant 1984-85 prices) in crop production per capita per year	-0.022***	-0.009*	-0.003	0.020***	-0.002**

Panel	Variables	Average annual compound growth rates				
		Pre-GR	**Early GR**	**Take-off GR**	**Mature GR**	**All stages**
		1948-59	**1960-75**	**1976-1985**	**1986-2006**	**1948-2006**
I	**Trends in DES**					
	Energy from foodgrain	-0.026**	-0.008*	0.010**	0.017***	0.004***
	Energy from non-cereals	-0.008	0.012	0.007	-0.007***	-0.002***
	Cash crops	-0.006	0.007	-0.007	-0.019***	-0.009***
	Pulses	-0.060***	0.014	0.059	-0.042***	0.001
	Oilseeds	-0.018	0.026***	0.043*	-0.026***	0.008***
	Spices	0.036***	0.014	-0.026**	0.039***	-0.002
	Potatoes	0.000	0.071***	-0.002	0.050***	0.027***
	Vegetables	-0.044***	-0.024**	-0.001	0.023***	-0.001***
	Fruits	0.012	-0.020**	-0.016***	0.009	-0.017***
	Energy from all crops	-0.022**	-0.003	0.009**	0.012***	0.003***

Note: All growth rates are computed using semi-logarithmic trend function: $lnY = \alpha + \beta T$, where Y is the target variable, T is time, ln is natural logarithm, and β is the growth rate.
Data available for HYV rice = 1972-2006; Local rice = 1972–2006; Potatoes = 1956–2006; Fruits = 1950–2006; Fertilizers = 1970–2006; Pesticides = 1977–2003; HYV seeds for cereals=1974-2006; and GVA = 1950-2002 only.
*** = significant at 1 % level ($p<0.01$)
** = significant at 5 % level ($p<0.05$)
* = significant at 10 % level ($p<0.15$)

Source: Computed from MoA 2008; BBS (various issues); Hamid (1991, 1993); Bangladesh Bank (various issues)

Table 3. Losses of fertility of soil by intensified crop cultivation, 1967-68 to 1997-98.

Agro Ecological zone (Number)	Types of land	Increase of cropping intensity (%)	Losses of Soil fertility (%)
Old Himalayann Piedmont Plain (1)	HL	100	25-45
Tista Floodplain (2)	HL	100	10-35
Tista Meander Floodplain (3)	HL	100	10-40
Old Brahmaputra Floodplain (9)	MHL	100	25-65
High Ganges River Floodplain (11)	HL	100	20-45
Middle Meghna River Floodplain (16)	MLL	100	15-40
Surma Kushiyara River Floodplain (20)	MLL	100	20-40
North Eastern Peidmont Plain (22)	HL	100	20-70
Chittagong Coastal Plain (23)	HL	100	10-30
Barind Tract (26)	HL	100	30-60
Madhupur Tract (28)	HL	100	40-65

Note: HL = High land, MHL = Medium high land, MLL = Medium low land.
The land type classification in Bangladesh is based on flooding depth. HL = no flooding, MHL = flooding depth of 0.01 – 0.90 m, MLL = flooding depth of 0.91 – 1.83 m, LL (Low land) = flooding depth of 1.83 – 3.05 m, VLL (Very low land) = flooding depth >3.05 m (Source: Land Resources Information database, Bangladesh Agricultural Research Council).

Source: Committee report for losses of soil fertility, 2004, BARI. (MoA, 2008, Table 4.04)

Table 4. Estimation of nutrient depletion in major cropping pattern in Bangladesh

Major cropping pattern	Total yield (ton/ha/yr)	Input (kg/ha)			Output (kg/ha)			Balance (kg/ha)			Approx. total depletion (kg/ha/yr)
		N	P	K	N	P	K	N	P	K	
Boro-T.Aus-T.Aman	11.5	350	60	151	469	57	368	-119	+3	-217	333
Mustard-Jute-T.Aman	7.5	340	75	205	430	79	429	-90	-4	-224	318
Potato-Jute-T.Aman	36	380	70	240	385	55	496	-5	+15	-256	246
Potato-T.Aus-T.Aman	38	386	67	220	430	53	435	-44	+14	-215	245
Wheat-T.Aus-T.Aman	10	335	65	166	420	64	292	-85	+1	-126	210
Sugarcane+Potato intercropping	100	190	55	150	210	60	320	-20	-5	-170	195
Mustard-Boro-T.Aman	9.5	378	73	183	404	95	326	-26	-22	-143	191
Boro-Fallow-T.Aman	8	248	49	118	324	32	234	-76	+17	-116	175
Boro-GM-T.Aman	8	285	0	135	324	32	240	-39	+28	-105	121
Wheat-Mung bean-T.Aman	8	275	64	190	305	52	284	-30	+12	-94	112

Note: Input: Fertilizer, manure, fixation (BNF), deposition (rain), sedimentation (flood) and irrigation; Output: Harvested product, residues removed, leaching, dentrification, volatilization and erosion (Source: Information based on research conducted by Bangladesh Agricultural Research Institute (BARI)).

Source: Adapted from MoA (2008, Table 4.04a).

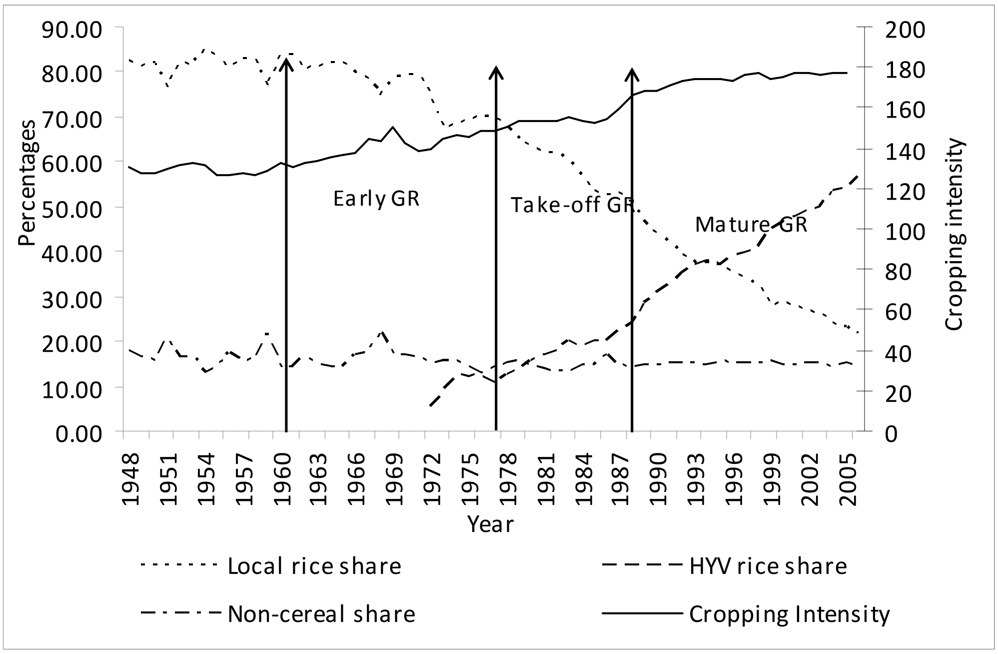

Figure 1. Trends in land use change in Bangladesh agriculture (1948–2006).

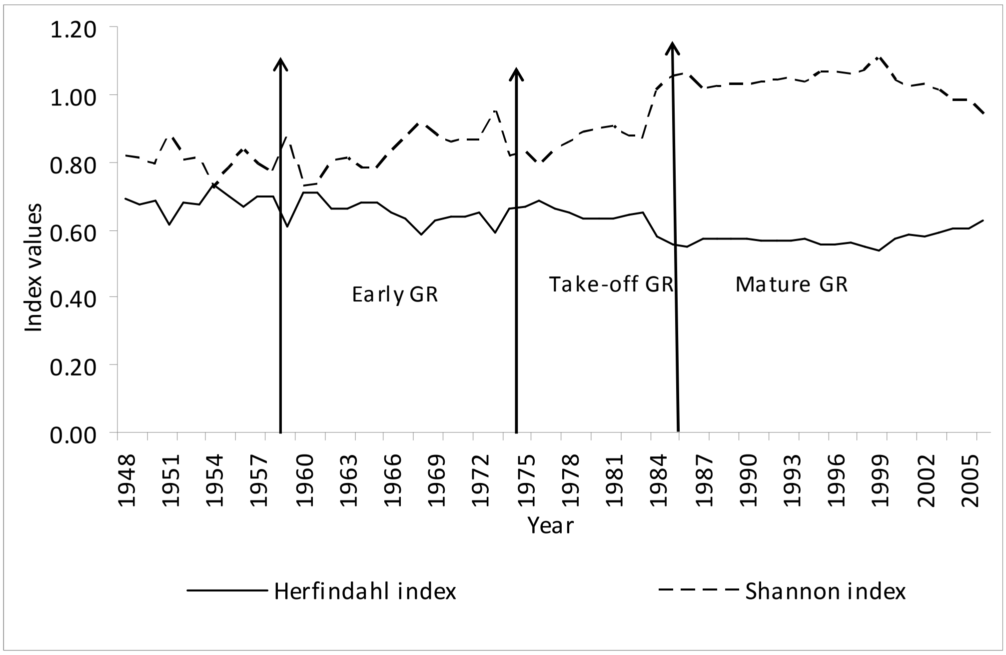

Figure 2. Trends in crop diversity in Bangladesh (1948–2006)

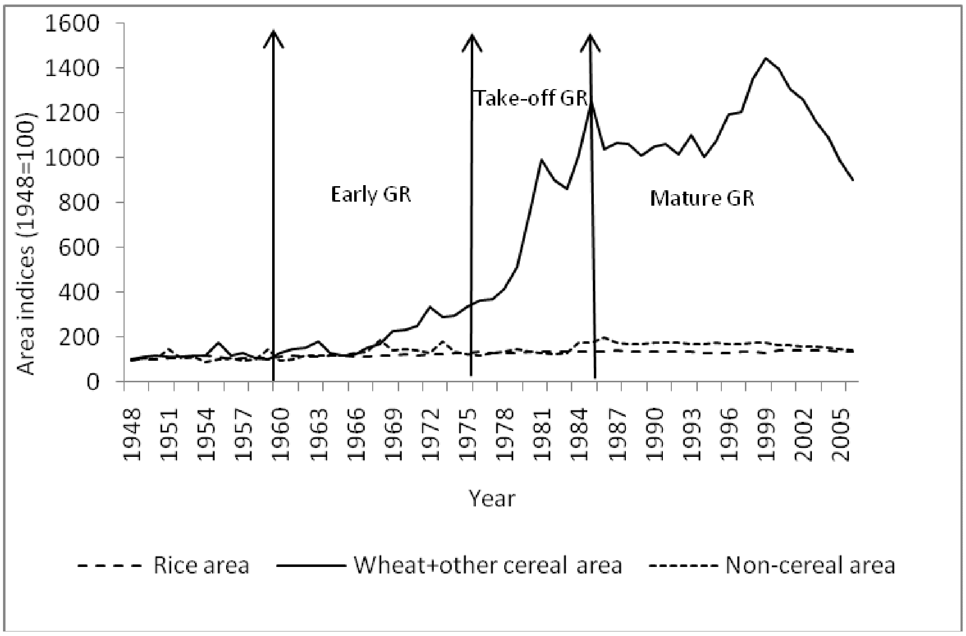

Figure 3. Trends in cropped area (1948 – 2006).

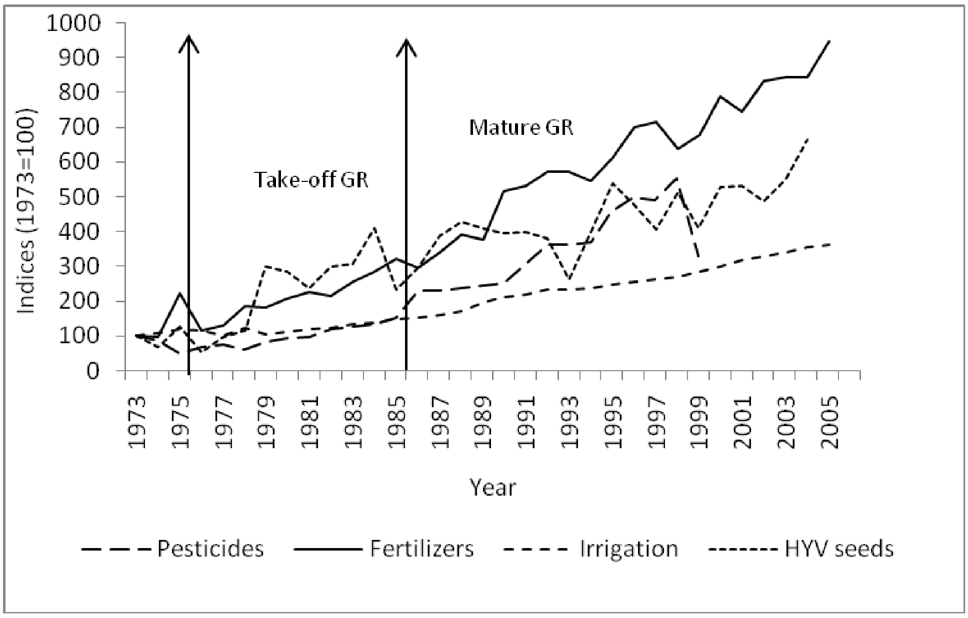

Figure 4. Growth in input use (1973–2005).

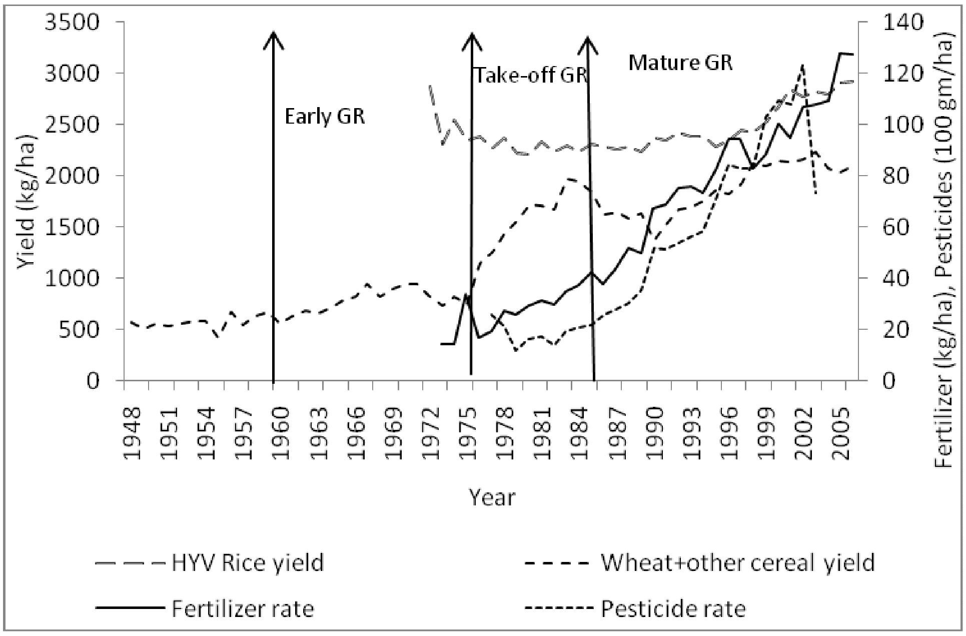

Figure 5. Trends in crop yield and input use rates (1948–2006).

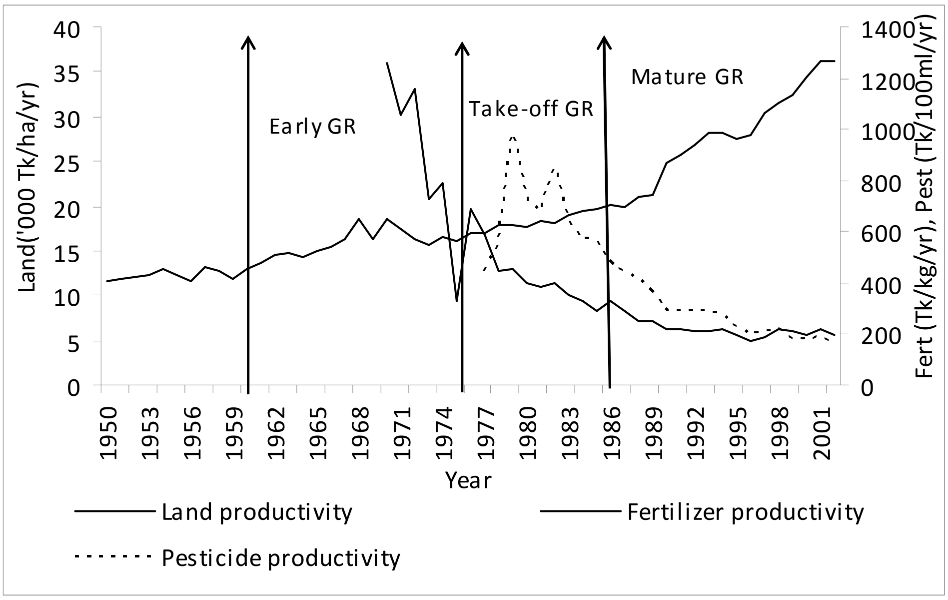

Figure 6. Trends in partial measures of land, fertilizer and pesticide productivity in Bangladesh agriuclture (1948–2006).

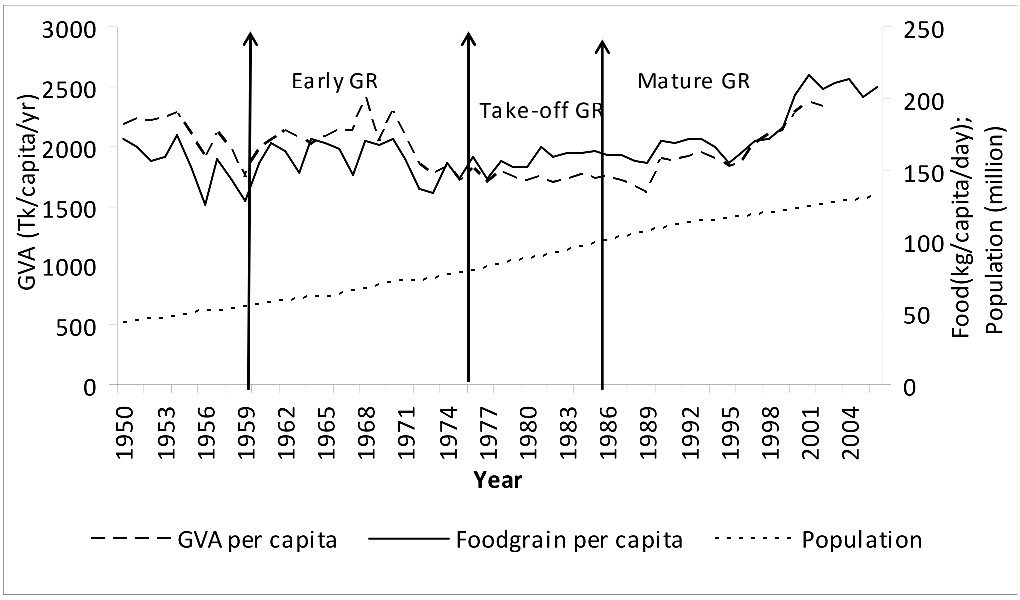

Figure 7. Trends in population growth and per capita food availability from crops (1948–2006).

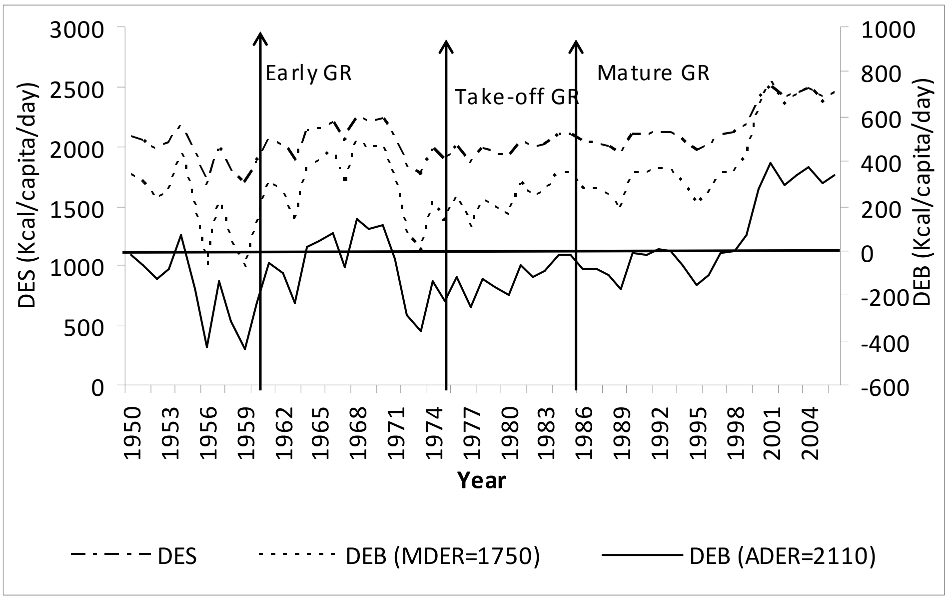

Figure 8. Trends in energy availability (Kcal) from food crops per capita per day (1948–2006).