SOCIO-ECONOMIC AND ENVIRONMENTAL IMPACTS OF TECHNOLOGICAL CHANGE IN BANGLADESH AGRICULTURE

by

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A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy

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DEDICATION

This dissertation is dedicated to my demised mother, Begum Shahan-Ara-Shafi, who could not see the success of her son.

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ABSTRACT

Widespread controversies exist on the delayed consequences of technological change or 'Green Revolution' technology in agriculture largely due to the approach utilized in the evaluation process and the extent of issues covered. Early evaluations, focussing on issues of production, employment, and income only, failed to account for the delayed consequences of technological change on regional variations, gender equity, poverty and the environment. The present study employed a holistic approach to evaluate the impacts of technological change in agriculture, specifically, on productivity, employment, gender equity, income distribution, poverty and the environment at the local level and on regional development, aggregate crop production and foodgrain sustainability at the national level. The overall hypothesis is that though modern agricultural technology increased production, employment and income, it has exacerbated income inequality, poverty, gender gap in employment, regional disparity and environmental degradation and is threatening food production sustainability. In this context, the research is designed with a blend of economic (crop input-output), biophysical (soil fertility) and behavioral (farmers' perception) analyses to capture the diverse issues (employment, income, income distribution, poverty and environment). Database of the study consists of time-series data for 47 years (1948 – 1994) and farm-level cross-section data of cropyear 1996 collected from three agro-ecological regions including soil samples from representative locations and information on infrastructural facilities. Economic principles and concepts are used as the basic tools of analysis and hypotheses are empirically tested using quantitative as well as qualitative techniques.

The results of the analyses validated the concerns raised at the outset of the study. At the national level, though technological change played a significant role in raising regional agricultural development level, it has also contributed significantly to regional disparity with most regions being stagnant and underdeveloped over the past 20 years. Technological change also significantly contributed to aggregate crop productivity over the past 30 years. Returns to scale estimation using conventional factors revealed that 'constant return to scale' prevails in Bangladesh agriculture. Incorporation of technological and infrastructural factors in the estimation revealed 'increasing returns to scale'. But, declining productivity of modern rice, the major vehicle of technological change, is raising doubts on sustaining food production. The current increase in food production is largely due to switching from local to modern rice varieties and may not be sustainable in the long run. Trend analyses of 47 years of foodgrain (rice and wheat) production revealed that productivity is reaching a saturation value of 2,200 kg/ha, raising doubts on food production sustainability to meet the growing demand for food.

Farm-level analysis of farmers' response to price changes revealed that probability of adopting modern technology increases with output price rise and decreases with input price rise. Intensity of modern technology adoption is higher in underdeveloped regions. Farmers have moderately inelastic response to price changes for foodgrain crops and highly elastic response for non-cereal crops. Consideration of the possibility of switching between local and modern foodgrain varieties, that is, allowing movement along a 'meta-production function' improved the elasticity estimates for foodgrain crops. Highly elastic response is observed for soil fertility improvement in foodgrain production and inelastic response for non-cereal crops. The response to infrastructural development and education work in opposite direction for these crop groups. While infrastructure development and farmers' education level increase input

demand and output supply of non-cereal crops, these decreases input demand and output supply of foodgrain.

At the local level, although modern agricultural technology significantly increased employment, input demand, prices and crop incomes, the gain from employment remained skewed in favor of men and income in favor of large/medium farmers. Also, significantly lower wage is paid to female labor, if hired, indicating further discrimination against women. Land and other resource owners are the highest beneficiaries of technological change. Production of modern varieties alone contributes 35% to total income inequality, thereby, indicating unexpected adversity of modern technology on income distribution. Poverty is estimated to be highest in 'high adopter villages' with 63% of population below poverty line, thus, reinforcing the unexpected adversity associated with technological change. 'Declining soil fertility', 'effect on human health', 'reduction of fish catch', and 'increase in insect, pest and disease attacks' are the major environmental impacts of technological change identified in the study regions as perceived by farmers. Soil fertility positively influences prices, modern technology adoption, crop and agricultural income and negatively influences demand for labor, animal power and pesticides, and non-agricultural income. Infrastructure development also positively influences prices and non-agricultural income and negatively influences technology adoption and input demand (except animal power and agricultural credit).

The 'medium adopter' villages characterized by diversified cropping system, larger with land endowment (0.96 ha/farm), better soil fertility and developed rural infrastructure revealed least income inequality and incidence of poverty. The gini-ratio of per capita income is estimated at 0.34 for the 'medium adopter' villages as compared to 0.44 and 0.45 for the 'high adopter' and 'low adopter' villages, respectively. Findings of this study, therefore, establish the superiority of 'medium adopter' villages with respect to distributional implications and challenge the conventional notion that high level of modern technology diffusion is the key to agricultural development and economic growth. Rather, a diversified cropping system including medium level of modern variety adoption yields higher income and causes least inequality and poverty.

Therefore, based on the study results, an integrated agricultural development planning model comprising of six components: (1) limited modern technology diffusion, (2) crop diversification, (3) soil fertility management, (4) rural infrastructure development, (5) price policy and (6) economic diversification to non-agricultural activities, is proposed. The first three components are interlinked and needs to be implemented simultaneously. The remaining three components will smoothen the process by: (a) enhancing effective input delivery and output marketing systems through developed infrastructure, (b) responding to price signals through appropriate pricing policies, and (c) engaging in other income generating activities through economic diversification. A policy of animal power and output price subsidy is suggested to curb price risk and promote crop diversification. Also, crop insurance policies, marketing, transportation and infrastructure development are suggested to reduce yield and marketing risks. Human resources development, intensification of bottom-up planning and collaboration with non-governmental organizations (NGOs) are suggested as strategies to improve farmers' technical skills. Integration and close coordination among facilitators: relevant government agencies, NGOs, financial institutes and the farmers are identified as the key to achieving the goal of sustainable agricultural development.

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CHAPTER I

INTRODUCTION

Technological change is an important factor in economic growth and development. Historical experience suggests that technology, by raising productivity of factors (e.g. labor, capital, land and other natural resources), played an important role in economic growth. Though developed countries, being the forerunner in technological innovations, benefited most from technical change, particularly industrial technology, the developing countries also benefited from the technological innovations, particularly in agriculture (Hayami and Ruttan, 1985).

Agriculture constitutes the major source of livelihood in Bangladesh. The agricultural sector accounts for more than 50 percent of national income and employs two-third of the labor force. Being one of the most densely populated country of the world, the land-man ratio is extremely low and majority of the population lack food security. Therefore, continued agricultural growth is deemed pivotal in alleviating poverty and raising the levels of living for the whole population. As such, over the past four decades, the major thrust of national policies were directed towards transforming the agricultural sector *via* the route of rapid technological progress. The purpose of the present study is to examine the distributional consequences and sustainability of this rapid technological progress in Bangladesh agriculture within the context of the nation's economic development. Specifically, the distributional consequences of modern agricultural technology were evaluated in terms of its impact on productivity, employment, income, income distribution and poverty. Sustainability is evaluated in terms of its impact on selected components of environment and trend in long-term productivity growth.

In this section, the importance of technological change in augmenting agricultural productivity is highlighted with particular emphasis on the role of 'Green Revolution' technology and its related controversies in order to focus on the research problem for the study. Furthermore, rationale of the study in the context of Bangladesh is provided. Finally, the research framework, specific research objectives, relevant hypotheses, scope of the study in general as well as within the context of rural-regional development planning, and structure of the dissertation are outlined.

1.1 Technological Change: Related Developmental Issues

It has now been widely recognized (Tisdell, 1988; Clapham, 1980) that a high level of interconnection exists among technological change, economic development, environmental quality, population growth and social change. Tisdell (1988) noted that, new technology (its availability and application) is vital not only as factor of economic growth and development, but also as a determinant of the nature and structure of society and as a contributor to changes in environmental quality. Dean (1955) suggested that the major reason for sustained economic growth commenced in the eighteenth century in Great Britain was the new inventions and their application rather than the high level of savings and capital accumulation (in Tisdell, 1988). Some researchers (Blum *et al.*, 1967 and Denison, 1962) claimed that for most of the developed countries, qualitative factors (such as improved technologies and their adoption) served as a major source of economic growth than the quantitative factors (such as increase in savings and capital accumulation). Such line of reasoning goes against the views of Rostow (1952) who prescribed that necessary condition for an economy to reach the take-off stage in economic growth is to achieve a high level of savings and capital accumulation. Though economists and social scientists now recognize the critical role of technological change in these respects, its importance has not been fully appreciated.

1.1.1 Technological Change in Agriculture

Technological change in agriculture has been one of the most rapidly growing area of study within the field of agricultural economics right after the World War II (Hayami and Ruttan, 1985). Two main reasons can be forwarded for its growing importance. First, prior to 1960s, particularly the first two decades after World War II, the agricultural productivity gap between the developed and developing countries widened. There has been an increase in the supply of agricultural products relative to its demand in the developed world, thereby leading to a decline in farm prices and incomes. The second reason for rapid growth in the study of technological change is due to the difficulty faced by the developing countries to increase their agricultural output to feed the growing population. Though the technical breakthrough in grain production during the 1960s opened up new opportunities for the developing countries to rapidly raise their output, a major issue faced by their policymakers and planners remain to determine, whether the potential agricultural surpluses that are produced can be sustained to continuously feed the engine of economic growth, without jeopardizing the environment (Hayami and Ruttan, 1985; Alauddin and Tisdell, 1991; and Murshid, 1986).

It should be recognized that there are multiple paths of technological development. Hayami and Ruttan (1985) noted that technology could be developed to facilitate the substitution of relatively abundant factors for relatively scarce factors. In terms of cost, it implies that the relatively cheap factors can be substituted for the relatively expensive factors. For example, the high-yielding crop varieties are one such categories of inputs that are developed to facilitate the substitution of fertilizer (or other inputs) for land, thereby releasing the constraints imposed by inelastic supply of land and can be termed as 'land-saving' technology. Similarly, in economies characterized by relatively scarce supply of labor, land and capital can be substituted for labor by developing improved agricultural machineries and equipments (e.g. tractors, irrigation equipments, combine harvesters, etc), which can be termed as 'labor-saving' technologies. Hayami and Ruttan (1985) named the land-saving technology as 'biological' and 'chemical' technology, and 'labor-saving' technology as 'mechanical' technology. However, it should be noted that in both cases the new technology, embodied in new crop varieties or new equipments, might not always substitute by itself for land and labor inputs. Sometimes, it may rather serve as a catalyst only to facilitate the substitution of the relatively abundant factors (such as fertilizers) for the relatively scarce factors (the land).

In agriculture, biological and chemical technologies are more basic than mechanization or mechanical technology. This is mainly due to the spatial nature of agricultural production that imposes constraints on efficiency of large-scale production using mechanized processes. The main thrust in the development of biological and chemical technology is to release the constraints imposed by the inelastic supply of land and therefore targeted to increase crop output per unit of land (land productivity) and/or increase the intensity of cropping by inducing multiple cropping technology. Hayami and Ruttan (1985) noted that technological change in crop production typically involves any of the three elements. One, land and water resource development to provide a more congenial environment for plant growth. Two, modification of the environment by adding organic and inorganic sources of plant nutrients to the soil, and biological and chemical compounds for protection of plants from insect-pest attacks and diseases. And three, selection and breeding of new biologically efficient crop varieties specifically adapted to respond to the controlled environment.

1.1.2 Technological Change and Agricultural Productivity

It has now been widely recognized that rapid growth in agricultural output and productivity is essential as effective development strategy particularly in the early stages of economic growth (Hayami and Ruttan, 1979, 1985; and Dayal, 1989). Historical experience from developed countries suggests that the key factor in accelerating the growth of agricultural output has been in the productivity of inputs (Hayami and Ruttan, 1979) and technological change is an important factor in influencing agricultural productivity growth (Tisdell, 1988; and Hossain, 1989). A widely accepted argument is that the basic source of technological change is in the improvement of the quality of factor inputs. Yudelman *et al.*, (1971) defined technological change in this context as "*the introduction of new or non-conventional resources into agricultural production as substitutes for the conventional resources. The effect of technological change must be evident as a change in the yield per acre, as a change in the cultivated acreage available or both*" (p.38-9).

Hayami and Ruttan (1985) identified that the capacity to develop technology that conforms to the existing resource endowments of respective economy is the single most important factor explaining differences in agricultural productivity among countries. Using a cross-country analysis of 43 countries: 21 developed countries (DCs) and 22 less developed countries (LDCs), Hayami and Ruttan (1985) concluded that high potential exists among the LDCs to increase their output by appropriate investments in education, research, and the supply of modern technical inputs.

Therefore, for the developing nations, an all out effort is required to accelerate the rate of agricultural productivity in order satisfy the increasing food demand owing to booming population pressure.

1.2 The 'Green Revolution'

Over the past centuries, the path of technological change in agriculture had passed through a smooth transition from a resource-based system to a science-based system. The twentieth century experienced a major technological breakthrough in agricultural history. The success was largely in the development of high-yielding modern grain varieties of wheat (from CIMMYT - International Maize and Wheat Improvement Centre, Mexico) and rice (from IRRI - International Rice Research Institute, Philippines) which are highly responsive to inorganic fertilizers, insecticides, effective soil management and water control. The high returns (reportedly) associated with the adoption of these new varieties of wheat and rice led to their rapid diffusion in countries of Asia and Latin America consequently leading to a dramatic increase in food production. The increase in food production was dramatic enough to be heralded as the 'Green Revolution' (Hayami and Ruttan, 1985) and the technology facilitating its widespread adoption is coined as the 'Green Revolution Technologies'. Wolf (1986) noted that, this strategy of developing new seed varieties, which has transformed the lives of millions of people, is considered to be the most successful achievement in international development efforts. The short-maturity and photo-period insensitivity of these high yielding modern varieties of wheat and rice enabled the farmers to dramatically increase their cropping intensity by harvesting two-three crops from a same piece of land in one year. In other words, by raising crop output per unit of land (hence land productivity) and increasing cropping intensity, 'Green Revolution' technically released the constraints imposed by the inelastic supply of land by substituting fertilizers (with associated crop management and water control practices) for scarce land.

1.2.1 'Green Revolution' Controversies

The impact of 'Green Revolution' has been mixed. Though the spread of this technology has been fastest of all in the history of technological innovations in agriculture, the post-adoption stage of 'Green Revolution' provide mixed consequences. Wolf (1986) noted that these modern grain varieties spread rapidly only in Asia (including China) and Latin America. Africa benefited least from the 'Green Revolution', as none of these grain varieties were staples for the life of rural Africans.

The critics of 'Green Revolution' (Wharton, 1969; Falcon, 1970; and Griffin, 1974), argued that the new technology is not scale neutral, that is, as farm size increases it becomes profitable to employ machineries. Also, the high-yielding variety technology tended to be monopolized by large farmers equipped with better information and financial capability. And the technology is capital intensive and, as such, small and poor farmers cannot adopt them.

However, contrasting views to the above are also being appreciated by many. It is suggested (Hossain *et al.,* 1990; Mellor, 1978; and Dantwala, 1985), that the new technology may benefit the poor in the long run in two ways. One, by reducing the cost of production and thereby lowering the prices of foodgrain on which the poor spent most of their money, and two, by generating more non-farm employment opportunities by suppressing real wages down and stimulating demand for non-farm goods and services. In this view, the cause of poverty is seen as the delayed adoption of technological change such that the beneficial effects tend to be offset by high population growth. Therefore, slow rate of technological progress will accentuate poverty.

Ruttan (1977) forwarded seven generalizations of 'Green Revolution' based on a comprehensive survey of early literature. First, modern varieties (MVs) of wheat and rice are adapted fast where they are technically and economically superior to local varieties. Second, farm-size and tenure do not pose serious constraints to the adoption of MVs. Third, farm-size and tenure has not been an important source of differential growth in productivity. Fourth, the introduction of MVs resulted in increased demand for labor. Fifth, landowners gained relative to tenants and laborers from the adoption of MVs. Sixth, the introduction of MVs contributed to widening the wage and income differentials across regions. And seventh, the introduction of MVs dampened the rate of increase in food grain prices at the consumer level. Lipton and Longhurst (1989), drawing on various literatures, also derived similar conclusions that although small farmers and tenants initially lag behind large farmers in the process, they catch up quickly thereby making farm size and tenurial status invariant to technological adoption.

Major criticism on ‘Green Revolution’ relates to equity concerns. It is suggested (Lipton and Longhurst, 1989; Hossain, *et al.*, 1990; and Singh, 1994) that the technology may accentuate regional inequality in the distribution of income. Therefore, technological change need support through investment on development of irrigation facilities, flood control and drainage for increased water control in order to bring in additional land that were previously unsuited for MV cultivation. Having done this, the increased diffusion of new technology will further widen the gap across region. Also, since the new technology reduces unit cost of production and output prices and raise real wages, farmers not adopting modern technology will lose due to the onset of external diseconomies of scale.

Freebairn (1995), analyzing the results of 307 studies undertaken during the period 1970-89, observed that about 80% of these studies had conclusions that the new technology widened both inter-farm and inter-regional income inequality. The interesting point in this study is that the nature of conclusion drawn from these evaluation studies were found to be influenced by regional origin of the authors, location of the study area, methodology followed, and the geographic extension of the study area. For instance, Freebairn (1995) summarized that, ‘*studies done by Western developed-country authors, those employing an essay approach, and those looking at multicountry region are most likely to conclude that income inequalities increased. By contrast, work done by Asia-origin authors, with study areas located in India or the Philippines, and using the case study method are more likely to conclude that increasing inequality is not associated with the new technology*’ (pp.265).

As a whole, one can see that there is considerable controversy relating to the distributional impact of ‘Green Revolution’ and/or the modern agricultural technology. In case of Bangladesh, which experienced the onset of ‘Green Revolution’ technology since the mid-sixties, similar controversies exists related to its distributional consequences.

1.3 The Research Problem

An interesting point to note that the early evaluations of modern technology and/or ‘Green Revolution’ (Sidhu, 1974; Cleaver, 1972; Gotsch, 1972; Griffin, 1974; Jose, 1974; Lal, 1976; Parthasarathy, 1974; Rao, 1976; Sen, 1974, Harris, 1977; and Bisaliah, 1982) centered mostly on the concerns of growth, productivity, efficiency and equity. The anticipation that the modern technology can affect other spheres of life remains ignored. Evaluation of the effect of modern technology, particularly ‘Green Revolution’, within the context of a broader perspective encompassing ecological and environmental compatibility was nascent. The delayed consequences of ‘Green Revolution’ on environment and sustainable development came up on the agenda for research only recently, for instance, Shiva (1991), Kang (1982), Brown (1988), Wolf (1986), Clapham (1980), Redclift (1989), and Bowonder (1979 and 1981).

Also, in identifying factors influencing the diffusion of technology, past studies (e.g., Sidhu, 1974; Hossain and Quasem, 1986; Boyce, 1986; Hossain, 1977; 1978; and 1986; Abedin, 1985) concentrated mainly on conventional factors such as irrigation, fertilizers, tenancy and farm sizes while paying no or little attention to other infrastructural factors, for example, roads and transportation networks, markets, storage facilities, service centers, extension networks, credit institutions, government agencies, etc. Therefore, policy recommendations emerging from these studies remained quite ineffective due to their partial nature.

Clapham (1980) noted that though evaluation of agricultural policy and farmers behavior are abundant, the environmental dimensions of agriculture remains unclear. Shiva (1991) claimed that though 'Green Revolution' is based on the assumption that technology is a superior substitute of nature and is a source of abundance (by releasing constraints imposed by nature), but at an ecological level, it produced scarcity and not abundance (by reducing the availability of fertile land and genetic diversity of crops). Brown (1988) noted that the foodgrain production has been dramatically falling, both nationally and globally, largely due to ecological instabilities including drought, climatic change, greenhouse effect and desertification. Hazell (1984) indicated that production and yield of foodgrain might have become more instable in the period following the introduction of modern technology in India. Bowonder (1979) identified a number of direct and indirect consequences of 'Green Revolution' (both positive and negative) on various sectors of the economy.

In addition to productivity, efficiency and equity concerns of technological change, the question of sustainability in food production is gaining momentum (Alauddin and Tisdell, 1991; Marten, 1988; and Redclift, 1989). Trends in global food outlook for the period 1984-94 presented in Table 1.1 are no doubt alarming. During the decade of 1984-94, the global cereal production increased only marginally, at an average annual growth rate of 0.9 percent. On the contrary, the world population grew at an average annual rate of 1.8 percent showing clearly that food production failed to keep up with the population growth. Simultaneously, on account of inputs, the net irrigated land increased in all regions and fertilizer use significantly increased in the developing countries of Asia-Pacific region, implying that despite increased input intensity, response of output is slowing down.

The fact that global food production is either stagnated or declining despite corresponding increases in inputs raised concerns over the future prospects of food security for the growing world population. There has been a growing interest in evaluating the merits of traditional agriculture and it was increasingly realized that modern technology, particularly the 'Green Revolution', though dramatically increased food production in its initial years of inception, its production potential is tapering off in later years.

Conway (1986) suggested that alternative agricultural technologies need to be judged against the criterion of stability (of yields and incomes) and sustainability (of production and yield). In recent years, focus of evaluation has shifted on considering the sustainability of the ecosystems and environmental factors on which agriculture depend (Alauddin and Tisdell, 1991; and Redclift, 1989).

Table 1.1 Global food outlook for the period, 1984-94.

Country	Average annual growth rate (%)				
	Population (1984-94)	Cereals[1] (1984-94)	Roots and tubers[2] (1984-94)	Irrigation[3] (1983-93)	Fertilizer[4] (1983-93)
Asia-Pacific	1.9	1.9	0.8	1.6	-0.1

Developing[5]	2.0	2.1	0.9	1.6	5.5
Developed[6]	0.5	-2.2	-1.0	0.7	-0.3
Rest of the world	1.7	0.2	0.2	1.1	-2.9
World	1.8	0.9	0.4	1.4	-0.1

Notes: [1] cereals include rice-paddy, wheat, maize and millet; [2] include cassava, potatoes, sweet potatoes, and taro; [3] refer to net irrigated land; [4] refers to fertilizer in plant nutrient units; [5] include 27 countries; [6] include 3 countries, namely, Australia, Japan and New Zealand.
Source:Based on FAO (1995, p. 5, 9, 11, 33, 51).

Thus far, most of the evaluation studies of modern technology remained partial in the sense that these studies focused either on issues of productivity, efficiency or equity, while paying little or no attention for other direct or indirect effects of technological change. Also, in identifying factors influencing diffusion of technology, the crucial role of infrastructure is ignored and less studied. Sustainability of a system requires that, the approach need to be holistic, meaning that one should focus on detailed assessment of a technology within the context of broadest possible perspective. In other words, it requires that the impact of technology need to be assessed by identifying its multifarious linkages with other sectors of the economy. Such an all encompassing impact analysis of modern agricultural technology will enable to identify the existing gaps and potentials and assist in devising policies for effective resource development planning. The present study is an attempt in this line and is conducted for one of the most vulnerable country of Asia in terms of food security, namely, Bangladesh.

1.4 Bangladesh: General Characteristics and Overview of the Agricultural Sector

Bangladesh, a predominantly agrarian economy, characterized by small-scale, fragmented farming, and employing primitive technology, is one of the poorest and most populous nations of the world. The country has to support an estimated 124 million people with a density of 860 persons per sq km (BBS, 1997). The majority of the population lack food security as reflected in extreme poverty and widespread hunger. Though agriculture serves as the mainstay of the population contributing about half of the Gross Domestic Product (GDP) and employing two-third of the total labor force, the high population growth rate offsets the increased agricultural production thereby exacerbating the food deficit and poverty. The land-man ratio is one of the lowest in the world. Hossain (1989) rightly remarked that, '*there are few countries in the Third World where technological progress is of higher importance in maintaining the food-population balance than in Bangladesh ... if the country is to maintain a modest per capita income growth of about 2 percent a year ... food production has to grow over 3.4 percent a year to avoid a further increase in cereal imports, which are currently about 10 percent of domestic demand*' (pp.14). Further, Hossain (1989) stressed that the agriculture does not have the resources to meet such a challenge as all the cultivable land is in use. In addition, the increasing population pressure dramatically reduced the average farm size holdings to less than a hectare. Therefore, he opted for rapid technological progress as the key to maintain the food-population balance in the country.

1.4.1 Overview of Agriculture

Agricultural sector dominates Bangladesh economy in terms of contribution to national income as well as employment. Bangladesh's export mainly consists of jute, jute goods, and tea. Crop production dominates Bangladesh agriculture accounting for more than 60 percent of agricultural value added (BBS, 1996). Alauddin and Tisdell (1991) noted that if supporting activities like transport and marketing of agricultural products are taken into account, the share of agricultural sector GDP is likely to be over 60 percent of total. Within the crop sub-sector, foodgrain production is central to the economy dominated by rice monoculture. About 80 percent of the gross cropped area is planted with rice that accounts for about 93 percent of total cereal production (BBS, 1996). In recent times, wheat is also gaining importance though its coverage remains extremely low.

Over the past forty years, the major development influence in Bangladesh agriculture has been the introduction of 'Green Revolution' technologies. This bio-chemical 'land-saving' technology which transformed much of the Asian region were introduced at a relatively later stage (during the late 1960s) and at a much slower pace (Alauddin and Tisdell, 1991).

Though the basic aim of agricultural development policies over the last four decades remained at increased food production, the program components underwent vast changes shifting from one category to the other. In the early 1960s, flooding during the monsoon and lack of irrigation facilities during the dry periods were identified as the major constraints hindering use of modern agricultural inputs. As such, the government aimed at building large-scale irrigation and drainage facilities (Alauddin and Tisdell, 1991; Hossain, 1989). From the late 1960s, the program strategies shifted from building large scale irrigation installations to more divisible and modern techniques of irrigation (e.g., shallow tube well, deep tube wells and low-lift pumps) coupled with increased distribution of highly subsidized chemical fertilizer and modern varieties of rice. In the early 1970s, modern varieties of wheat were introduced. As noted by Alauddin and Tisdell (1991), during the initial years until the early 1970s, modern varieties of rice (e.g., IR-8, IR-5, and IR-20) used to be imported directly. However, subsequently the Bangladesh agricultural research system adapted and indigenously developed different varieties of rice and wheat, which were then multiplied and released for farm production.

1.5 Rationale of the Study

Given the dependence of a vast majority of total population on agriculture for their livelihood, and relative contribution of this sector to national income, it is evident that, the key to economic development of Bangladesh lies in the growth of the agricultural sector even in much of the foreseeable future. As mentioned earlier, since the sector does not have the adequate resources to meet the growing challenge, the key to maintain food-population balance was sought in accelerating the rate of technological progress. Accordingly, development programs were diverted in spreading the modern varieties of rice and wheat with corresponding support in the provision of modern inputs, e.g., irrigation installations, chemical fertilizers, pesticides, institutional credit, product procurement, storage and marketing facilities. However, after the lapse of first two decades of 'Green Revolution', i.e., by early 1980s, it was felt by many (e.g., Ahmed and Hossain, 1990; Khan, 1985) that modern technology has contributed in worsening income inequality and exacerbating absolute poverty. Other studies mainly dealing with movement of real wages and nutritional issues revealed downward trends in real wages in agriculture as well as decline in calorie intake of the rural poor (Hasan and Ahmad, 1984).

On the other hand, contradictions to above are evident as well. Hossain (1989), Alauddin and Tisdell (1991), Hossain *et al.*, (1990), Ahmed and Sampath (1992), claimed that modern technology as a whole increased productivity, increased real wages (marginally) and contributed positively towards distribution of income. However, on the question of improving nutrition the result was not decisive. Alauddin and Tisdell (1991) claimed that food consumption per capita failed to increase (though not declined) on one hand, and become less varied on the other, since the average Bangladeshi seemed to increase his/her dietary dependence on cereals alone and less on other protein rich food.

A major disturbing conclusion is arrived by Bera and Kelly (1990) who claimed that the ceiling adoption level for modern varieties of rice in Bangladesh has nearly been reached. Whereas in reality, only 41 percent of all rice area is planted by modern varieties until 1989 (Hossain, *et al.*, 1990) which is even less than half of total rice area. Furthermore, Bangladesh Agricultural Sector Review (BASR, 1989) observed that there is a widespread slow-down in cereal production during the 1980s, particularly in previous high-growth regions and continued sluggish-growth in the low-growth regions. More specifically, in terms of varieties, negative growth rates are observed for all three major MV rice crops: MV *Aus*, MV *Aman* and MV *Boro*. On the other hand, Alauddin and Tisdell (1991) concluded that foodgrain production recorded a higher growth rate during the post-Green Revolution period, particularly, due to change in cropping intensity (owing to the introduction of MV rice), and boost in productivity of MV wheat. Their analysis of regional (inter-district) variation in growth revealed that though there remain differences in inter-district growth of production and yield, the extent of divergence has been moderated in the post-Green Revolution period. The proportion of area under MVs has been identified as an important determinant for output increase per unit of land area.

Given such controversial results it is worthwhile to investigate the nature and extent of technological progress in agriculture and its impact on production growth, income, employment, income distribution, poverty, regional disparity, and other spheres of human welfare at this later stage of diffusion. Thus far, the issue of technological change in agriculture has been less studied in the Bangladesh context (Alauddin and Tisdell, 1991; Hossain, 1989; and Hossain *et al.*, 1990). As mentioned earlier, most of the studies dealing with the issues of technological change were partial in nature. Also, past studies on agriculture dealing with issue of regional variation in growth performance (BASR 1989; Hossain, 1984; Boyce, 1986; Alauddin and Tisdell, 1991) based their analyses on arbitrary regional units (the administrative districts) which has no bearing in depicting the agro-ecological, socio-economic and infrastructural characteristics in influencing growth patterns. Also, the issue of sustainability as well as environmental consequences of modern agricultural technology, though gained momentum only recently, has not been explicitly dealt in case of Bangladesh. Moreover, in identifying factors influencing agricultural growth, much emphasis has been laid only on irrigation, tenurial status, and inputs. The crucial role of technological, biophysical as well as rural infrastructure in influencing growth has been less studied. Only a few studies (Ahmed and Hossain[1], 1990 and Hossain *et al.,* 1990) explicitly dealt with the role of rural infrastructure in agricultural and economic development. Evenson (1986) and Easter *et al.*, (1977) noted that investments in rural infrastructures are designed to change the behavior of farmers and identification of their contribution are important in providing insights for the direction of agricultural development efforts.

The proposed study is aimed at explicitly incorporating the deficiencies mentioned above. That is to say, analyze the impact of technological change in influencing regional variation of agricultural development levels and aggregate crop production and examine the sustainability of food production at the national level. At the local level, examine the influence of technological, soil fertility and rural infrastructural factors on crop production decision and examine the factors affecting modern technology diffusion as well as assess the impact of technological change on employment, income, distribution of income, poverty and the environment. The study is expected to enhance existing knowledge on the differential impact of modern agricultural technology and will assist in formulating policy guidelines and strategic recommendations for an integrated rural-regional development planning. In this study, two terms 'technological change' and 'modern agricultural technology' is used interchangeably. Both these terms refer to the 'Green Revolution' technology or the 'modern varieties-fertilizers-pesticides-irrigation' technology.

1.6 Research Framework

Given the importance of technological innovation in agriculture and associated controversies discussed so far, a conceptual framework of the study is developed and is presented in Figure 1.1.

[1] Though this study is considered as a seminal work conducted by IFPRI (International Food Policy Research Institute), the survey period dates back to crop-year 1982, a period when the MVs of rice started to depict a declining trend and MV wheat is at its initial stage. Also, the level of rural infrastructural development during that period has been rudimentary.

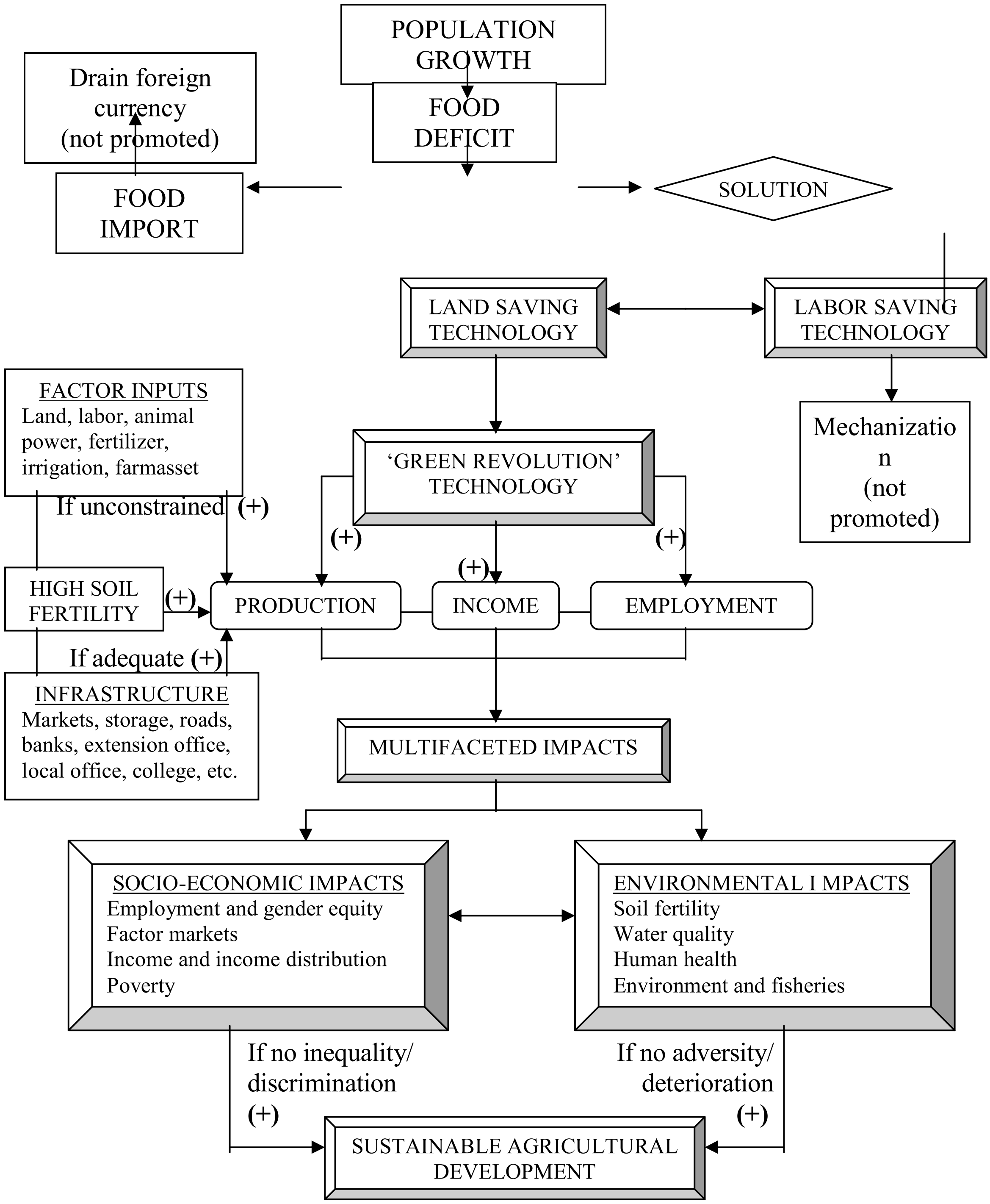

Figure 1.1 Conceptual framework of the study.

The framework is developed hypothesizing that undertaking the route of technological progress as a solution to chronic food deficit provided mixed results. The exclusive promotion of 'Green Revolution' technology though apparently succeeded in providing increased production and income, its distributional consequences have been mixed. In addition to its influence on distributive justice and poverty, 'Green Revolution' technology is believed to have widespread direct and indirect impact on the environment and other sectors of the economy.

Further, serious constraints exist among various factors, particularly rural infrastructure and soil fertility, which contributes positively to production growth, income and employment. Removal of these bottlenecks is a priority concern. Thus, the present study will adopt an evaluative approach to provide a detailed understanding of the aforementioned issues in order to formulate viable policy prescriptions.

1.7 Objectives of the Study

The main objectives of the study are to conduct a detailed evaluation of the delayed consequences of technological change in agriculture and to examine the prospect of sustaining food production in Bangladesh. The focus is on evaluating the multifaceted socio-economic and environmental impacts of modern agricultural technology within a broadest possible perspective. As such, the present study employed a holistic approach consisting of a blend of aggregate analysis at the national level as well as in-depth farm survey analysis at the local level. Specifically, the study is aimed at evaluating the impacts of modern agricultural technology on productivity, employment, gender equity in employment, operation of factor markets, income, distribution of income, poverty and the environment at the local level and on regional disparity, aggregate crop production and food production sustainability at the national level. The research is designed with a blend of economic (crop input-output), biophysical (soil fertility) and behavioral (farmers' perception) analyses to cover the diverse range of issues.

The national level analysis deals with time-series analysis of the impacts of technological change on regional variation in agricultural development levels for the period 1972/73 - 1992/93 and on aggregate crop production using regionwise data for the period 1960/61 - 1991/92, respectively. It also deals with the examination of food production sustainability by analyzing the long-run trend in crop productivity growth for the period 1947/48 - 1993/94. Therefore, the specific objectives dealing with impacts of technological change at the national level are:

(1) to examine the impact of technological change on regional variation in agricultural development levels and to identify relatively homogenous agricultural regions with respect to a set of technological, demographic, infrastructural, and crop production efficiency parameters,

(2) to examine the impact of technological change on long-run aggregate crop production,

(3) to estimate the output elasticities and returns to scale from the aggregate crop production function in order to determine the prospect of sustaining food production in future,

(4) to examine the long-run growth path of crop productivity using logistic and linear functions in order to determine the prospect of food production sustainability,

The local level analysis deals with identification of the influence of technological, soil fertility, and infrastructural factors in crop production and technology adoption decisions, and a detailed impact analysis of technological change on crop production, employment, income, distribution of income, poverty, and the environment. Therefore, the specific objectives dealing with identification of factors influencing crop production and modern technology adoption decisions at the local level are:

(5) to assess the soil fertility status of the farmers' field in terms of availability of major plant nutrients influencing crop productivity,

(6) to analyze the farmers' decision making process in foodgrain production with respect to changes in variable input prices at the same time allowing for making a choice between local and modern varieties of rice and wheat using 'meta-production function' approach,

(7) to identify determinants of modern agricultural technology adoption at the farm-level,

(8) to identify the role of technological, infrastructural and soil fertility factors in influencing crop production decisions,

And the specific objectives dealing with multifaceted impacts of technological change at the local level are:

(9) to examine the impact of modern agricultural technology on employment and gender equity in employment in the rural labor market as well as on factor markets, such as, fertilizers, pesticides, crop output, agricultural credit, and tenancy markets,

(10) to examine the impact of modern agricultural technology on income, distribution of income and poverty,

(11) to examine the impact of modern agricultural technology on selected aspects of environment, such as, soil fertility, water quality, human health and fisheries resources.

The final task is to synthesize the multifaceted impacts of technological change in agriculture based on the outcomes of national level and local level analyses and then to integrate the results to formulate strategies for an integrated agricultural development plan.

1.8 Hypotheses of the Study

The overall premise of the study is that though the diffusion of modern agricultural technology contributed to increased production, income and employment, its distributional consequences have been mixed. Also, it has exerted adverse impacts on the environment. Moreover, diffusion of modern agricultural technology has not been uniform across region and, therefore, contributed to regional disparities. Finally, the long-run crop productivity is reaching a saturation value thereby posing a threat to keep up with rapid population growth.

Therefore, hypotheses to fulfill the specified objectives of this study are grouped under following basic categories outlined below. For the purpose of deducing concrete and specific results, the hypotheses are postulated in null form with open alternative hypotheses since relationship of factors, particularly the non-conventional factors with crop production cannot be determined *a priori*. Therefore, the null-hypotheses to be tested are:

Hypotheses Related to Impacts of Modern Agricultural Technology at the National Level

(H1) There is no influence of technological, demographic, infrastructural, and crop production efficiency factors on regional variation in agricultural development levels. There are no regional differences in levels of agricultural development.

(H2) Technological, human capital and infrastructural factors do not influence aggregate crop production growth.

(H3) Aggregate crop production in Bangladesh exhibits constant returns to scale.

(H4) The long-run growth rate of crop productivity is zero.

Hypothesis Related to Farmers' Decision Making Process in Changing Production Environment

(H5) Farmers in Bangladesh are not profit-maximizers. Farmers do not respond to variation in input prices and changing production environment by reallocating resources and switching between local and modern agricultural technologies.

Hypotheses Related to Factors Influencing Adoption of Modern Agricultural Technology

(H6) Socio-economic factors, such as, land ownership, farm size and tenurial status does not influence modern technology adoption decisions.

(H7) Non-conventional factors, such as, technological, soil fertility and rural infrastructural factors does not influence modern technology adoption decisions.

Hypotheses Related to Impacts of Modern Agricultural Technology at the Local Level

(H8) Modern agricultural technology does not influence employment, operation of the labor market as well as operation of other factor markets.

(H9) Modern agricultural technology does not influence income from agricultural production.

(H10) Modern agricultural technology does not contribute to income inequality and influence poverty.

(H11) Modern agricultural technology does not have adverse effects on selective environmental factors, such as, soil fertility, water quality, human and animal health, and fisheries.

1.9 Scope and Limitation of the Study

Detailed impact analysis of a technological innovation on each and every sector of the economy is a formidable task. The present study, therefore, utilizes the economic principles and concepts in analyzing the issues. It also contains a blend of biophysical as well as behavioral analyses in order to capture the diverse range of issues. As the study is mainly targeted to evaluate the delayed consequences of three decades of modern agricultural technology diffusion in Bangladesh, it is based on a blend of aggregate time-series analysis at the national level as well as cross-section farm-survey analysis at the local level. Though time-series data in Bangladesh is far from being comprehensive (Pray, 1980), as elsewhere in most of the developing countries, it is nevertheless essential to make use of the existing information and construct required indices from these existing sets of statistical series on the basis of certain assumptions. For the local level analysis, it would have been highly desirable to possess detailed information at the village levels for all the regions of Bangladesh. However, such a desire need to be restricted based on time, budget and analytical tractability. As such, only three agro-ecological regions were selected for local level analysis.

As mentioned earlier that the scope of analysis is limited to economic and selective biophysical and behavioral analysis to capture the dynamics of technological change. Therefore, details of technical issues (such as, agronomic features of crop production, nutrient uptake mechanisms of plants) and social issues (such as, change in the composition of inter and intra-household division of labor, kinship and community structures, nutritional intake at household level) related to modern agricultural technology are not covered.

1.10 Scope of the Study within the Context of Rural-Regional Development Planning

Within a decentralized planning framework, forwarded by Thapliyal (1990), the four principle components of planning are: *(i) development of production sectors, (ii) development of basic infrastructure, (iii) development of social amenities, and (iv) poverty alleviation*. The former two falls under the purview of *resource development planning* conducted at the area level, and the later two fall under the purview of *rural development planning* conducted at household/village level. The integration of both types of planning leads to an *integrated rural-regional development planning* for a specific region (Fig.1.2).

In order to operationalize a decentralized planning process there are four basic steps (Thapliyal, 1990). First, *decide on a basic planning unit* for resource development planning through an 'spatial analysis' as it requires a larger unit consisting of a cluster of villages with greater degree of homogeneity in terms of geography, resource distribution pattern and socio-economic status. Second, *planning for production sectors* which includes analysis of past performance and present status of the sectors, identification of alternative strategies and thrust areas, and then formulation of projects and phasing them over a time period. Third, *planning for infrastructural facilities* involving identification of existing gaps in the requirement and availability of infrastructural facilities, estimate the future demand taking into account the population increase and determine additional capacities to fill the gaps with locational specifications. And fourth, *planning for rural development* through poverty alleviation and minimum needs programs which involves village-level analysis of extent of poverty, existing occupation pattern, assessment of resource and infrastructural requirements, identification of target beneficiaries for projects.

Figure 1.2 Conceptual Framework for Decentralized Planning

Objectives	Growth oriented		Quality of life oriented	Equity oriented
Components	Development of production sectors	Development of basic infrastructure	Development of social amenities	Poverty alleviation
Elements	**Agriculture** **Irrigation** **Livestock** **Fisheries** Forestry Mining Industries	**Road/Transport** **Market** **Credit** **Storage** Institutions Power/Energy Communication	Safe water/sanitation Primary health care Education for all Housing/slum dev. **Family welfare** **Environment** Public distribution	**Income** **Employment** **Skills training** Nutrition
Approach	Area level		Community level	Household level
Concept	Resource development planning		Rural development planning	
	Integrated rural-regional development planning			

Note: The present study covers the issues written in bold letters.
Source: Modified from Thapliyal (1990).

The present study, in this context, is designed to serve as information base to provide basic analytical information required for aforementioned four steps of planning that are necessary to successfully accomplish an integrated rural-regional plan for a specific region.

1.11 Usefulness of the Study

The study makes following contributions to empirical knowledge, particularly for agricultural development in Bangladesh. The study highlighted the significant role of technological and infrastructural factors in determining regional variation and identified regions that are relatively homogenous with respect to agricultural development levels and corresponds to existing administrative regions for which time-series data were published, thereby, will facilitate in decentralized planning. Second, the study offered policy-relevant estimates of the economic parameters of foodgrain and non-cereal crop production, their factor demand and output supply responses in Bangladesh. Third, the study highlighted the significant role of technological, infrastructural as well as soil fertility factors in influencing crop production decisions. Fourth, the study provided a detailed analysis on the gender inequality in gains from employment owing to technological change. Fifth, the study confirmed the claim of worsening income distribution owing to technological change and exacerbation of rural poverty in technologically developed villages. Sixth, the study provided information on specific environmental impacts of modern agricultural technology. Seventh, the study provided an evaluation of long term productivity of foodgrain crops and the prospect of sustaining food production in Bangladesh. Finally, the study also indicated on the correspondence between short-run factor utilization pattern with the long-run pattern through the comparison of returns to scale estimates directly from time-series aggregate production function and indirectly from cross-section farm-level profit function.

The study, by providing in-depth analytical information on the multifaceted impacts of modern technology diffusion in the agricultural sector, will therefore, strengthen the existing information base essential for undertaking planning decisions, particularly decentralized planning decisions. The study will be particularly useful in facilitating implementation of integrated rural-regional plans that are more realistic and wellsuited within the socio-economic and environmental constraint imposed by each specific region of Bangladesh.

1.12 Structure and Outline of the Dissertation

The dissertation is organized into ten chapters (Figure 1.3). The review of relevant literatures on evaluation of modern agricultural technology is presented in Chapter II. The research design, description of the study area, and principal methodologies utilized for quantitative and qualitative evaluation of technological change in agriculture at the national and local level is presented in Chapter III.

The impacts of technological change on regional variation in agricultural development levels and aggregate crop production are presented in Chapter IV. Also, an examination of food production sustainability is presented in this chapter. Stepwise forward regression procedure is used to select significant indicators (including technological factors) in explaining regional variation and then composite indices of weighted standard scores are constructed to rank the regions. Finally, the regions are delineated in descending orders of development by weighting their relative standings in three periods, namely, Period 1 (1973 – 1975), Period 2 (1980 – 1983), and Period 3 (1990 – 1993). Aggregate crop production function of the Cobb-Douglas form is estimated to determine the impact of technological change on long run aggregate crop production and estimate output elasticities and returns to scale using regionwise time-series data covering 29 years (1960/61 – 1991/92). Logistic and linear regression analyses were utilized to determine the productivity path of foodgrain and its sustainability using the longest time-series data of Bangladesh covering 47 years (1947/48 – 1993/94). This chapter, therefore, accomplishes all the national level objectives, Objective #1, Objective #2, Objective #3, and Objective #4, respectively, as well as finalizes the selection of the study area for farm survey at the local level.

The farm-level decision analysis of alternative technologies is presented in Chapter V. The analysis is conducted for local and modern varieties of rice and wheat utilizing the 'meta-production function' approach that allows for switching between varieties while responding to changing input prices and production environment by profit maximizing farmers. The dual measure of technological change, that is, the profit function analysis is used for the purpose using normalized restricted translog profit functions for local rice as well as modern rice and wheat varieties, respectively. The chapter also contains a composite profit function analysis of other non-cereal crops in order to provide the complete scenario if an agricultural diversification policy is sought. This chapter, therefore, accomplishes Objective #6 of the study.

Analysis of factors affecting adoption of modern agricultural technology is presented in Chapter VI utilizing multivariate regression procedures. In addition to conventional variables, the effect of soil fertility and infrastructure on adoption decision is analyzed. This chapter, therefore, accomplishes Objective #7 and Objective #8 of the study.

The analyses of socio-economic and environmental impacts of technological change are provided sequentially in Chapters VII, VIII and IX. The socio-economic component is composed of impacts on employment and gender equity in employment in the rural labor market, and on other factor markets, income, income distribution and poverty. The environment component is composed of impacts on soil fertility, water quality, human health, and fisheries resources.

Impact analyses of technological change on employment, gender equity in employment, demand for hired and total labor, wages, animal power prices, land rent, agricultural credit, fertilizer, pesticide, irrigation and output markets is presented in Chapter VII. Multivariate analysis as well as simultaneous equation estimation procedures were utilized for the purpose. This chapter, therefore, accomplishes Objective #9 of the study.

Analyses of determinants of rural household income, distributional consequences of modern technology adoption and its impact on poverty are presented in Chapter VIII utilizing multivariate analysis as well as various income distribution and poverty measures, thereby, accomplishing Objective #10 of the study.

Environmental impacts of technological change are analyzed using a combination of qualitative as well as quantitative methods. Firstly, the farmers' perceptions on specific environmental impacts and their relative ranking are computed. Then, available material evidences, such as results of soil fertility analysis, nutrient pathway analysis, time-trend analysis of relevant variables, were used to support or refute these perceptions. This chapter, therefore, accomplishes Objective #5 and Objective #11, respectively.

Summary of the findings of the study, results of hypothesis tests, synthesis of the multifaceted impacts of technological change, policy options and conclusions drawn from this dissertation research are presented in Chapter X.

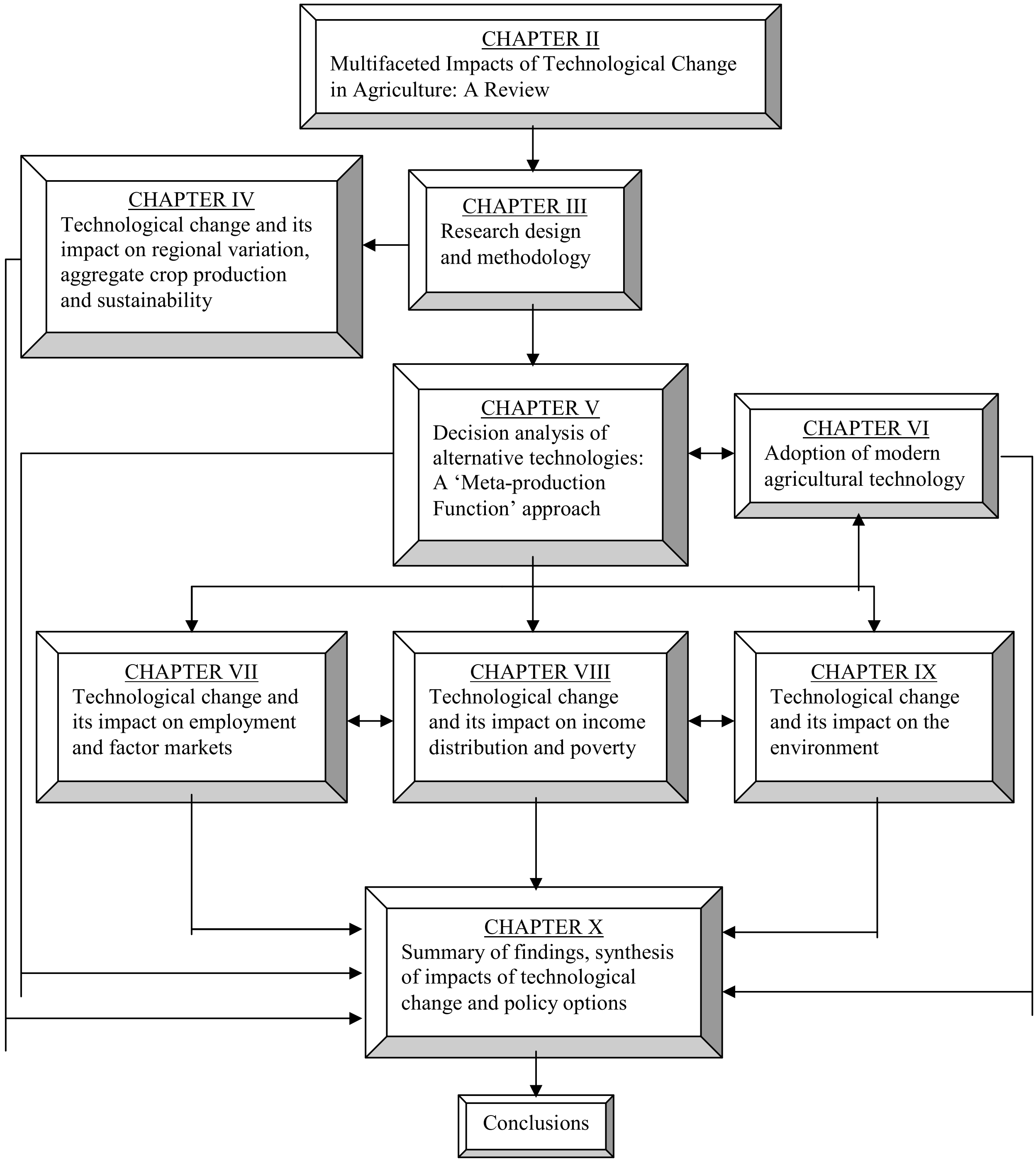

Figure 1.3 Structure of the dissertation.

CHAPTER II

MULTIFACETED IMPACTS OF TECHNOLOGICAL CHANGE IN AGRICULTURE: A REVIEW

The literature on agricultural development is replete with studies on technological change and its impact on production growth and income distribution. The reason that this issue has received such a prominent place in the development literature is due to its far-reaching impact on economic growth and development. In this chapter, a brief review on the relevant literature is presented. For simplicity, the review is broadly categorized into three sections. The first section deals with the concepts, definitions and measurements of technological change and the approach adopted in this study. The second section highlights the role of research, infrastructure, and institution alongwith the influence of factor inputs in augmenting agricultural productivity through technological innovation. The third section concentrates on selected impact evaluation studies of modern agricultural technology. The intent is to highlight the advances made in: (a) conceptualizing technological change in agriculture, (b) identification of factors influencing agricultural productivity, and (c) understanding the nature and dimension of multifaceted impacts that the modern agricultural technology has on the economy. Also, gaps in knowledge regarding the multifaceted impacts of technological change in agriculture are identified that forms the premise of the present study.

2.1 Concepts, Definitions and Measurement of Technological Change

There are two broad views of defining technology and technological change: the general view and the economic and/or neoclassical view. Generally, technology is defined as the operative knowledge of means of production of a particular group of goods or services (Yudelman *et al.*, 1971). Technological change, in this respect, refers to the changes in a production process that comes from the application of scientific knowledge. Morroni (1992) defined technological change as a variation in the method of production and/or quality of goods produced. He emphasizes that, though the distinction between changes in processes and changes in products are very important, they are intricately linked with each other in the sense that a change in the product leads to a change in the process and *vice versa*. Cyert and Mowry (1987) noted that technological change has two major effects: (1) it transforms the processes by which inputs (including labor, capital and other forms of materials) are transformed into outputs; and (2) it enables the production of entirely new outputs. They distinguished between *process innovation* and *product innovation*. Process innovation is referred to as the technological change that improves efficiency, with which inputs are transformed into outputs, whereas product innovation leads to the production on new products.

The neoclassical definition of technology is based on the production function. The latter defines the maximum output obtainable from a specified set of inputs. In other words, the production function defines the upper bound or the frontier of the production possibility set in an input-output plane. In economics, there are two ways to define technological change. One in terms of productivity index and the other in terms of production function. The former is defined as the production of a greater output with a given amount of resources. According to this definition, technological change, therefore, leads to an increase in output per unit of input. Peterson and Hayami (1977) indicated that the method of production function views technological change in a production context and defines it as a change in the parameters of the production function or a creation of a new production function. More specifically, technological change is defined as a shift of the production function (Nelson, 1981 and Fan, 1991). However, both ways of defining technological change is complementary to each other, because construction of a productivity index implies the existence of a production function and *vice versa*.

Thorbecke (1973) classified technologies into three categories: (a) traditional technology (involving no increase in the use of intermediate (biological-chemical) or capital (monetized) inputs); (b) intermediate technology (characterized with increased use of intermediate inputs but no further mechanization); and (c) modern technology (characterized with increased use of intermediate inputs and mechanization). Bartch (1977) noted that any change brought in traditional, intermediate and modern categories of technologies would have differential implications on the labor use patterns which is a major source of concern in the agricultural sector.

Technological changes in the production process at the farm level can be realized in various ways. For instance, if the change is realized through improved methods of utilizing available resources so that a higher level of output per unit of input is obtained, then this change is termed as **disembodied technological change**. Disembodied technological change can be modeled in terms of the shift in the production function and is relatively simpler to measure. If the technological change occurs through changes in the quality of inputs utilized, then it is referred to as **embodied technological change**. Embodied technological change, a measure of input quality change, introduces measurement problems, and in economic literature, this problem is often dealt in terms of measurement of the physical capital. Antle and Capalbo (1988) noted that technological change might occur also through introduction of new processes and new inputs. And in such cases the technology becomes both multiproduct and multifactor technology and introduces measurement problems. In order to tackle the problems, it is sometimes easier to utilize the duality theory, and estimate either the profit function or the cost function to measure the technological change, instead of estimating the production function. Here, the effects of technological change are expressed in terms of either a reduction in the cost of production (given input prices) or an increase in profits (given output prices).

Technological change can either be neutral or biased in favor of specific factor inputs. Hicks (1963) defined the concepts of **neutral and biased technological change** in terms of the marginal rate of technical substitution (MRTS) in the production process. He mentioned that if we consider only two groups of factors, labor and capital, then we can classify different technology according to their initial effect on the marginal product ratio of capital to that of labor. Hicks identified three possibilities. One, if the technology **increases** the marginal product ratio of capital to labor, then the technology is termed **'labor-saving'** (i.e., the technology is biased toward saving labor). Two, if the technology leaves the marginal product ratio of capital to labor **unchanged**, then the technology is termed **'neutral'**. And three, if the technology **decreases** the marginal product ratio of capital to labor, then the technology is termed as **'capital-saving'** (i.e., the technology is biased toward saving capital). The 'Green Revolution' technology is viewed to be biased towards use of labor and is termed as **labor-using** (capital–saving) technology.

When technological change is measured directly by estimating the production function then the measure is termed as the **primal rate of technological change**. When dual measure (profit function or cost function) is used the resulting measure is termed as **dual rate of technological change**. Antle and Capalbo (1988) noted that dual measures of technological change also contain difficulties. For instance, when the technological change involves use of new inputs or production of new outputs, it might happen that some input are not used or some outputs are not produced, resulting in corner solutions for the firm in question. This violates the assumption of duality theory which is based on interior solutions only meaning no inputs can be used or outputs can be produced at zero level. However, with certain modifications in assumptions, such obstacles can be tackled. The primal rate of technological change and dual rate of technological change will differ if the scale of the firm changes. That is, when firms adjust its production optimally in response to technological change. Such scale effects are required to take into consideration while comparing the primal and dual rate of technological change. It can be asserted that the primal and dual rate of technological change must be equal to each other, if and only if, the technology exhibits a constant return to scale.

In the present study, the production function based definition of technological change is adopted. The 'Green Revolution' and/or 'modern agricultural technology', which is under scrutiny in this study, is an amalgamation of embodied as well as disembodied technological change. The modern varieties of rice and wheat seeds are basically change in input quality, and hence reflect embodied technological change. On the other hand, the use of chemical fertilizers, pesticides, irrigation and water control and transplanting technique are new inputs and new ways of producing rice or wheat crops, and hence reflect disembodied technological change. Two separate profit functions (dual measure of production functions), one for local varieties of rice and wheat and the other for modern varieties of rice and wheat, are estimated within a meta-production function framework in order to determine the nature of farmers' decision making process in a changing production environment. It should be noted that no attempt has been made to measure the specific rate of technological change since the focus in this study is on evaluating the multifaceted impacts of three decades of modern agricultural technology diffusion in the economy. However, the nature of bias in technological change (as noted by Hicks, 1963) with its impact on the gender distribution of labor is explicitly examined in this study.

2.2 Factors Influencing Productivity Growth

Historically, it was assumed that conventional inputs are the major determinants for raising agricultural productivity. However, in recent years, it was increasingly recognized that, apart from conventional inputs, such as, labor, fertilizers, pesticides, irrigation and water control, non-conventional inputs, such as, rural infrastructure and institutions, play a vital role in the diffusion of modern agricultural technology.

Technological change is an important factor influencing agricultural productivity growth. In a land scarce country, increase in land productivity is viewed the key to output growth. The 'Green Revolution' technology, which incorporates the biological technology (BTC), can raise land productivity by substituting, e.g., fertilizers, for scarce land. Diwan and Kallianpur (1985) in an attempt to quantify the contribution of BTC (proxied by fertilizers) to agricultural production over time observed that contribution of BTC to foodgrain production is quite low. This raises the important policy questions related to finding alternatives on how to increase food production and alleviate world hunger. Alauddin and Tisdell (1991) applying the method of Diwan and Kallianpur (1985) on foodgrain production in Bangladesh using historical data (1949-84) observed relatively higher contribution of BTC to agricultural production. Hossain (1984) in analyzing the long-term (1949-84) growth performance of Bangladesh noted that the decline in per capita agricultural production is mainly due to stagnation during the late fifties and the early seventies caused by natural factors and disruptions of the liberation war. The 'Green Revolution' contributed only one-fourth of the growth during the decade of sixties. However, during the post-1975 period the new technology accounted for more than two-third of the growth. Hossain (1984) argued that there is little scope for promoting future growth by providing price incentives as it might even put negative pressure on agricultural growth. Therefore, he recommended for public policy aiming at accelerating the diffusion of new technology. However, the decline in the productivity of modern varieties of rice noted by BASR (1989) for all crop seasons raises doubt on the merit of new technology in sustaining food production. The observed increase in productivity growth in late 1980s is perhaps due to shift from local to modern varieties of rice whose yield levels are still substantially higher resulting in increased productivity. Also, there are concomitant increase in inputs, particularly, fertilizers and pesticides coupled with irrigation and water control. For example, a re-survey of the same two villages during crop 1977/78 and 1983/84 revealed that fertilizer consumption has increased by 68 percent (Hossain and Quasem, 1986).

Apart from BTC (fertilizers), irrigation and/or water control has been a major driving force in boosting agricultural production through the adoption of modern agricultural technology. Irrigation served as the leading input in Asian rice agriculture (Ishikawa, 1967). Hayami and Ruttan (1979) noted that at the beginning of the modernization in Japan, Taiwan, Korea and the Philippines, land-man ratios were less disparate and when adjustment is made for the differences in irrigation development, the land productivity become comparable to each other. Boyce (1986) examining the role of water control in agriculture for the period 1949-81 identified strong complementarity among water control[2], fertilizer use and adoption of MVs and suggested that water control may pose the key to technological constraint to agricultural growth in Bangladesh. Hossain (1986) utilizing the cross-section districtwise data of 1983/84 observed stronger relationship between irrigation and crop productivity growth, thereby, reinforcing Boyce's (1986) conclusion. Rahman (1983) also noted that irrigation is the most important supply side constraint to modern technology expansion in Bangladesh.

Thus far, the expansion of modern irrigation facilities has been highly skewed across regions. The irrigated area as percent of gross cropped area varies from 2 – 45 percent across regions with mean level at 21 percent in 1993. It should be noted that, in Bangladesh, modern varieties of rice is also grown under rainfed conditions in the monsoon (Aman) season though the productivity level might not be as high as those grown under irrigated condition.

Credit (both formal and informal) is also considered as an important factor influencing agricultural growth, particularly in developing countries. As such, governments in these countries lay significant emphasis on providing institutional credit to farming population and Bangladesh being no exception in the process. Elahi (1995), using farm level data of Boro rice

[2] It should be noted that water control differs from other inputs in that it requires prior investment and institutional arrangements for co-ordinated action among farmers.

for the crop year 1991/92, noted that credit has significant impact on production of crops where purchased inputs are used in greater amount, i.e., Boro rice crop. The weighted average production elasticity of all paddy was 0.13 while for Boro it was 0.20. Therefore, provision of credit is also vital for agricultural growth in Bangladesh.

2.2.1 Role of Infrastructure, Research and Extension on Productivity Growth

The key to transform traditional agriculture into a productive source of economic growth is to invest in making modern inputs available to the farmers (Schultz, 1964). This implies three types of investments for agricultural development. These are, to increase the capacity of: (a) the agricultural experiment stations to produce new knowledge, (b) industries to develop, produce and market modern inputs, and (c) the farmers to utilize modern inputs and technologies effectively (Hayami and Ruttan, 1985).

Starting from the late fifties till the end of seventies, a considerable number of studies undertaken worldwide, demonstrated the high private and social returns to investment in education (both formal and informal), research, and extension[3] (Hayami and Ruttan, 1985). However, the crucial role of infrastructure and institutions in augmenting agricultural productivity has been felt only recently, in the mid-eighties, spurred by the observation of widespread stagnancy and sluggish growth in agricultural productivity. Evenson (1986) noted that investments in rural infrastructures, such as roads, rural electrification, etc., is designed to change behavior of farmers, and so is the land reform. The main intent is to make the farmers respond to changes: changing in quantities they produce and quantities they utilize in production. Also, it is expected to increase productivity. Mann (1992) drawing on experience from Pakistan suggested that a realistic strategy to promote agricultural growth through national policies would be to repair the massive infrastructure of the agricultural system since the root causes of low farm productivity lies into biological, institutional and social constraints.

Empirical studies on the contribution of infrastructure, human capital, research and extension in Asian region are limited. Evenson (1986), using time series data (1948 – 84) of Philippine agriculture, suggested that technological variables (modern varieties, research and extension programs) showed strong factor bias in favor of fertilizer and tractor use. Research expenditure showed a bias against labor use while extension and modern varieties use labor. Regional and national research showed the highest impact and provided highest rate of return to investment. Roads (infrastructure variable) had a substantial impact on use of input and output. Land reform also had positive impact on productivity. Easter *et al.*, (1977), using pooled data for 1959-62 and 1967-69 in rice and wheat regions of India, suggested that in the wheat region, quality and quantity of irrigation and improved crop varieties are important sources of growth. In the rice region, development of rural roads and markets, quality of irrigation and improved rice varieties are important. Quasem (1992), using farm level data for 1989/90, suggested that ecologically unfavorable areas are not financially worse than the favorable areas in terms of both household as well as per capita income despite lower income from crops. He attributed this to significant higher earning from non-farm sources (more prominent in salinity affected areas), remittances from abroad and larger farm sizes, and

[3] For details, please see Table 3.A1, 3.A2, and 3.A3 in Hayami and Ruttan (1985).

therefore, recommended for enhancing non-farm activities in rural areas through roads, markets and skills development. Feder and Slade (1986), analyzing the impact of Training and Visit System (T&V) in India suggested that extension agents' interaction with farmers is a significant source of information in areas covered by T&V system than in areas with different extension system. Yield levels of farmers whose main source of information is the T&V extension agent are found to be higher and the incremental investment in T&V extension seem to generate at least 15-20 percent rate of return. Khan and Akbari (1986), using Pakistan data for 1955 – 81, suggested that the internal rate of return for research and extension is around 36 percent (a high return) and as such recommended for higher allocation of resources for research. However, Zahid and Mukhtar (1989) challenged the findings of Khan and Akbari (1986) on methodological grounds and claimed that the conclusions reached by them is incorrect and misleading.

Rajeswari (1995) emphasized on getting a clear conceptual clarity while modeling agricultural research efforts as it will help reduce the misinterpretation of historical and institutional contexts underlying research efforts. She argued that each of the geographical, institutional and organizational, disciplinary, resource, entrepreneurial, social and cultural, contexts would have a particular impact on the measure of research effort and therefore on the econometric model used for estimating returns to research effort. Therefore, she concluded that conceptual clarity regarding the measure is essential in the understanding of the research process, the social, economic and organizational constraints and conflicts that engender research.

Eicher (1995) asserted that the biggest challenge for Zimbabwe's maize-based 'Green Revolution' is to develop cost-effective marketing policies and institutions. He also suggested that countries trying to replicate the model of Zimbabwe should focus on fulfilling four interrelated preconditions: political, technological, economic and institutional. Smale (1995) also maintained that the pattern of maize seed development in Malawi demonstrated the importance of the farmers' capacity to articulate their interests through collective action and institutions. In the past, limited research in maize seed development resulted in technological stagnation.

Azhar (1991) examined the effect of education on technical efficiency in Pakistan hypothesizing that education affects productivity in two ways: (a) via a choice of better inputs and outputs, implying improvement in allocative efficiency, and (b) through better utilization of existing inputs, implying technical efficiency improvement. Utilizing farm level data for the crop year 1976/77, he concluded that education has a more pronounced effect on technical efficiency in case of modern crop varieties. However, the elementary education, i.e. four years of schooling, is not sufficient to ensure a positive impact on productivity. Deb (1995), using time series data for 1961-92 of Bangladesh, also observed negative influence of education in agricultural growth in Bangladesh

Momin (1991) examining the impact of agrarian structure on agricultural growth performance in Bangladesh concluded that the country is in a low level productivity trap. The tenurial structure plays a negative role in augmenting agricultural investment. Also, the present land distribution pattern and physical characteristics of landholding are not conducive to adoption of capital-intensive modern technologies required to enhance production growth. Renkow (1993), in his examination of intertemporal behavior of land prices and land rents in two production environments (irrigated and rainfed) in Pakistan, indicated that agricultural technology adoption had a strong impact on real land rents over the past 30 years in both irrigated and rainfed areas.

From the aforementioned studies it is clear that non-conventional factors, such as, infrastructure, human capital, research and extension play a significant role in agricultural growth. However, the effects are not uniform depending on the technological, institutional, political, and economic situation of individual countries. Also, results on the same set of parameters differ when one uses cross-section farm level data against the time series data. While time series analysis tend to provide consistent results across nations, the farm level analyses fail to validate and/or verify the national level notions of the problem under investigation. This calls for an examination of the correspondence between the results from national level analysis as well as local level analyses which is however seems to be absent in most of the aforementioned studies. The present study attempted to overcome such shortcomings by setting the research design covering both national and local context of the impacts of technological change in agriculture. For example, the correspondence between the impacts of technological change and infrastructures on the same set of key economic variables at the national and local level are examined to allow valid inferences and conclusions.

2.3 Multifaceted Impacts of Technological Change in Agriculture

A comprehensive assessment of the multifaceted impacts of technological change is a huge task. Bowonder (1979) presented a multi-criteria analysis approach to analyze the impact of 'Green Revolution' by deriving its effect on different sectors of the economy, e.g., industrial, economic, social, agricultural, demographic, political, and ecological impacts, respectively. However, the study was based on broad perspectives and is indicative in nature. The present study, in fact, attempted to provide an in-depth analysis of impacts of technological change on most of the mentioned sectors (except political) with a national-local coverage. The present section provides a review of selected literatures that examined some of the multifaceted impacts of technological change in agriculture in developing economies and inferences drawn from them.

Since the widespread diffusion of 'Green Revolution' technology throughout Asia, Latin America and Africa in the early 1960s, hundreds of studies are conducted on analyzing the welfare impact of modern technology, particularly on income distribution. The major criticism of these studies is that new technology is not scale neutral, the modern technology is capital intensive and it tend to be monopolized by large farmers equipped with better information and financial capability (Wharton, 1969; Falcon, 1970; Griffin, 1974; etc.). Lipton (1978) claimed that the new technology on average benefits the small farmers as well. But it is the public policy on prices, credit, irrigation, fertilizers, mechanization, research and extension, which is highly skewed towards favoring the large farmers. In fact, the landless are supposed to gain relatively more as compared to the landowners from modern varieties through rise in wages and employment and lowering of food prices. Distortions in urban price policies resulted in gain of less-poor urban consumers at the expense of the rural poor. The later argument, were also supported by Ruttan (1977), Mellor (1978), Dantwala (1985), Hossain (1989), Lipton and Longhurst (1989), and Hossain *et al.* (1990).

Freebairn (1995) analyzing the results of 307 studies undertaken during the period 1970-89, observed that about 80 percent of these studies had conclusions that the new technology had widen income inequality both inter-farm and inter-regional. The interesting point in this study is that the nature of conclusion drawn from these evaluation studies were found to be influenced by regional origin of the authors, location of the study area, methodology followed, and the geographic extension of the study area. For instance, Freebairn (1995) summarized that, "*studies done by Western developed-country authors, those employing an essay approach, and those looking at multicountry region are most likely to conclude that income inequalities increased. By contrast, work done by Asia-origin authors, with study areas located in India or the Philippines, and using the case study method are more likely to conclude that increasing inequality is not associated with the new technology"* (p.265).

2.3.1 Technological Change and Its Impact on Income Distribution

The distributional impact of technological change is usually analyzed mainly at two levels, national level and local level. At national level, the analyses base on either partial equilibrium models or the general equilibrium models. For the local level, the approach varies widely, ranging from comprehensive farm surveys to in-depth participatory observations to case study analyses.

Hayami and Herdt (1977), using Philippines data for the period 1968-73 developed a market model (later widely known as H-H model) and suggested that modern technology benefited both consumers and producers. Within agriculture, modern technology promoted income distribution by depressing prices and hence incomes of large farmers with a large proportion of marketable surplus. The 'Green Revolution' technology tended to transfer income from large commercial farmers to urban poor and landless and they suggested policies to intensify the efforts for developing improved technology for the subsistence crop sector. However, in order to avoid the adverse effects of modern technology, efforts should be focussed on to facilitate the adoption of technological innovations by small farmers through improving public services for extension, credit, marketing as well as irrigation.

Singh (1994) examined the long-term impact of new technology on employment and income distribution in rural areas of India's semi-arid tropics. The farm-level data was collected for consecutive 9 cropping years (1981-90) to enable detailed analysis on the issues of income distribution. Results suggested that mean income is substantially higher in areas where rainfall is assured and where the adoption of modern technology is also high. The differential effect of new technology is partly due to physical conditions and level of infrastructural development. Further, he observed that though income of all households increased over time through increased adoption of new technology, the inequality has not widened than the previous level, implying new technology did not increase inequality. At the farm level, the largest contributor to income variability were the farmer's resource base, labor participation and managerial practices, and at the regional level, agro-climatic factors were also important. Shrestha (1982) analyzing the impact of irrigation technology on the rural poorest in Nepal concluded that productivity and income of small farmers were higher than big farmers due to labor intensive farming by the former. Therefore, breaking of larger landholdings may promote employment as well as production. He prescribed for designing taxation and credit policies in such a way so as to push the big landowners to reduce their holdings while enabling the very small farmers to increase their holding to a more economic size.

Otsuka *et al.* (1992) examined the impact of differential adoption of modern varieties and land reform on functional and household income distribution using farm level data for the crop year 1985 in five villages of Philippines. Their results suggested that income distribution has not been very adverse because the inequitable effect of modern variety adoption on regional income distribution in favorable areas is mitigated by the implementation of land reform and reallocation of resources to non-rice production in unfavorable areas. They indicate that since the poor are geographically mobile, their relative incomes are not significantly affected by differential modern variety adoption in the long run. They recommended for further research on other crops suitable to these environments, such as corn, root crops, and trees. Behrman and Murty (1985) evaluated the market impacts of technological change for a near-subsistence crop, sorghum, in semi-arid tropical India utilizing a dynamic multi-commodity market model on panel data for the period 1957-74 for 73 districts. They suggested that increased sorghum productivity would have spillover effects on other markets and increase the welfare of the sorghum consumers.

The available literature on the distributional consequences of modern agricultural technology in Bangladesh, however, provides controversial results depending on the levels at which the analyses are done as well as the time when the studies were conducted. The aggregate level as well as selective nationwide farm-survey analyses suggested that the modern technology improved welfare of the poor (Alauddin and Tisdell, 1991; Ahmed and Sampath, 1992; Hossain, 1989; and Ahmed and Hossain, 1990). On the other hand, with few exceptions, the intensive local level studies suggested adverse distributional consequences of 'Green Revolution' in Bangladesh (Hamid, 1982; Abedin and Bose, 1988; Hossain *et al.*, 1990).

Alauddin and Tisdell (1991) applying the H-H model on Bangladesh rice economy suggested that the gains of consumers were higher after the introduction of modern varieties. Ahmed and Sampath (1992) using an improved version of the H-H model suggested that, with the irrigation induced technological change (ITC), the annual growth rate of rice production would surpass the population growth resulting in an increase in per capita rice consumption. Rice production has a substantial impact on GDP growth through its significant linkage effects in the economy. Their analysis projected a 16 percent increase in average per capita income from 1987 level to 1995 and concluded that ITC would significantly reduce poverty on one hand and promote distributive justice on the other. Therefore, they recommended that ITC should be the basic rice production strategy requiring large investments from government, donor agencies and the private sector. Hossain (1989), using farm level data of crop year 1981/82, concluded that there is high potential for increasing rural incomes through diffusion of modern technology. The proportion of people below poverty line, the poverty gap ratio and the concentration ratio of income of the poor are lower in technologically developed villages. In fact, the income is about 40 percent higher in villages having more than 65 percent of area under modern varieties.

However, contrasting evidence to above for the Bangladesh case is also available. Hamid (1982) analyzing the impacts of ITC on agricultural productivity, employment and income concluded that ITC actually widened the existing income gap between the 'haves' and 'have-nots'. In his words, *"because of the prevailing socio-politico-economic circumstances superimposed by the organizational and institutional factors, the diffusion of this technology seems to have stagnated around 11.5 percent of the total cropped area"*. He recommended for an effective rural institution containing a built-in mechanism for the poorest to participate in the process of development as none of the existing rural institution fulfill this condition and hinted that the government and donors should act as a catalytic rather than directing agents. Hossain *et al.* (1990), using nationwide farm level data collected for the crop year 1987, observed that Gini-ratio for both agricultural and total household income is higher for high-adopter villages compared to low-adopter ones suggesting that income inequality increases with the diffusion of modern varieties. However, they also observed that diffusion of modern technology had a positive effect on the alleviation of poverty measured in terms of proportion of poor. However, this difference is only marginal, 55 percent in non-adopting villages and 51 percent in adopting villages, and may be not significant at all. Abedin and Bose (1988) noted that there is a positive relationship between farm size and productivity in Bangladesh, so far as modern rice production technology is concerned, implying 'Green Revolution' widens income gap between small and large farms. However, they cautioned on generalizing their result because the analysis is based on farm level data for the crop year 1983/84 collected in only one area and for a single crop, modern transplanted Aman rice.

From the aforementioned selective studies, it can be safely concluded that when national level analysis is employed, the general tendency is to conclude in favor of modern technology, while in-depth local level studies provide mixed results. The implication is that modern technology, as a whole promote, equity through the operation of market forces, which is best analyzed at an aggregate level. In farm level surveys, information pertains to certain socio-economic environment within which a given market operates and, therefore, provides mixed results, as evidenced from six studies on Bangladesh. In the present study, the distributional consequence of modern agricultural technology is analyzed at farm-level.

2.3.2 Technological Change and Employment Effects

In general, technological change is aimed at augmenting land and labor productivity, and as such has profound implication for labor absorption and/or employment in agriculture. Jayasuriya and Shand (1986) claimed that though the new seed-fertilizer technology increased labor absorption at its initial stage, but the rapid adoption of the new labor-saving chemical and mechanical innovations[4] in developing countries is resulting in net reductions of agricultural labor use. They recommended that the solution to underemployment need to be sought in developing the off-farm sector for increased absorption. Balisacan (1993) analyzing patterns of employment, income and poverty in Philippines for the period 1961-88 noted that though rapid agricultural growth has contributed to the reduction of rural poverty, its effect has been minimal as compared to other Asian regions. The root causes, he claimed, are low productivity, landlessness, high underemployment and high incidence of rural poverty, and solution of those would go beyond agricultural development policies. Therefore, he recommended for a

[4] These new mechanical and biological technologies generally originate from the developed world. These technologies are adopted increasingly by farmers in developing countries due to their cost saving characteristics.

nationwide policy reform aimed at correcting the disincentives against the production of labor intensive goods, particularly, exports and at promoting backward regions.

Ahmed (1976) in evaluating the employment potential of 'Green Revolution' at its early stage (1969/70) concluded that: if the objective of introducing 'Green Revolution' is to maximize employment the agricultural innovation would have to be aimed at attaining the combination of modern technology in association with traditional power technology. This implies that promotion of labor saving mechanization that generally accompanies the modern technologies should be avoided. Laxminarayan (1982) from his experience on Punjab for the period 1961-77 predicted that as agricultural development continues labor demand will increase. This increase demand will be felt strongly in regions where industrialization is also in progress and will consequently raise the wages leading farmers to seek for mechanization. He prescribed for promoting selective mechanization and facilitating labor mobility from depressed regions to booming regions and emphasized the need for a national policy rather than a regional outlook.

Ahmed (1982) analyzing the impact of modern post-harvest technology suggested that rice mills displaced 29 percent of the total husking labor. Almost all hired labor displaced were women who have limited alternative employment opportunity. His crude nationwide estimate revealed that, if rice mills are made adequately available throughout the country, a total of 45 million person-days of hired labor would be displaced leading to a reduction of rural poor's income of about Tk.450 million. Khan (1985), examining the pattern of labor absorption in Bangladesh for the period 1953-83, suggested that demand for labor in agriculture increased mainly due to: (a) increase in cropping intensity (explaining more than 50 percent of total), and (b) adoption of modern varieties (relatively less important in explaining labor absorption). He recommended for policies to increase cropping intensity in order to improve labor absorption in agriculture.

In contrast, Alauddin and Tisdell (1995), observing historical data for Bangladesh, claimed that significant employment gains has resulted from the 'Green Revolution' technologies in Bangladesh. The employment in the dry season increased four times from 1960s to 1980s while the wet season employment remained stagnant. However, they concluded that the employment generating effect of the 'Green Revolution', in recent years, is slowing down showing little prospect for increased absorption. Also, there is little prospect of having a major turning point in labor absorption in non-farm sector to lead a successful industrialization as observed in East Asian regions, thereby providing a gloomy future for Bangladesh. Similar conclusion has also been arrived by Osmani (1990). He noted that the drastic fall in total labor force in agriculture is not an indication of a turning point[5] but rather the consequence of increasing work-sharing arrangement and consequent decline in average productivity per worker. He claimed that the true nature of shift gets revealed in areas where technological change has opened up new opportunities for gainful employment in agriculture. In these areas, a reverse flow of surplus labor from non-farm sectors to farm activities, are observed.

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[5] The notion is that the slow growth rate of agricultural labor force implies a movement towards a priori expectation of reaching a turning point in the growth of agricultural labor force. Such an occupational shift from agriculture to non-agriculture and/or modern sector implies the onset of a Lewisian transition of labor surplus economy.

Analysis on the impact of technological change on gender distribution of labor is limited. A large number of studies are mainly confined to time-use studies of men and women. Sharma (1995), using time-use of men and women in intra-household activities in two villages of Nepal, concluded that there was variation in the division of labor across the types of crops cultivated. Labor allocated for rice cultivation is strictly based on exclusive role as compared to wheat and maize crops. Both men and women spent a longer average time each day in the irrigated area as compared to rainfed area. Her policy interventions and mechanisms to improve gender balances included introduction of labor saving productive and reproductive technologies to reduce existing workloads of women, thereby, encouraging men's sharing in the reproductive spheres. Zaman (1995) also observed increased workload for women engaged in agriculture in rural Bangladesh.

It is clear from the aforementioned studies that controversies also exist on the issue of employment effect of technological change in agriculture. It seems that the modern technology has a depressing effect on labor absorption and employment at the later stage where the level of technological diffusion is tapering off towards a saturation point. Also, it is the increase in cropping intensity, which can be accomplished with crop diversification as well, accounts more for increased demand for labor rather than the diffusion of modern agricultural technology. Particularly lacking, in case of Bangladesh, is the knowledge on the impact of technological change on gender equity. If Hamid's (1982) estimate is taken seriously, then the picture is quite disturbing. Since, women constitute half of the total population, their equity in terms of employment must be ensured in setting any policy for pursuing the goal of sustainable development. The present study, therefore, attempts to contribute to the existing literature on the effect of modern agricultural technology by explicitly analyzing its effect on gender equity with respect to employment and participation in the rural labor market.

2.3.3 Technological Change and Regional Disparities

It has been widely argued that technological change though significantly enhances agricultural productivity, the level and distribution of this productivity vary across regions (Easter *et al.*, 1977; Lipton and Longhurst, 1989; Hossain *et al.*, 1990; Singh, 1994 and Freebairn, 1995). Therefore, technological change need to be supported through investment in the development of irrigation facilities, flood control and drainage for increased water control in order to bring in additional land that were previously unsuited for modern variety cultivation. As a result, with the diffusion of new technology the gap across region will widen.

Considerable amount of work has been done on the issue of regional differences in agricultural productivity in India (Easter *et al.* 1977; Routray and Patnayek, 1981; Prahladachar, 1989; and Goel and Haque, 1990). Easter *et al.* (1977) in their analysis of the sources of regional differences concluded that infrastructural and environmental factors are important in explaining productivity differences across rice and wheat regions of India. Routray and Patnayek (1981) emphasized on a detailed study of soil fertility status by watersheds as essential to implement new cropping pattern induced by technological change. Goel and Haque (1990) conducted a zoning exercise for India and suggested that there is a need for reclassification of Indian States due to the prevalence of wide variations in the availability of resources and their use patterns to assist in devising specific programs. Goldman and Smith (1995) in their analyses of agricultural transformation in India and

Nigeria suggested that introduction of new varieties resulted in bringing a broad set of mutually reinforcing changes, such as alteration in cropping patterns, changes in labor economy, changes in the utilization of power sources, etc. These has resulted in substantial increase in regional income and output owing to intensification and extensification of agriculture. They further noted that the market force rather than the population pressure have been the result of such transformation. The diffusion of modern technology and consequent changes has been geographically uneven and there is need to mitigate the regional inequities by suppressing the factors that are responsible.

Prahladachar (1989), summarizing studies of regional disparities in India, outlined three salient features. First, the pace of diffusion of modern varieties of specific crops among farms and across regions overtime revealed a linkage with the nature and level of regional development in terms of physical and institutional infrastructure. Second, the ‘Green Revolution’ positively impacted on the absolute income status of the landless laborers through increased demand for labor, though the producers gained more from the technological change than the laborers. And third, the regional income differences widened through modern variety adoption mainly due to differentials in levels of physical and infrastructural development of regions and product-location-specificity characteristics of the modern varieties.

There is a dearth of knowledge on the effect of technological change on regional disparity in Bangladesh, though such analyses are abundant in India. To note among the few existing ones, Alauddin and Tisdell (1991) and the BASR (1989) both concluded that widespread regional disparity exists in productivity growth in Bangladesh. However, there are controversies related to the identification of sources of these differences. The BASR (1989) attributed the differential expansion of irrigation facilities while Alauddin and Tisdell (1991) hinted on differential rate of adoption of modern varieties. The present study, therefore, attempts to contribute to the literature by determining the sources responsible for the observed regional disparities and regroup regions according to similarities in agricultural development levels using historical cross-section data.

2.3.4 Technological Change and Demographic Effects

Robinson and Schutjer (1984) argued that the link between agricultural development and demographic change has not been studied well. Though there are abundant literature in each of the three areas: agricultural development, general economic development, and population change in relation to economic development, they represent totally different perspectives on the same process. Robinson and Schutjer (1984) noted that it is important for the agricultural sector to assist in creating and supporting a dynamic domestic urban industrial sector, because the long-term perspective suggests that the future of the rural sector will depend on inputs, which it can obtain only from such a sector. This requires spread of market based commercial activities and public services, such as health and education, in the countryside since these are most closely related with decline of fertility level, particularly in developing nations.

There is also a dearth of knowledge on the demographic effect of technological change. Only one study, Chaudhury (1981), analyzed explicitly the dynamics of relationship between population pressure and agricultural productivity in Bangladesh using data for the period 1961-64 and 1974 -77. His hypothesis was that land-man ratio will be inversely related to agricultural yield and results validated the notion. He observed that the relationship becomes weak when districts are classified according to their productivity levels and there is a dynamic relationship between yield and population pressure with the causation from higher productivity leading to higher density by attracting migrants from other non-developing areas. This movement of population from poor agricultural districts to districts of better agricultural performance has resulted in higher population density in high growth rate districts and lower density in low and negative growth rate districts. In the present study, the effect of population density in influencing agricultural production and in explaining regional disparity is examined at the national level.

2.3.5 Technological Change and Consumption Effects

Major thrust of technological change in agriculture of developing countries is in the foodgrain sector. Though a positive impact on calorie intake is expected from this technological change, the composition of food consumed may become less varied with high proportion of starch in diet. Alauddin and Tisdell (1991) noted that the food consumption in Bangladesh not only declined but also became less varied. They claimed that now, the average Bangladeshi diet depends solely on cereals and is forced to reduce consumption of pulses, fruits, vegetables and other protein-rich foods due to considerable price hike. Braun (1988) using Gambian data from West Africa noted that technological change lead to increased food consumption (calories) at the household level, thereby, significantly improving children's nutritional status, especially in the 'rainy' season. Such increase in food consumption occurred through the increased income effected through technological change. Chaudhri and Dasgupta (1985) indicated that a change in the food consumption is observed in rural Indian Punjab in the 'post-Green Revolution' period (1979/80). The striking increase has been in the share of milk and milk products. Also, the average calorie intake in rural Punjab is 3,000 calories, which is quite high with respect to developing country standard.

The number of studies dealing directly with consumption effects of technological change in the developing countries are limited and results from those studies are not uniform, as indicated above. For example, the per capita food intake in Bangladesh declined and became less varied while in Gambia and Indian Punjab, the nutrition level increased substantially. Though, examination of consumption effects of technological change is important, it cannot be included in the present study mainly due to the requirement of multi-period farm level consumption expenditure data which is beyond the scope, given time and budget constraints.

2.3.6 Environmental Impacts of Technological Change and Sustainable Development

The question of sustainability of agricultural growth is gaining momentum in recent times (Marten, 1988; Redclift, 1989; and Alauddin and Tisdell, 1991). Though there are early indications of the need to incorporate environmental issues in evaluating technological change (Clapham, 1980 and Bowonder, 1979 and 1981), the delayed consequences of 'Green Revolution' technology on environment received priority only recently (Wossink *et al.*, 1992; Shiva, 1991; Redclift, 1989; Brown, 1988; and Wolf, 1986). Also, during the early eighties, studies dealing with variability in crop production following the introduction of 'Green Revolution' technology were undertaken (Hazell, 1984 and Murshid, 1986 and 1987). For example, Hazell (1984) indicated that production and yield of foodgrain might have become more instable in the period following the introduction of modern technology in India. Murshid

(1986 and 1987) noted that the impact of the diffusion of the 'Green Revolution' on instability of foodgrain production in Bangladesh has not been great so far. However, he cautioned that a higher rate of adoption is likely to generate further instability and, therefore, it is important to recognize the potential hazard and undertake preparatory measures. He recommended for the development of institutional and organizational structure to ensure smooth irrigation systems and timely delivery of critical inputs and promotion of crops that are less critically dependent on favorable weather or man-made factors. Brown (1988) noted that the foodgrain production has been dramatically falling, both nationally and globally, largely due to ecological instabilities including drought, climatic change, greenhouse effect and desertification.

Clapham (1980) noted that though evaluation of agricultural policy and farmers' behavior are abundant, the environmental dimensions of agriculture remains unclear and therefore should be studied in greater details. Bowonder (1979 and 1981) identified a number of direct and indirect consequences of 'Green Revolution' (both positive and negative) on various sectors of the economy and forwarded an early apprehension on the ills of technological breakthrough in agriculture.

It was the study of Shiva (1991) that spurred widespread concern over the environmental impacts of technological change in agriculture. Shiva (1991) in her analyses of agricultural transformation in Indian Punjab concluded that 'Green Revolution' produced scarcity and not abundance (by reducing the availability of fertile land and genetic diversity of crops), though it was believed to be the superior substitute of nature and a source of abundance. Redclift (1989) examining the issues of environmental degradation in rural areas of Latin America noted that it is closely linked to agricultural modernization, which is relatively more advanced in Latin America as compared to other developing countries. He noted that the environmental problems of rural areas will not be addressed until and unless policies are undertaken to improve food security, secure the livelihoods of the rural poor and conserve rural resources. Alauddin and Tisdell (1991) examining historical data, suggested that Bangladesh is failing to produce sufficient food to sustain its growing population and becoming increasingly dependent on food import. However, they were unclear about the ecological sustainability of food production as a consequence of modern technology and recommended further intensification of food production in order to restore supply-demand balance. Wossink *et al.* (1992) urged that measures to control increasing environmental problems in agriculture should be effective both from the ecological point of view (a public goal) and farmers' point of view (a private goal) and necessitates information on complex interaction of production intensity, environmental aspects and farm income. Chapman and Barker (1991) argued that the threat to sustained agricultural growth comes mainly from energy consumption in the non-agricultural sector. Also, the present policy and short-run price incentives are unlikely to encourage investment in environmental protection and research in alternative energy sources, particularly by the developing countries. They noted that, among the alternative technologies, biotechnology possesses the potential for reducing threat to sustainability for both the developed and developing nations. However, if the issue were to be addressed from a global perspective, both the developed and developing countries would benefit from biotechnology research.

Though widespread concern over the environmental impacts of technological change is observed these days, the explicit incorporation of this issue in evaluation studies has been nascent, particularly, in case of Bangladesh. Studies on 'Green Revolution' in Bangladesh dealing with production variability (Murshid, 1986 and 1987) dealt with impact of environment on agriculture and therefore should not be taken as studies on environmental impacts of technological change. Given the deficiency in knowledge on the environmental impacts of modern agricultural technology, the present study attempted to contribute to the existing literature by explicitly analyzing the issue with a broadest possible perspective. The major focus is on understanding the level of farmers' awareness on the issue of environmental impacts of technological change in agriculture on other spheres of life, the nature of impacts, and if possible, the extent of these impacts. Further, the issue of sustainability has also been explicitly analyzed using the longest possible constructed historical data covering 47 years (1947/48 – 1993/94).

2.4 Concluding Remarks

Significant advances have been made in the analysis of technological change and associated impacts. In this chapter, selective empirical studies are reviewed which show the various ways the impacts of technological change are analyzed and relevant policy implications drawn from them. The chapter demonstrated the contrasting conclusions that one arrives based on one's individual circumstances. Further, the chapter also highlighted the deficiency in areas of knowledge regarding the understanding of multifaceted impacts of technological change in agriculture on other spheres of the economy, which formed the basis of the present study.

It can be concluded that the findings from the review are indicative of the forces at work in the process of agricultural development in developing countries following the widespread diffusion of modern agricultural technology, the 'Green Revolution', and the resulting consequences arising thereof. Also, the mutually reinforcing effect of infrastructure and technological change in augmenting productivity growth and in increasing income and employment opportunities has been a major driving force in economic development. The burning question remains that how far can we sustain the food production by undertaking the route of technological change alone and what are the socio-economic and environmental consequences of this pursuit for food production sustainability. A question the present study attempts to answer or at least provide a reflection to some extent.

CHAPTER III

RESEARCH DESIGN AND METHODOLOGY

The primary goal of this research is to evaluate the socio-economic and environmental impacts of technological change in Bangladesh agriculture. The research is geared towards formulating policy guidelines and strategies for effective agricultural and rural-regional development planning by explicitly taking into account the scope and limitations posed by regional characteristics of the country.

Given the objectives and specific hypotheses, analyses was set out to test the hypotheses through testing of models and/or theories by application of quantitative and qualitative techniques relevant to objectives of the study. The following sections provide details of the research design and methodologies of the study.

3.1 Data Source

The research is based on primary data as well as secondary data and extensive literature review. As most of the aggregate data for this study is not readily available in the form required, extensive field works, for collection, coordination and screening of data from secondary sources were done. For primary data collection, field observation, participatory rural appraisal (PRA) technique, and structured questionnaire survey was conducted. A detailed coordination schema is prepared (Appendix B) which is designed to identify sources of data from the structured questionnaire (Appendix C) against each parameters of the study.

3.1.1 Secondary Data Source

The first level of analysis in this study is based on the analysis of aggregate time-series data constructed from secondary sources. The principle sources are: Various issues of *Yearbook of Agricultural Statistics in Bangladesh, Statistical Yearbook of Bangladesh, Bangladesh Economic Survey, Bangladesh Census of Agriculture and Livestock, Bangladesh Population Census, Bangladesh Labor Force Survey, Five Year Plan Documents, Agricultural Databeses of Bangladesh, and Baseline Studies of Farm-level Fertilizer Use Surveys.*

In addition, studies conducted by Bangladesh Institute of Development Studies (BIDS), International Food Policy Research Institute (IFPRI), Bangladesh Agricultural Research Institute (BARI), Bangladesh Rice Research Institute (BRRI), Bangladesh Agricultural Research Council (BARC), Bangladesh Agricultural University Research System (BAURES), and other Ph.D. dissertations served as useful secondary sources for this study. Among the unpublished sources, farm-level survey data of BRAC, a national private development organization, served as an important source for selected sections of the study.

3.1.2 Primary Data Source

Primary data for this study is required to analyze the dynamics of technological progress at the farm level and its associated multifaceted impacts. Primary data, therefore, was generated from an extensive farm-survey at three distinct agro-ecological regions of Bangladesh. In order to select the regions for farm-level survey, a major exercise at the national level was performed as outlined in the following section (detail analysis of this exercise is presented in Chapter IV).

3.2 Study Area

For the national level analysis, the proposed study area comprises of all the agricultural regions of the country. For in-depth local level analysis the following method was adopted. First, relatively homogenous agricultural regions with respect to a set of technological, demographic, infrastructural, and crop production efficiency parameters were identified at the national level which were then classified into five levels of development[6]. Then, one region each from 'high', 'medium', and 'low' level is selected[7]. The specific selected regions are Comilla, Jamalpur, and Jessore region, respectively. Once the regions are selected, multi-stage random sampling technique was employed. As each of these selected regions comprises of a number of districts, one district from each of the three regions is selected at random in the first stage. The selected districts are Chandpur, Jamalpur, and Jessore, respectively. In the second stage, one thana (sub-district) from each of the selected three districts is selected at random. The selected thanas are Matlab thana of Chandpur district in Comilla region, Jamalpur Sadar thana (central administrative sub-district) of Jamaplur district in Jamalpur region, and Manirampur thana of Jessore district in Jessore region, respectively.

The third stage is the random selection of specific villages in each of the selected thanas. As a first step, 8 villages from each of the three thanas were randomly selected which resulted in a large sample size. However, in order to decide concretely on the number of villages and corresponding households to be covered in order to make the study finding as true representive of the regions, advantages of having any additional unpublished information with respect to in-depth farm-level data were taken into account. A carefull scrutiny revealed that, BRAC (one of the largest non-governmental organization in the Asia and Pacific region) which operates in over 50 districts covering about 35,000 villages of rural Bangladesh collects large-scale baseline information on rural livelihood in a number of its operational areas for its program purposes. From the scrutiny, it was observed that BRAC has extensive unpublished raw data on agricultural production and technology in all of the selected 8 villages of Jamalpur Sadar thana and 6 out of 8 selected villages of Manirampur thana[8]. The information pertains to crop year 1989. Also, limited relevant household information on 7 out of 8 selected villages of Matlab

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[6] Essentially, this is an outcome obtained by accomplishing specific study objective (1) conducted at national-level. The five levels are: 'very high', 'high', 'medium', 'low', and 'very low' level, respectively. For details, please see Chapter IV.

[7] Regions from the two extremes, 'very high' and 'very low' level are avoided. The justification is that Chittagong region falling under 'very high' level is already transforming into an urban indiustrial region and the regions under 'very low' level, namely, Khulna, and Faridpur regions, suffers from agro-ecological and other biophysical constraints.

[8] BRAC collected these data mainly to serve as base-line information for a ten-year longitudinal study project, the Village Study Project (VSP). As such, a census of all the 14 villages were conducted on virtually all types of information prevailing in a rural setting, for the cropyear 1989. The base-line data collection took about 6 months engaging 16 field researchers who were stationed in the core village of each thana. The author of this dissertation was then entrusted as the coordinator of the baseline data collection team.

thana for the cropyear 1992[9] were available. Therefore, in order to make use of such valuable farm-level information, number of sample villages were restricted to those 8 villages of Jamalpur Sadar thana, 6 villages of Manirampur thana and 7 villages of Matlab thana. Then, at the final stage, sample households were selected at random using standardized sampling technique discussed in the following section.

3.3 Sampling Design

Having arrived at the sampling of villages, the sample households were selected as follows. The total households in each village with land-ownership category were obtained from BRAC, which served as the population for the present study. Then the sample size (n) of household units in the study area is determined by applying the following formula (Arkin and Colton, 1963):

$$n = \frac{Nz^2 p(1-p)}{Nd^2 + z^2 p(1-p)} \text{.......(3.3.1)}$$

Where: n = sample size
N = total number of households (2,717)
z = confidence level (at 95% level z = 1.96)
p = estimated population proportion (0.5, this maximizes the sample size)
d = error limit of 5% (0.05)

Application of the above sampling formula with the values specified, which in fact maximizes the sample size, yielded a total required sample of 337. Including a reserve of 20 percent, the total sample requirement stands at 404. The present study collected 406 samples (Table 3.1). Having determined the sample size (n) using the aforementioned method, the households are then classified into five groups on the basis of size of landholding. Then proportionate random sampling was applied in order to ensure representation of all land-ownership categories in the sample.

3.3.1 A Test of Representativeness of the Sample

In order to test the strength of the sampling procedure for the present study, a test of representativeness of the current sample is conducted by comparing mean owned land per household of respective land ownership categories for the two time periods. The assumption is that mean owned land per household is a fairly stable criteria and does not vary quickly over time and represents the household's wealth status. F-test is used for the purpose. The basic hypothesis is that the sampled households of the two time periods belong to the same population. Therefore, non-significance of the F-test will validate that the samples drawn for both time periods belong to the same population, thereby, establishing the representativeness of the current samples to those of samples collected in 1989. It should be mentioned that such exercise is done

[9] BRAC collected these data mainly to serve as base-line information for a five-year joint study project with ICDDR,B (International Centre for Diarrhoeal Disease and Research, Bangladesh) and BRAC, the BRAC-ICDDR,B Joint Research Project. The base-line data cover 12,500 households of the thana with general information.

for Jamalpur Sadar thana and Manirampur thana only, as no prior detailed information from Matlab thana exists to permit such comparison. The result of this exercise revealed that except the landless category, all other categories including the overall category are representative of each other (Appendix Table A3.1). The deviation of the landless category is largely due to exclusion of landless households who do not cultivate any crop in the current sample, as the focus of the study is in identifying socio-economic and environmental impacts of technological change, the actual crop producers are more relevant respondents.

Table 3.1 Sample size of the study, 1996.

Name of the region	Village	Households in 1989[a] and 1992[b]	Required sample size	Households sampled in 1996
Jamalpur region (Jamalpur Sadar thana of Jamalpur district)	Rupshi	110	14	26
	Karanipara	106	13	19
	Munshipara	161	20	30
	Sonakata	289	36	60
	Jaliarpar	69	9	9
	Sapleja	64	8	9
	Deuliabari	79	9	13
	Manikbari	56	7	9
	Sub-total	**934**	**116**	**175**
Jessore region (Manirampur thana of Jessore district)	Mohanpur	164	20	20
	Taherpur	146	18	20
	Juranpur	138	17	17
	Monaharpur	163	20	20
	Chandipur	83	10	10
	Subalkati	127	17	18
	Sub-total	**821**	**102**	**105**
Comilla region (Matlab thana of Chandpur district)	Dhakirgaon	81	10	11
	Shilmondi	75	9	9
	Fatehpur	169	20	20
	Sonaterkandi	152	19	20
	Uddamdi	202	26	28
	Khas Uddamdi	120	15	18
	Begumpur	163	20	20
	Sub-total	**962**	**119**	**126**
All region	**Grand-total**	**2,717**	**337**	**406**

Note: [a] = The base-line information of villages of Jamalpur Sadar thana and Manirampur thana is for the cropyear 1989.
[b] = The base-line information of villages of Matlab thana is for the cropyear 1992.
Source: Field survey, 1997; BRAC-VSP Survey, 1990; and BRAC-ICDDR,B Joint Research Project, 1992.

3.4 Location of the Study Areas

The location of the study areas is provided in Figures 3.1, 3.2, 3.3 and 3.4. Figure 3.1 provides the location of study areas at the national level. Figures 3.2, 3.3, and 3.4 provide a detailed location of specific study villages within their respective thana*s*. The shaded areas in the maps represent the study locations.

The study area of Jamalpur region is located within Jamalpur Sadar thana which in turn is located at southeastern part of the Jamalpur district. The distance of the study area is about 11 km by road from district headquarter and 182 km northwest from the capital Dhaka. The total area of the Thana is 489 sq km of which water bodies including river occupy 23.7 sq km and occupy 13 sq km forest area (SRDI, 1991; and BBS, 1996a).

The study area of Jessore region is located at Manirampur Thana in southern part of the Jessore district. The distance of the study area is about 20 km by road from district headquarter and 294 km southwest from the capital Dhaka. The total area of the thana is 445 sq km of which river and water bodies occupy 7 sq km (SRDI, 1990; and BBS 1996b).

The study area of Comilla region is located at Matlab Thana in southeastern part of the Chandpur district. The distance of this study area is about 18 km by road from Chandpur district headquarter and 120 km southeast from the capital Dhaka. The Chandpur district as well as Matlab Thana is also easily accessible by river transport. The distance is about 55 nautical miles from Dhaka. The total area of the Matlab Thana is 409 sq km of which river and water bodies occupy 61 sq km. (BBS, 1996c).

3.4.1 Agro-ecological Characteristics of the Study Areas

The Land Resources Appraisal (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. These units combine four levels of environmental information. These are: (a) physiography (providing information on landforms and soil parent material); (b) soils; (c) land levels in relation to seasonal flooding; and (d) agro-climatology (which includes four individual elements: (i) length of rainfed *kharif* (summer) and *rabi* (winter) growing seasons; (ii) length of the pre-*kharif* period of unreliable rainfall; (iii) length of the cool winter period; and (iv) frequency of occurrence of extremely high (>40^0) summer temperatures (UNDP/FAO, 1988). Table 3.2 provides brief characteristics of the agro-ecological characteristics of the study locations.

The Jamalpur study region falls under *Agro-ecological* Region *9* defined as *Old Brahmaputra Floodplain*.This region occupies a large area of Brahmaputra sediments, which were deposited since the river shifted to present Jamuna channel about 200 years ago. This region encompasses large areas of Sherpur, Jamalpur, Tangail, Mymensingh, Netrakona, Kishoreganj, Narshingdi, and Narayanganj districts. Small areas of east of Dhaka and Gazipur districts are also included. The region covers a total area of 7,230 sq km. The entire region has broad ridges and basins with irregular relief. The elevation between ridge tops and basin centres range between 2-3 m. There are five sub-regions in this region with transitional delineations across sub-regions. The study area specifically falls under sub-region 9b characterized as medium high land and is mainly shallowly flooded during peak monsoon.

Flooding is entirely by rainwater and/or raised groundwater table. Table 3.2 provides the land type distribution based on flood depth. *Noncalcareous Dark Grey Floodplain Soils*[10] are predominant (63% of total area) in this sub-region 9b. The *silt loam* and *silty clay loams* are prominent. A total of 17 soil series are identified in Jamalpur Sadar Thana. However, for the specific study area, the dominant soil series are, *Sonatala*, and *Silmandi* (details of soil fertility evaluation of the study villages are analyzed in Chapter IX). The agricultural system is mainly rainfed. However, a large land area of Jamalpur Sadar Thana is irrigated with Shallow Tube Wells and Deep Tube Wells. Two rice crops Aman and Boro dominate the cropping pattern.

The Jessore study region falls under *Agro-ecological* Region *11* defined as *High Ganges River Floodplain*.This region includes the western part of the *Ganges River Floodplain*, which is predominantly composed of highland and medium highland. This region encompasses Chapai Nawabganj, Rajshahi, southern Pabna, Kushtia, Meherpur, Chuadanga, Jhenaidah, Magura, Jessore, and northern parts of Satkhira and Khulna districts. The region covers a total area 13,205 sq km. Most areas have complex relief of broad and narrow ridges and inter-ridge depressions. There are three sub-regions in this region. The study area specifically falls under sub-region 11a with smooth ridge and basin relief crossed by broad and narrow belts of irregular relief adjoining old river channels. Lower ridges and basins are shallowly flooded by either rainwater or by raised groundwater table during heavy rainfall. Table 3.2 provided information on land types. The overall soils are olive-brown *silt loams* and *silty clay loams* on the upper part of floodplain ridges and dark gray clay soils on lower ridges and in basins. *Calcareous Dark Grey Floodplain Soils*[11] (54% of total area) and *Calcareous Brown Floodplain Soils*[12] (24% of total area) are predominant in this sub-region 11a. A total of 7 soil series are identified in Manirampur thana. However, for the specific study area, the dominant soil series are, *Gopalpur, Ishwardi*, and *Gheor* (details of soil fertility evaluation of the study villages are analyzed in Chapter IX). The agricultural system is mainly rainfed. However, a large land area of Manirampur thana is irrigated with Shallow Tube Wells and Deep Tube Wells. Two rice crops Aman and Boro dominate the cropping pattern.

Table 3.2 Agro-ecological characteristics of the study regions.

Characteristics	**Jamalpur region**	Jessore region	Comilla region

[10] Floodplain soils refer to soils that have formed in river and piedmont alluvium ranging from very recent to several thousand years old. All except highest soils are subject to seasonal flooding either by accumulated rainwater or by raised groundwater table. Noncalcareous Dark Grey Floodplain Soils are seasonally flooded soils, which is dominantly dark grey and/or dark grey gleyans; not calcareous within 125 cm from surface. Topsoil generally is slightly to very strongly acid; lower layers are less acidic to moderately alkaline (UNDP/FAO, 1988).

[11] Calcareous Dark Grey Floodplain Soils are seasonally flooded soils whcih either is dominantly dark grey or has prominent dark grey gleyans or pressure faces; calcareous within 125 cm from surface. Many basin soils have a nuetral to acid topsoil and a near neutral subsoil over a calcareous substratum at 40-60 cm (UNDP/FAO, 1988).

[12] Calcareous Brown Floodplain Soils are moderately well to imperfectly drained floodplain reidge soils; calcareous throughout or within 125 cm from surface (UNDP/FAO, 1988).

Geographic location	North *latitude* East *longitude*	$24^0 42' – 24^0 58'$ $89^0 52' – 90^0 12'$	$22^0 55'$ - $23^0 06'$ $89^0 09'$ - $89^0 22'$	$23^0 15' – 23^0 30'$ $90^0 33' – 90^0 49'$
Area (sq km)	**Total** Water body	489 24	445 7	409 61
Distance (km)	District HQ Capital Dhaka	11 182	20 294	8 120
Direction from Capital Dhaka		Northwest	Southwest	Southeast
Agro-ecological region		Old Brahmaputra Floodplain (9b)	High Ganges River FP (11a)	Middle Meghna River FP (16)
Land types [13] (%)	High (F_0)	28	43	<1
	Medium high (F_1)	43	33	8
	Medium low (F_2)	16	10	29
	Low (F_3)	3	2	25
	Very low (F_4)	-	-	11
	Homestead, Rivers	10	12	27
Annual rainfall (mm)	Mean of 1992	2000 +	1300 - 1600	2200 - 2300
	Monthly average of 1962 – 77	2160	1625	1708
Annual Temperature (^{0}C)	Min-Max (1992)	17 – 34	21 – 32	19 – 33
	Average min-max of 1971 – 81	10 – 35	10 – 35	11 – 34
Soil types (%)	NC D G FS	63	6	4
	NC G FS	23	-	56
	C D G FS	-	54	-
	C B FS	-	24	-
	NC Alluvium	-	-	13
Soil texture (%)	Sandy	1	<1	14
	Loamy	52	51	59
	Clayey	47	49	27
Major irrigation source		Ground water	Ground water	Surface

Note: FP = Floodplain, NC = Noncalcareous, C = Calcareous, D = Dark, G = Grey, B = Brown, FS = Floodplain soils.
Source: Adapted from UNDP/FAO (1988), SRDI (1990, 1991), BBS (1994), and Rashid (1991).

The Comilla study region falls under *Agro-ecological* Region *16* defined as *Middle* Meghna *River Floodplain*.This region occupies the abandoned channel of river *Brahmaputra* on the border of the Dhaka and Comilla regions. This region occurs between the southern part of the *Sylhet* basin and the confluence of river Meghna with *Dhaleshwari* and *Ganges* rivers. The region encompasses parts of Kishoreganj, Brahmanbaria, Comilla, Chandpur, Narsingdi, and Narayanganj. This region covers a total area of 1,555 sq km. No sub-region is recognized.

[13] The land types are classified according to flooding depth during the flooding season: (1) Highland (F_0): land that is above normal flood level; (2) Medium Highland (F_1): flooded up to about 90 cm deep; (3) Medium Lowland (F_2): flooded up to 90 – 180 cm deep; (4) Lowland (F_3): flooded up to 180 – 300 cm deep; and (5) Very Lowland (F_4): flooded deeper than 300 cm (UNDP/FAO, 1988).

Most soils are deeply flooded, except on high floodplain ridges. Basins and inter-ridge depressions flood early and drain late. River levels starts to rise in March, following early rains in the upper catchment area of the Meghna. The rivers are tidal in the dry season but are not saline. Table 3.2 provides the distribution of the land types. Three main kinds of soils occur in this region. The *grey loams* and *clay* in areas of Meghna *alluvium* occupies greater part of the region. *Noncalcareous Grey Floodplain Soils*[14] (56% of total area) and *Noncalcareous Alluvium*[15] (13% of total area) are predominant in this region. Ample surface water resource exists in the Meghna channels to irrigate the agricultural crops throughout the area. A Flood Control, Drainage and Irrigation (FCD/I) project is constructed with embankment on only one side of the Matlab Thana in 1987. This lead to increase in cropping intensity inside the embankment, with two or three rice crops grown in a year.

3.5 Questionnaire Design

Two sets of structured questionnaires (Appendix C) were administered to collect information on following broad categories:

1. Detailed statistics on household characteristics, household assets and liabilities; Costs and returns of farm production activities covering all three seasons: Aus - the summer season, Aman - the autumn, and Boro - the winter season[16]. Weekly expenditures: on food and non-food necessities, non-farm income, employment, and wage earnings[17]. Monthly/annual expenditure: on durables, such as clothing, household durables, education, health, housing, acquisition of physical assets, and credit.

2. A village level questionnaire to provide information on infrastructure: access of study areas to transport, communication, electricity, markets, cooperatives, banks, extension services, supply points of modern inputs, storage, educational institutes, hospitals, and health service centres.

A pre-testing of the questionnaire was conducted in Kotchandpur thana of Jessore district. The questionnaire is then revised. The revision was mainly in organizing the sequence of questions that are aimed at extracting information on impacts. The questionnaires were administered during the months of mid-February to mid-April, 1997 covering the information for the cropyear 1996.

[14] Noncalcareous Grey Floodplain Soils are similar to Noncalcareous Dark Grey Floodplain Soils except the color is greyish rather than dark grey (UNDP/FAO, 1988).

[15] Noncalcareous Alluvium are raw or stratified alluvium; not calcareous or sulphidic within 125 cm from surface (but generally neutral to moderately alkaline) (UNDP/FAO, 1988).

[16] Ideally, questionnaire should be administered at the end of each season. However, since this is not feasible, information on production activities of all three seasons was collected once solely based on recall basis of the respondent.

[17] Ideally, data should be collected at least eight times in a year to capture the seasonality in expenditure patterns. However, since this is infeasible at the present context, only expenditures records for the week preceding the date of interview was collected

3.6 Methodology for National Level Analyses

For national level analysis, the basic unit is the region (former greater districts). Also, analysis on country level is used.

3.6.1 Methodology for Analyzing Regional Disparity

Numerical taxonomy technique was utilized to identify differences among districts (or) to regroup districts according to their similarities with respect to selected technological, infrastructural, crop production efficiency, and demographic parameters. First of all, from a given set of indicators, the significant indicators influencing agricultural growth is identified by applying Stepwise Forward Regression procedure. Then, these numerical indexes for each administrative region were standardised by using the regression coefficients of the significant indicators selected from the regression. Finally, the regions were delineated using mean and standard deviation criteria and are displayed in maps.

The basic assumption of the model is that there exists a linear relationship among the explained indicator and the set of explanatory indicators (Pokhriyal and Naithani, 1996). Consider that an explained indicator Y has a linear relation with K number of explanatory indicators, X_1, X_2... X_k, Then the model can be expressed as (Gujarati, 1978):

$$\boldsymbol{Y} = \boldsymbol{X}\beta + \varepsilon, \quad (3.6.1.1)$$

Where, $\boldsymbol{Y}$ = N x 1 column vector of observations on the explanatory indicators, Y.

$\boldsymbol{X}$ = N x (K + 1) matrix of N observations on K explanatory indicators with all elements in the first column being set to 1.

β = (K + 1) x 1 column vector of unknown parameters

ε = N x 1 column vector of the error term.

The model is true under the following assumptions:

1. $E(\varepsilon) = 0$
2. $E(\varepsilon\varepsilon') = \sigma^2 I$
3. Matrix $\boldsymbol{X}$ is non-stochastic
4. Rank of $\boldsymbol{X}$ is (K + 1) and N > (K + 1).

Applying the Stepwise Forward Regression estimation procedure, we can identify the significant indicators on the basis of partial F-test to examine the significance of the marginal contribution of an explanatory indicator on the value of adjusted coefficient of multiple determination, $\bar{R}^2$. Let the number of selected significant indicators be P < K, then based on these P indicators, weighted standard score for each region can be computed using the following method by Bhagat (1982) (cited in Pokhriyal and Naithani, 1996).

$$Z_{wj} = \Sigma r_i * z_{ij} / \Sigma r_i; \quad j = 1, 2, ..., N; \text{ and } i = 1, 2, ..., P; \quad (3.6.1.2)$$

Where, Z_{wj} = weighted standard score of j<u>th</u> region.

$z_{ij} = (X_{ij} - \bar{X}_i)/s_i$ is the standard score of the ith indicator in the jth region, and $\bar{X}_i$ and s_i is the mean and standard deviation of ith indicator.

r_i = correlation coefficient between the explained and ith explanatory indicator.

Pokhriyal and Naithani (1996) claimed that theoretically Bhagat's weighting criterion fails when the sum of r_i's is zero and provided following alternatives:

$$Z_{wj} = \Sigma\, \beta_i \text{ x } z_{ij} / \Sigma\beta_i; \qquad (3.6.1.3)$$
$$Z_{wj} = \Sigma\, |r_i| \text{ x } z_{ij} / \Sigma |r_i|; \qquad (3.6.1.4)$$
$$Z_{wj} = \Sigma\, |\beta_i| \text{ x } z_{ij} / \Sigma |\beta_i|; \qquad (3.6.1.5)$$

where, β_i = is the regression coefficient of the ith explanatory indicator. Eq. (3.6.1.4) and (3.6.1.5) differs from eq. (3.6.1.2) and (3.6.1.3) in that they use the absolute values of the coefficients to prevent the denominator being zero. The preference lies in the choice of eq. (3.6.1.2) and (3.6.1.3) provided the denominators are non-zero. In this study, eq. (3.6.1.3) is preferred and used in all the subsequent analyses. The reason is that eq. (3.6.1.3) utilizes the regression results as compared to eq. (3.6.1.2) which uses the correlation results. The advantage of using regression result is that it provides information on the strength of the concerned indicator in influencing the dependent variable. Also, the overall explanatory power of the model can also be determined from the coefficient of determination (R^2/Adjusted R^2) provided by the regression function.

Based on the weighted-standard score, the regions can be arranged in descending order. The categorization of regions into various levels of development can be done, by using the following method:

$$L_k = \bar{Z}_{wj} \pm m\sigma_j, \qquad (3.6.1.6)$$

Where, L_k = the kth level of development,

m = is the level of deviation from the mean standard score.

However, prior to the computation of L_k's, an adjustment in Z_{wj} is necessary to express the scores in positive integers which is done using the following method (Pokhriyal and Naithani, 1996):

$$Z_{wj}\,(\text{adj.}) = Z_{wj} + A; \qquad (3.6.1.7)$$

where A = is an arbitrary positive integer just greater than the absolute value of the most negative Z_{wj}.

In the present study, the model is used including indicators representing crop production efficiency, technological, agro-ecological, demographic, human capital, as well as infrastructural factors. The specific variables used for the analysis are detailed in Chapter IV.

3.6.2 Methodology for Aggregate Production Function Estimation

An aggregate production function of the Cobb-Douglas form is given by:

$$\ln Y_{ij} = \ln \alpha_{ij} + \beta_{ij} \ln X_{ij} + \varepsilon_{ij} \qquad (3.6.2.1)$$

where Y_{ij} = is the crop output of the i<u>th</u> region in the j<u>th</u> year,
i = 1, 2, ... 19, (1 = region 1, 2 = region 2, ... 19 = for region 19),
and j = 1, 2, ..., 29 (1 = 1960/61, 2 =1962, ... 29 = 1991/92).
X_{ij} = is the matrix of factor inputs for ith region in the jth year,
α and β = parameter to be estimated.
ε = error term.

Since the Cobb-Douglas specification is in double-log form, vector β becomes the estimate of output elasticities.

For the Cobb-Douglas case, returns to scale of crop production can be directly estimated by summing up the output elasticities with following conditions:

If the sum of
[β's > 1], then there is increasing returns to scale in factor utilization,
[β's = 1], then there is constant returns to scale in factor utilization,
[β's < 1], then there is decreasing returns to scale in factor utilization.

The indication on the sustainability in food production is, therefore, can be obtained by analyzing aforementioned estimation results. As the issue of sustainability is complex and multifaceted, a further analysis that would serve as a complement to the results of the aggregate production function analysis is provided below. The additional advantage of using the following methodology is that it utilizes a longer time-series data (47 years) on foodgrain crops.

3.6.3 Methodology for Analyzing Food Production Sustainability

The long-term trend in productivity of foodgrain (rice and wheat) for 47 years (1947/48 – 1993/94) is estimated by applying linear semi-log trend function. Sustainability of food production is analyzed by superimposing the logistic function on the linear trend function as well as the observed values.

The models are as follows:

<u>Linear semi-log trend function</u>:

$$\ln Y = \alpha + \beta t + \varepsilon \qquad (3.6.3.1)$$

where Y = yield rate of foodgrain output (rice and wheat of all varieties)
t = time
α and β = parameters to be estimated.
ε = error term.

ln = natural logarithm.
The parameter β is the average annual exponential compound growth rate.

Logistic trend function:

$$P = 1/(1 + e^{-X\beta}) \qquad (3.6.3.2)$$

$$\ln [P/(1-P)] = X\beta + \varepsilon$$
$$= \alpha + \beta t + \varepsilon \qquad (3.6.3.3)$$

where P is the yield rate of foodgrain output in proportion form.

The concluding remark on the sustainability of food production is, therefore, can be arrived by considering the outcome of all the analyses presented in sections 3.6.2 and 3.6.3, respectively.

3.7 Methodologies for Local Level Analyses

For the local level analysis the basic unit of analysis is household unit as well as the crop production unit, that is the individual farm plots allocated for specific crops by same farm households. The basic method used is the comparison of relevant constructed variables across regions to identify inter- and intra-regional differences and/or similarities.

3.7.1 Methodology for Farm-level Decision Analysis of Alternative Technologies

The analytical framework utilizes the 'meta-production function' hypothesis and is detailed in Chapter V. The empirical estimation procedure essentially incorporates the joint determination of demand for input and output supply at the same time allowing for farmers to switch between local and modern varieties of seed. In this study the two distinct technologies under scrutiny are the local varieties of rice and wheat versus the modern varieties of rice and wheat. In order to determine jointly the farm-level input demand and output supply of foodgrain (rice and wheat) crops while allowing for chosing between modern and local varieties, the following model is postulated.

Farmers are assumed to choose between modern varieties and local varieties of rice and wheat, respectively, so as to maximize profits. With every combination of fixed factors and variable factor prices, there is an associated variable profit for the two sets of seed varieties. Farmers will choose to plant modern seeds if the variable profit obtained by doing so exceeds that obtained by planting local seeds.

The general model consists of two regimes described by the simultaneous equations,

$$\pi_{hi} = P_i\beta_h + Z_i\gamma_h + \varepsilon_{hi} \qquad (3.7.1.1)$$
$$\pi_{li} = P_i\beta_l + Z_i\gamma_l + \varepsilon_{li} \qquad (3.7.1.2)$$
$$I' = (\pi_{hi} - \pi_{li})\lambda - \varepsilon_i \qquad (3.7.1.3)$$

where P_i is a vector of variable factors and output prices; Z_i is a vector of fixed factors; π_{hi} and π_{li} represent variable profits under the modern and local variety regime, respectively; i = 1, 2, .. N; β_h, β_l, γ_h, γ_l, and λ are vector of parameters; and

$$\varepsilon_h \sim N(0, \sigma_h{}^2),\ \varepsilon_l \sim N(0, \sigma_l{}^2),\ \varepsilon_i \sim N(0, \sigma_\varepsilon{}^2)$$

Equations (3.7.1.1) and (3.7.1.2) are variable profit functions. Equation (3.7.1.3) is the selection criterion function, and I' is an unobservable variable. A dummy variable, I_i is observed. It takes the value of 1 if a plot is planted with modern varieties, 0 otherwise: i.e.,

I_i = 1, if $I'_i \geq 0$
= 0, otherwise (3.7.1.4)

Since modern and local varieties are mutually exclusive, planting of both varieties cannot be observed simultaneously on any one plot. Thus, observed variable profit π_i take the values

$$\pi_i = \pi_{hi},\ \textit{iff}\ I_i = 1$$
$$\pi_i = \pi_{li},\ \textit{iff}\ I_i = 0 \qquad (3.7.1.5)$$

Heckman (1976) indicated that, all of the models in the literature developed for limited dependent variables and sample selection bias may be interpreted within a missing data framework. Suppose that we seek to estimate equation (1), but that for some observations from a larger random sample data are missing on π_q. But, there is a sample of N_1 complete observations.

The population regression function for equation (3.7.1.1) may be written as

$$E(\pi_{hi} \mid P_i, Z_i) = P_i\beta_{hi} + Z_i\gamma_{hi},\quad i = 1,.....N \qquad (3.7.1.6)$$

This function could be estimated without bias from a random sample of the population of rice and wheat cultivators. The regression function for the incomplete sample (modern variety cultivators only) may be written as

$$E(\pi_{hi} \mid P_i, Z_i, \textit{sample selection rule})$$
$$= P_i\beta_{hi} + Z_i\gamma_{hi} + E(\varepsilon_{hi} \mid \textit{sample selection rule}),\quad i = 1,.....N, \qquad (3.7.1.7)$$

where without loss of generality the first N_1 observations are assumed to contain data on π_h. If the conditional expectation of ε_{hi} is zero, regression on the incomplete sample will provide unbiased estimates of β_{hi} and γ_{hi}. Regression estimates of (3.7.1.1) fitted directly on a selected sample omit the final term, i.e., the conditional mean of ε_{hi}, shown on the right hand side of equation (3.7.1.7). Thus the bias that arises from using least squares to fit models for limited dependent variables or models with truncation solely because the conditional mean of ε_{hi} is not included as a regressor. Therefore, the bias that arises from selection may be interpreted as arising from an ordinary specification error with the conditional mean deleted as an explanatory variable (Heckman, 1976).

However, it is not likely that both

$$E(\varepsilon_{hi} \mid I_i = 1) = 1, \;\; E(\varepsilon_{li} \mid I_i = 0) = 0 \qquad (3.7.1.8)$$

This would occur only in very special situations (Lee, 1978). In the model, suppose that $\lambda > 0$, then it is likely that an observation of $I_i = 1$ will be associated with a positive value of ε_{hi} or negative value of ε_{li}. That is, random factors associated with high modern variety profit are likely to be associated with observed adoption.

3.7.1.1 Estimation

The variable profit functions of (3.7.1.1) and (3.7.1.2) are represented by Transcendental Logarithmic (translog) functions. The translog form is much less restrictive than the Cobb-Douglas form. It does not maintain additivity or unitary Hicks-Allen elasticities of substitution (Pitt, 1983). A general normalized restricted translog profit function for a single output is written as (Sidhu and Baanante, 1981):

$$\ln \pi' = \alpha_0 + \alpha_i \sum_{i=1}^{n} \ln P'_i + \tfrac{1}{2} \sum_{i=1}^{n} \sum_{d=1}^{n} \gamma_{id} \ln P'_i \ln P'_d + \sum_{i=1}^{n} \sum_{i=1}^{k} \delta_{ik} \ln P'_i \ln Z_k + \sum_{i=1}^{k} \beta_k \ln Z_k$$
$$+ \tfrac{1}{2} \sum_{i=1}^{k} \sum_{j=1}^{m} \psi_{kj} \ln Z_k \ln Z_j \qquad (3.7.1.9)$$

where $\gamma_{id} = \gamma_{di}$ for all *d, i,* and the function is homogenous of degree one in prices of all variable inputs and output. *P'* is the restricted profit (total revenue less total costs of variable inputs) normalized by output price, P_i' is the price of variable input X_i, normalized by the output price, Z_k is the kth fixed inputs; $i = d = 1,2,3,\ldots,n+k = j = 1,2,3,\ldots,m$; *ln* is the natural logarithm; the parameters α_0, α_i, γ_{ij}, β_k, δ_{ik} and ψ_{kj} are to be estimated.

From the profit function (3.7.1.9), the following equation can be derived for a variable input (Diewert, 1974 and Sidhu and Baanante, 1981)

$$S_i = -\frac{P'_i X_i}{\pi'} = \frac{\partial \ln \pi'}{\partial \ln P'_i} = \alpha_i + \sum_{d=1}^{n} \gamma_{id} \ln P'_d + \sum_{i=1}^{k} \delta_{ik} \ln Z_k \qquad (3.7.1.10)$$

where S_i is the ratio of variable expenditures for the *i*th input to variable profit. Profits and variable input demands are determined simultaneously. Under price-taking behavior of the farms, the normalized input prices and quantities of fixed factors are considered to be the exogenous variables.

Estimation of the variable profit functions (3.7.1.9) with selected samples can be done with the Two-stage Switching Regression method described by Lee (1978) and Heckman (1976). The objective is to find an expression that adjusts the profit function error terms so that they have zero means. A reduced-form seed selection equation is obtained by substituting the profit functions (3.7.1.1) and (3.7.1.2) into the seed selection equation (3.7.1.3).

$I'_i = \theta_0 + P_i\theta_1 + Z_i\theta_2 - \varepsilon'_i$ (3.7.1.11)

By estimating (3.7.1.11) as a typical probit equation, it is possible to compute the probability that any plot has missing data on π_{hi} or π_{li}. The probit reduced form itself shows how prices and fixed factors affect the probability of adopting modern varieties. If the joint density of ε_{hi}, ε_{li} and ε_i is multivariate normal, then the conditional expectation on right-hand side of (3.7.1.11) is

$$E(\varepsilon_{hi} \mid I_i = 1) = \sigma_{1'_\varepsilon} \left(\frac{-f(\phi_i)}{F(\phi_i)}\right) \quad (3.7.1.12)$$

where F is the cumulative normal distribution and f is its density function, both evaluated at ϕ_i. $F(\phi_i)$ is the probability that π_{hi} is observed.

The two-stage procedure uses $-f(\phi_i)/F(\phi_i)$ and $f(\phi_i)/[1 - F(\phi_i)]$ as regressors in the modern and local variety profit function, respectively, to purge them of bias. Estimates of ϕ_i are just $\theta\text{^}_0 + P_i\theta\text{^}_1 + Z_i\theta\text{^}_2$, obtained from the estimated probit reduced-form equation (3.7.1.11).

We get estimates $\theta\text{^}_0$, $\theta\text{^}_1$, and $\theta\text{^}_2$ using the probit Maximum Likelihood Estimation (MLE) method. Then, conditional on selection status, the variable profit equation for modern varieties is

$$\pi_{hi} = P_i\beta_h + Z_i\gamma_h + \sigma_{1'_\varepsilon} \left(\frac{-f(\phi_i)}{F(\phi_i)}\right) + \xi_h \qquad (3.7.1.13)$$

where f is the density function and F the distribution function of the standard normal, $\phi_i = \theta_0 + P_i\beta_h + Z_i\gamma_h$, and $\sigma_{1\varepsilon'} = Cov(\varepsilon_h,\varepsilon')$. Similarly, conditional on selection status, the variable profit equation for local varieties is,

$$\pi_{li} = P_i\beta_l + Z_i\gamma_l + \sigma_{2'_\varepsilon} \left(\frac{f(\phi_i)}{1 - F(\phi_i)}\right) + \xi_l \qquad (3.7.1.14)$$

where $\sigma_{2\varepsilon'} = Cov(\varepsilon_l,\varepsilon')$. After getting $\phi\text{^}$ from the probit estimates of θ_0, θ_1 and θ_2 and substituting it for ϕ_i in equations (3.7.1.13) and (3.7.1.14), these equations can be estimated by Ordinary Least Squares (OLS). However, a more efficient estimate would be obtained by estimating jointly the profit function and the share equations using Zellner's Seemingly Unrelated Regressions

Estimator (SURE) (Heckman, 1976). The coefficient estimates of the profit functions obtained from this two-stage procedure are consistent (Lee, 1978).

3.7.1.2 Input Demand Elasticities

After obtaining the parameter estimates of equations (3.7.1.9) and (3.7.1.10), one can compute the elasticities of variable input demand and output supply with respect to all exogenous variables evaluated at averages of the S_i and given levels of variable input prices and fixed factors. However, in order to allow for the seed switching options a further treatment would be necessary on these estimates discussed later in this chapter.

From (3.7.1.10) the demand equation for the *i*th variable input can be written as (Sidhu and Baanante, 1981)

$$X_i = \frac{\pi}{P_i}\left(-\frac{\partial \ln \pi}{\partial \ln P_i}\right) \qquad (3.7.1.15)$$

$$\ln X_i = \ln \pi - \ln P_i + \ln\left(-\frac{\partial \ln \pi}{\partial \ln P_i}\right) \qquad (3.7.1.16)$$

The own-price elasticity of demand (η_{ii}) for X_i then becomes

$$\eta_{ii} = -S'_i - 1 - \frac{\gamma_{ii}}{S'_i} \qquad (3.7.1.17)$$

where S_i' is the simple average of S_i.

Similarly, from (3.7.1.16) the cross-price elasticity of demand (η_{id}) for input *i* with respect to the price of the *d*th input can be obtained

$$\eta_{id} = -S'_d - \frac{\gamma_{id}}{S'_i} \qquad (3.7.1.18)$$

where $i \neq d$.

The elasticity of demand for input i (η_{iy}) with respect to output price, P_y, can also be obtained from (3.7.1.16),

$$\eta_{iy} = \sum_{i=1}^{n} S'_i + 1 + \sum_{i=1}^{n} \frac{\gamma_{id}}{S'_i} \qquad (3.7.1.19)$$

where $i = 1, \ldots. n, h = 1, \ldots.., n$.

Finally the elasticity of demand (η_{ik}) for input *i* with respect to *k*th fixed factor Z_k is obtained from (3.7.1.16)

$$\eta_{ik} = \sum_{i=1}^{n} \delta_{ik} \ln P_i + \beta_k - \frac{\delta_{ik}}{S'_i} \qquad (3.7.1.20)$$

3.7.1.3 Output Supply Elasticities

Output supply elasticities with respect to output prices and variable inputs of production and quantities of fixed factors evaluated at averages of the S_i and at given levels of exogenous variables, can also be expressed as linear functions of parameters of the restricted profit function. From the duality theory (Lau and Yotopoulus, 1972) the equation for output supply V can be written as (Sidhu and Baanante, 1981)

$$V = \pi + \sum_{i=1}^{n} P_i X_i \qquad (3.7.1.21)$$

The various supply elasticity estimates can be derived from this equation. Rewriting (3.7.1.21) with the help of (3.7.1.15) as follows

$$\ln V = \ln \pi + \ln(1 - \sum_{i=1}^{n} \frac{\partial \ln \pi}{\partial \ln P_i}) \qquad (3.7.1.22)$$

Then the elasticity of supply (ε_{vi}) with respect to the price of the *i*th variable input is given by

$$\varepsilon_{vi} = -S'_i - \frac{\sum_{d=1}^{n} \gamma_{di}}{1 + \sum_{d=1}^{n} S'_d} \qquad (3.7.1.23)$$

where *i=h=1,.....,n.*

The own-price elasticity of supply (ε_{vv}) is given by

$$\varepsilon_{vv} = \sum_{i=1}^{n} S'_i + \frac{\sum_{i=1}^{n} \sum_{d=1}^{n} \gamma_{id}}{1 + \sum_{d=1}^{n} S'_d} \qquad (3.7.1.24)$$

Finally, the elasticity of output supply (ε_{vk}) with respect to fixed inputs Z_k is given by

$$\varepsilon_{vk} = \sum_{i=1}^{n} \delta_{ik} \ln P_i + \beta_k - \frac{\sum_{i=1}^{n} \delta_{ik}}{1 + \sum_{d=1}^{n} S'_d} \qquad (3.7.1.25)$$

3.7.1.4 Input Demand Elasticities Allowing for Seed Switching

The price elasticity of demand for inputs allowing for seed switching can be readily calculated from the parameters of the probit seed selection equation and the corresponding three sets of input demand equations or share equations.

The expected demand for variable input *i* by a representative cultivator having mean levels of fixed factors and facing mean prices is (Pitt, 1983):

$$E(X_i) = E(X_i|I = 1)\ Prob\ (I=1) + E(X_i|I = 0)\ Prob\ (I=0), \qquad (3.7.1.26)$$

where $E(X_i \mid I = 1)$ and $E(X_i \mid I = 0)$ are the demand for input *i* under a modern and a local variety regime, respectively; and Prob (I = 1) and Prob (I = 0) are probabilities of observing a modern and a local variety regime, respectively. The log derivative of this expectation with respect to the price of *i*th input is the total price elasticity of demand (η), which can be reduced to:

$$\eta = \frac{\eta_h E(X_i \mid I=1) \Pr ob(I=1)}{E(X_i)} + \frac{\eta_l E(X_i \mid I=0) \Pr ob(I=0)}{E(X_i)} + \frac{\zeta_h [E(X_i \mid I=1) - E(X_i \mid I=0)] \Pr ob(I=1)}{E(X_i)} \qquad (3.7.1.27)$$

where ζ_h is the elasticity of the probability of choosing modern variety with respect to the price of the *i*<u>th</u> input, and for estimating the total own price-elasticity of demand, η_h and η_l are given by

$$\eta_p = -S'_i - 1 - \frac{\gamma_{ii,p}}{S'_i} \qquad p = Modern, local\ \text{var}iety, \qquad (3.7.1.28)$$

Similarly, the total cross-price elasticity of demand with respect to input prices and cross-price elasticities with respect to fixed factors can be obtained from the above expression (3.7.1.27) by replacing (3.7.1.28) with (3.7.1.18), (3.7.1.19) and (3.7.1.20) as required.

The vectors of explanatory variables used are the variable input prices, fertilizer, labor and animal power, and the levels of fixed factors, land area, value of non-land fixed farm capital assets, index of underdevelopment of infrastructure, soil fertility index, and education level of the farmer.

3.7.1.5 Methodology for Constructing Composite Index of Infrastructure

In this study, the following elements of infrastructure were identified to construct a composite index of development infrastructure. These are: primary markets, secondary markets and/or growth centres, primary school, secondary school, college, post ofice, thana headquarter, bus stop, paved road, river jetty, rail station, bank, storage facilities and/or food godowns, rural electrification, agricultural extension office, and union council office.

First, distance from the study villages to these elements of infrastructure, were empirically measured using the Thana Base Maps[18] (1:50,000 scale). Also, the village-level questionnaire (Appendix C) contained questions relating to distance, travel time and travel costs for each of these elements of infrastructure, thereby, providing an opportunity for double-check. Second, total cost (*TC*) of access was computed by summing up individual costs (IC_i) of access. Then, following the method proposed by Ahmed and Hossain (1990), the *TC* was correlated with costs for each element (IC_i) which provided correlation coefficients (W_i). The formulation is:

$$IC_i = \text{distance x cost per km to element } i$$
$$TC = \sum_i IC_i$$
$$W_i = \text{correlation of } IC_i \text{ with } TC\text{, and}$$
$$INF = \sum_i (W_i \times IC_i) / \sum_i W_i$$

Here the set of infrastructural variable is expressed as a single index, which is later incorporated explicitly for analytical purposes.

3.7.2 Methodology for Analyzing Determinants of Adoption of Modern Technology

In analyzing the determinants of modern agricultural technology adoption multivariate regression analyses is performed.

The explanatory variables are: prevailing wage rate; number of members participating in income earning activity; proportion of female workers; land ownership; farm size; amount of land rented-in; family size; dependency ratio; value of non-land capital assets; education; index of underdevelopment of infrastructure index, and soil fertility index.

3.7.3 Methodology for Analyzing Impact of Modern Technology on Employment, Labor Market and other Factor Markets

In determining the impact of modern agricultural technology on employment, labor market, and various factor markets multivariate analyses is utilized by postulating relevant regression models, such as, labor demand function, wage function, fertilizer price function, pesticide demand function, land rent function, agricultural credit function, and output price function, respectively. Ordinary Least Squares (OLS) regression as well as Tobit (Two-limit Probability) or Truncated regression procedures were applied as required.

[18] The Local Government and Engineering Department (LGED) published Thana Base Maps for each of the 490 thanas of Bangladesh in 1994. These Base Maps contain explicit information of various physical, agricultural, and socio-economic infrastructures, most of which is utilized in this study.

Also, to determine the relationship between technological change and joint demand for inputs, a simultaneous equation model incorporating fertilizer demand function, labor demand function, animal power demand function, modern technology adoption function, and irrigation demand function is estimated using Three-Stage Least Squares (3SLS) procedure.

The set of explanatory variables incorporated in individual model varies from function to function. However, the following variables comprise the total set of explanatory variables. These are, family labor, hired labor, wage rate, animal power services and price, fertilizer quantity and price, pesticide cost, number of working members in the family, area under modern varieties, irrigated area, male and female workers, land ownership, farm size, amount of land rented-in, family size, dependency ratio, value of non-land capital assets, farmers' education level, non-agricultural income, agricultural credit, soil fertility index, and index of underdevelopment of infrastructure.

3.7.4 Methodology for Analyzing Distributional Impact of Modern Technology

The income effect of modern agricultural technology was estimated by using multiple regression technique. Crop production income, agricultural income, non-agricultural income as well as overall household income (farm family income) are regressed separately by the following explanatory variables. These are, land ownership, amount of land rented-in, value of non-farm capital assets, farmers' education level, number of working members in the family, technology index, index of underdevelopment of infrastructure and soil fertility index.

To examine distribution of income, Lorenz curve and Gini-coefficient of income and land is computed. To analyze the contribution of technological change on income inequality, gini-decomposition analysis is applied. Further, to analyze the impact of technological change on poverty, poverty line expenditure, head count index, poverty-gap ratio, Sen's poverty index, Kakwani's poverty index, and FGT (Foster-Greer-Thorbecke) distributionally sensitive index of poverty are estimated.

3.7.5 Methodology for Analyzing Environmental Impacts of Modern Technology

For analyzing the environmental impact of modern technology, two approaches were utilized. In the first approach, the farmers' responses on impact of modern agricultural technology on various components as well as their corresponding ranks in terms of intensity of impacts were identified. These informations were then standardized by the use of Likert Type Scale with ranks as weights.

$$IEE = \frac{I_1 r_1 + I_2 r_2 + ...I_n r_n}{N}, ...(3.7.5.1)$$

Where: IEE = environmental impact index

I_1 to I_n = individual impacts

r_1 to r_n = ranks of individual impacts used as weights
N = total number of cases

This analysis provided the level of awareness of the farmers about the impact of modern agricultural technology.

The second approach is the validation of the farmers' perception rankings on the basis of analyzing relevant material evidences that either support or refute these perceptions. The major thrust is in evaluating the soil fertility status of the study areas since there is a widespread belief that the diffusion of modern agricultural technology resulted in rapid depletion of soil fertility. Also, water quality is evaluated since chemical pollution, particularly arsenic pollution in the northern regions of the country raised worldwide concerns. Further, time trend analyses of the relevant indicators of various sectors at the regional-level is also conducted that are supposed to be affected with the diffusion of modern agricultural technology. The methodology utilized for soil and water quality evaluation is provided in the following section.

3.7.5.1 Methodology for Soil Fertility and Water Quality Evaluation

In order to identify a comprehensive information on the socio-economic and environmental impacts of modern agricultural technology, it would be inadequate if some important agronomic aspects were overlooked. Therefore, physical and chemical analyses of soil and irrigation water was conducted to evaluate the general fertility status of the soil and the inter-regional differences (if any) of the study areas.

The following soil parameters were specifically analysed:

1. Soil reaction (pH)
2. Available Nitrogen (N)
3. Available Phosphorus (P)
4. Available Potassium (K)
5. Available Sulphur (S)
6. Available Zinc (Zn)
7. Organic Matter Content (OM)
8. Cation Exchange Capacity (CEC)
9. Electric Conductivity (μS)
10. Textural Analysis (proportion of clay, sand, and silt)

For water quality analyses, samples of groundwater as well as surface water used for irrigation were collected. The specific analyses accomplished for the groundwater properties are:

1. Water reaction (pH)
2. Electric conductivity (μS)
3. Available Chlorine (Cl)
4. Available Iron (Fe).
5. Level of Arsenic concentration (As).

The specific analyses accomplished for the surface water properties are:

1. Water reaction (pH)
2. Electric conductivity (μS)
3. Available Nitrogen (N)
4. Available Phosphorus (P).

It should be mentioned that the soil test results are a measure of accessible nutrient contents in the soils and they do not provide indication on the quantity of nutrients required for a given level of output. As such, the soil test provides only an index of soil fertility status. Similar is the case with water quality status that is used to irrigate these agricultural lands.

3.7.5.2 Soil and Water Sampling

A total of 15 composite soil samples (5 composite samples from each region) of rice fields were randomly selected from within the total sampled households. In order to ensure the representativeness of the soil, sub-samples were collected from interior of the large patches of irrigated rice fields (about 100 to 250 ha) and three such sub-samples together form each composite sample. The soil samples were taken from recently transplanted rice fields of *Boro* season. Soil samples were taken at a vertical depth of plow layer (15-20 cm) by spade. Each plastic bag contained about 1 kg of soil. The crop/fertilizer use history for one year was labeled to the respective sample bags and send to the Soil Test Laboratory of Department of Soil Science, University of Dhaka, Bangladesh.

A total of 6 surface water samples (2 samples from each region) and 7 groundwater samples (2-3 samples from each region) from source were collected. Each water sample contained about 1 litre kept in plastic bottles. The choice of water samples was made in such a way that it directly corresponds with the soil samples collected for the study. In other words, water samples were taken from the source of irrigation for the lands from which soil samples were also collected.

In order to identify relationship among soil fertility and productivity of various crops, multivariate regression analyses was conducted.

3.7.5.3 Composite Index of Soil Fertility

To analyze soil fertility information, a series of weighted-index was constructed to summarize each of the soil test results. Finally, a composite weighted-index was constructed utilizing information from the individual indices. The basic format is as follows:

$$SFERT = \frac{SP_1 w_1 + SP_2 w_2 + ... + SP_n w_n}{N} \text{,......(3.7.2.3)}$$

where :SFERT = overall soil fertility
SP_1 to SP_n = response to each of soil quality parameters, i = 1, ... n

w_1 to w_n = weights, $i = 1, ...n$
N = total number of samples.

This composite index of soil fertility is incorporated as an independent explanatroy variable in all the relevant economic decision making analyses in this study.

CHAPTER IV

TECHNOLOGICAL CHANGE AND ITS IMPACTS ON REGIONAL VARIATION, AGGREGATE CROP PRODUCTION AND SUSTAINABILITY

Analysis of regional variation in agricultural development process is important for spatial as well as development policy perspective. Regional variations arise largely due to diverse agro-ecological factors as well as disparate access to technological innovation and infrastructural facilities among regions. As a result, the capacity for utilization of these inputs varies across regions. Moreover, study on regional variation help to identify policy biases (if any) and its consequences.

The major thrust of the agricultural development policies for the past four decades was in achieving self sufficiency in food production, particularly, foodgrain (rice and wheat) production. A number of factors influence decision to adopt modern agricultural technology. Spurred by the introduction and diffusion of 'Green Revolution' technology, it was hoped that such dream would come true. The foodgrain production grew at an estimated annual rate of about 3.25 percent during the period 1947/48 – 1993/94 while the population growth rate kept increasing at an estimated annual rate of 2.45 percent during the period 1949/50 – 1993/94. However, it is increasingly felt that in the later years the productivity from new technology is tapering off towards a saturation value which is a threat to sustainability of economic development in Bangladesh (Alauddin and Tisdell, 1991). Adoption of modern technology is dependent upon availability of land, irrigation facilities, fertilizers, infrastructure, human capital, etc. Also, it was widely accepted that there is a greater degree of complementarity in these sets of technologies: water control, biological (new seed varieties) and chemical (fertilizers) technologies. Moreover, since the 'Green Revolution' technology is modern input intensive, it subsequently increased dependency on imported inputs.

Therefore, in this chapter, the impact of technological change on regional variation is analyzed using cross-section regionwise data for three periods covering a span of 20 years (1972/73 – 1992/93). In addition, impacts of infrastructural, demographic and crop production efficiency factors on regional variation are also examined. Then weighted standard scores are constructed and used to delineate the regions in descending orders of development levels in order to identify homogenous agricultural regions that will facilitate in identifying sampling locations for the local level component of this study.

The impact of technological change on crop production is analyzed by estimating an aggregate crop production function with regionwise disaggregated data for 29 years (1960/61 – 1991/92). In addition, an estimate of long run output elasticities of conventional and non-conventional factor inputs as well as the returns to scale in crop production is presented. Finally, an attempt has been made to see to what extent growth rates in food production is likely to be sustained by applying logistic function and comparing it with the linear trend function on the data of foodgrain yield per net hectare for 47 years (1947/48 - 1993/94). Also, long term compound annual growth rates of food crops were estimated for the entire period by breaking the time into two segments, the pre-technological change period (1947/48 - 1967/68) and post-technological change period (1969/70 - 1993/94).

4.1 Technological Change and Regional Disparity

Over the past two decades, large number of studies were undertaken to analyze regional variation in development efforts in the Indian context using a variety of approaches (Pokhriyal and Naithani, 1996; Routray, 1993 and 1984; Sidhu, 1992; Goel and Haque, 1990; Shastri, 1988; Yadav and Minocha, 1987; Tewari and Singh, 1985; Suar, 1984; and Routray and Patnaik, 1981). Review of these studies reveals that the major trend in these analyses is in the use of principal component and/or factor analysis (Routray, 1993 and 1984; Sidhu, 1992; Shastri, 1988; Suar, 1984; and Routray and Patnaik, 1981). However, multiple regression techniques were also applied in some of these studies (Yadav and Minocha, 1987; Tewari and Singh, 1985; and Easter *et al.*, 1977).

Another feature that emerges from the review is that there exists a strong tendency to add a large number of variables in these studies to explain regional variations. For instance, Shastri (1988) used 32 indicators to identify regional disparities in economic development of Rajasthan on a cross-section data of two periods, 1961 and 1984 respectively. Goel and Haque (1990), applying cluster analysis, used a total of 39 indicators to identify regional variations of Indian States. Routray (1984) utilized 21 indicators to identify levels of development vis-a-vis development potential for Boudh-Khandmals district of Orissa, India.

Pokhriyal and Naithani (1996) claimed that factor analysis assumes equal weights for each of the indicators used and as such significant role of individual indicators in explaining the regional variations can not be obtained from such analysis. Also, most of the countries do not systematically report a wide range of indicators at much disaggregated level suitable for such analysis. Therefore, in the present study, an attempt is made to identify the significance of technological change as well as other explanatory indicators and eliminate the less important ones in explaining regional variation in agricultural development levels in Bangladesh. As such, multiple regression technique using Stepwise Forward Regression procedure is applied, which selects significant variables and discards the insignificant ones from a complete model. Also, by using this approach, the problem of assuming equal weights for each of the indicators, as done in the case of factor analyses is eliminated. Next, using the information from the regression results, a composite index of agricultural development is constructed which is then used to delineate the regions into five categories of development levels. The theoretical basis of the methodology including the assumptions for the model is discussed below.

4.1.1 Specification of the Model

The theoretical framework and the methodology are detailed in Section 3.3 of Chapter III. The basic assumption of the model is that there exists a linear relationship among the explained indicator and the set of explanatory indicators (Pokhriyal and Naithani, 1996). In the present study the model is specified including indicators representing technological, infrastructural, agro-ecological, crop production efficiency, demographic, and human capital factors. The complete specification is given by:

$$GVFOOD = \beta_0 + \beta_1 MVYLD + \beta_2 LVYLD + \beta_3 WHTYLD + \beta_4 FERT + \beta_5 PEST + \beta_6 PMVAR + \beta_7 PIRRIG + \beta_8 CI + \beta_9 SEED + \beta_{10} RAIN + \beta_{11} DENS + \beta_{12} HCAP + \beta_{13} CREDIT + \beta_{14} ROAD + \beta_{15} RDQLTY + \varepsilon \quad (4.1.1)$$

where, GVFOOD = vector of explained indicator.
MVYLD... RDQLTY = vectors of explanatory indicators
β_0 .... β_{15} = parameters to be estimated.
ε = vector of error term.

The explanatory notes for variables are presented in Table 4.1.

4.1.2 The Data

In the present study, regional variation in gross value of foodgrain production per ha of gross cropped area (GVFOOD)[19] is analyzed for three specific time periods in order to identify the inter-regional disparities within each time periods as well as inter-period disparity for each regions of Bangladesh.

Period 1 (1973-75) refers to the period just following the independence of Bangladesh which is also considered as the beginning of the take-off stage for technological breakthrough in agricultural development through the diffusion of modern varieties of rice and wheat. Period 2 (1981-83) is the stage at which the first phase of the thrust in modern technology diffusion in agriculture started to pay off. Period 3 (1991-93) is considered as one of the most normal years in terms of agricultural production and achievement towards self-sufficiency, since the devastating floods of 1987 and 1988. Also, all these periods incorporate exact count of population coming from three population censuses, Population Census of 1974 (BBS, 1974), Population Census of 1981 (BBS, 1981a) and Population Census of 1991 (BBS, 1991a).

The triennium average of years 1972/73, 1973/74, and 1974/75 centered at the year ending 1973/74 is designated as Period 1 (1973-75). Similarly, triennium average of years 1980/81, 1981/82 and 1982/83 centered at the year ending 1981/82 is designated as Period 2 (1981-83), and triennium averages of years 1990/91, 1991/92, and 1992/93 centered at the year ending 1991/92 is designated as Period 3 (1991-93). This is done mainly to tackle the year to year variability in the selected indicators. However, it should be noted that, a single year is used for cases where triennium averages for certain indicators could not be computed or such computation would reduce the validity of the data, for instance, use of population census data for computing population density and literacy.

Table 4.1. List of indicators used for identifying regional disparities in agricultural development of Bangladesh, 1973 – 93.

	Indicators	Variable	Data period

[19]The study concentrates only on foodgrain production which is used as a proxy for agricultural development because rice and wheat alone accounts for about 80 percent of the gross cropped area. Moreover, the major technological breakthrough and policy thrusts for the past four decades focussed on diffusion of modern varieties of rice and wheat only.

		Name	Period 1	Period 2	Period 3
1	Weighted average yield per ha of all modern varieties of rice (ton/ha)	MVYLD	1973-75 average	1981-83 average	1991-93 average
2	Weighted average yield per ha of all local varieties of rice (ton/ha)	LVYLD	1973-75 average	1981-83 average	1991-93 average
3	Weighted average yield per ha of all varieties of wheat (ton/ha)	WHTYLD	1973-75 average	1981-83 average	1991-93 average
4	Fertilizer used per ha of gross cropped area (kg/ha)	FERT	1973-75 average	1981-83 average	1989/90[20] single
5	Pesticide used per ha of gross cropped area (Tk/ha)	PEST	not available	1981-83 average	1987-89 average
6	Area of all modern rice variety and wheat as percent of gross cropped area (%)	PMVAR	1973-75 average	1981-83 average	1991-93 average
7	Irrigated area (all types) as percent of gross cropped area (%)	PIRRIG	1973-75 average	1981-83 average	1991-93 average
8	Cropping Intensity (%)	CI	1973-75 average	1981-83 average	1991-93 average
9	Improved seed of rice and wheat distributed per ha of gross cropped area (kg/ha)	SEED	1973-75 average	1981-83 average	1991-93 average
10	Actual total annual rainfall (mm)	RAIN	1973-75 average	1981-83 average	1990-92 average
11	Population density per ha of gross cropped area (persons/ha)	DENS	1974 census	1981 census	1991 census
12	Percent of literate population (%)	HCAP	1974 census	1981 census	1991 census
13	Agricultural credit disbursed per ha of gross cropped area (‘000 Tk/ha)	CREDIT	1973-75 average	1981-83 average	1991-93 average
14	Road density per sq km of land area (km/km^2)	ROAD	1965[21] single	1984 single	1992 single
15	Ratio of unpaved road to paved road (unit less)	RDQLTY	Not available	1984 single	1992 single
16	Gross value of all varieties of rice and wheat per ha of gross cropped area (‘000 Tk/ha)	GVFOOD	1973-75 average	1981-83 average	1991-93 average

Source: BBS (Various issues), Khalil (1991), Verma (1974) and Hamid (1991).

The set of explanatory indicators representing crop production efficiency (1 through 5), technological (6 through 9), agro-ecological (10), demographic (11), human capital (12), and infrastructural (13 through 15) factors is presented in Table 4.1. Gross value of foodgrain produced per ha of gross cropped area (GVFOOD) is used as the explained indicator. The basic data for the study is mainly collected from various issues of the Statistical Yearbook of Bangladesh (BBS, 1979; 1980; 1981; 1992; and 1994), Yearbook of Agricultural Statistics of Bangladesh (BBS, 1978; 1986; and 1992a), and Hamid (1991). Appendix Table A4.1 presents

[20] Data is computed from Khalil (1991).
[21] Data is adapted from Verma (1974).

the regions and the composition of the individual districts in each of these regions[22]. Period 1 includes a total of 19 regions, as Jamalpur was included in Mymensingh district. Period 2 and 3, however, includes a total of 20 regions following the separation of Jamalpur in 1978.

The mean values and standard deviation of the selected indicators for the three time periods are presented in Appendix Table A4.2. At current prices, though it seems that the gross value per ha of foodgrain production increased by a remarkable 720%, but at real prices (i.e., at 1972/73 constant prices) the actual increase is only a meagre 18% in about two decades revealing the stagnancy in the agricultural sector. Further, it is clear from Appendix Table A4.2 that despite increase in the use of fertilizers, area under modern varieties, irrigation, and pesticides, the yield level of modern varieties of rice showed a decline, a finding consistent with the report of *Bangladesh Agricultural Sector Review* (BASR, 1989). However, it is encouraging to note the increase in yield levels of local varieties of rice, which could be due to use of modern inputs, such as fertilizers and irrigation that resulted in increased production. The yield levels of wheat though increased during Period 2, but recorded a decline in Period 3. There has been a marked increase in road communication, an indicator apparently reflecting major infrastructural improvement and increased access to secondary and tertiary markets for agricultural produces.

4.1.3 Determinants of Regional Variation: A Multivariate Analysis

Applying the Stepwise Forward Regression estimation procedure to Eq (4.1.1), we can identify the significant indicators on the basis of partial F-test to examine the significance of the marginal contribution of an explanatory indicator on the value of adjusted coefficient of multiple determination, R^2.

Table 4.2 presents the result of the regression analysis wherein the set of explanatory indicators listed in Table 4.1 was regressed against the single explained indicator GVFOOD using the Stepwise Forward Regression procedure[23]. The complete model for Period 1 consists of 13 explanatory indicators as information on the remaining three indicators are not available. Period 2 and 3 utilizes all of the 15 explanatory indicators.

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[22] It should be noted that major changes occurred in classifying total number of adiministrative regions since the early 1970s. Prior to the independence of Bangladesh in 1971, the total number of administrative regions/ districts was 17. After 1972, the total number of regions/districts was increased to 19. Currently, the number of districts stands at 64 while, until today, major time-series data are usually published for only 20 regions or former/greater districts.

[23] SPSS for Windows Version 7.0 software was used for the analysis.

Table 4.2 Determinants of regional variation: A multivariate analysis.

Explanatory indicators	Period 1 (1973 – 75)	Period 2 (1981 – 83)	Period 3 (1991 – 93)
Intercept	-0.012	0.515	-4.627[a]
PMVAR	1.882[a]	3.496[a]	6.762[a]
LVYLD	0.829[b]	1.921[a]	5.042[a]
RAIN	-	0.003[b]	-
RDQLTY	-	-	0.360[a]
PIRRIG	-	-	5.849[a]
ROAD	-	-	26.279[a]
DENS	-	-	-0.109[b]
Adjusted R^2	0.76	0.80	0.92
F – ratio	29.28[a]	25.90[a]	37.66[a]
Degree of freedom	2, 16	3, 16	6, 13

Note: [a] = significant at 1 percent level ($p<0.01$); [b] = significant at 5 percent level ($p<0.05$).
- = not selected in the regression.
Source: Computed.

The technology indicator (PMVAR) is the single most important variable that enters first in the models for all three periods emphasizing its crucial role in explaining regional variation in foodgrain production (Table 4.2). The coefficient is significantly ($p<0.01$) postitively related to foodgrain output. The second most important variable is the yield levels of local varieties of rice (LVYLD), which enters second in all three regressions. The yield levels of modern varieties does not enter the regression probably because the yield levels are more or less similar across regions and its effect is realized by the technology indicator (PMVAR). However, since local rice variety yield vary largely across regions, it exerts profound influence on regional variation in foodgrain production.

Apart from technological and crop productivity factors, demographic as well as infrastructural factors (DENS, ROAD, RDQLTY) also influence foodgrain production. The irrigation factor was also found to be an important in explaining regional variation. For Period 2, the naturally occurring annual rainfall (RAIN) and for Period 3 the percentage of area under irrigation (PIRRIG) was identified as important factors. BASR (1989) as well as Alauddin and Tisdell (1991) attributed varied access to irrigation as the major reason for regional variation in crop production growth.

The infrastructural variables were also found to be significant in explaining regional variation, as indicated by the road density (ROAD) as well as the ratio of unpaved to paved road (RDQLTY) reflecting quality of the road for Period 3 (Table 4.2). It was increasingly recognized that infrastructure play a dominant role in agricultural growth (Mann, 1992; Quasem, 1992; Ahmed and Donovan, 1992; Ahmed and Hossain, 1990; Evenson, 1986; and Easter *et al.*, 1977). All these findings are consistent with a priori expectation.

Increased population pressure (DENS) negatively influence the foodgrain production, a finding consistent with a priori expectation (Table 4.2). It should be noted that indicator representing popoulation pressure (DENS) is selected only at Period 3 when the population density is highest. One can take this finding as an indication of surpassing the threshold level of carrying capacity of the agricultural land, thereby, exerting a negative influence on foodgrain production.

As a whole, the explanatory power of the selected indicators are very high, as indicated by the values of Adjusted R^2: 0.76, 0.80 and 0.92 for Period 1, Period 2, and Period 3, respectively. The sequence with which indicators enter in subsequent iterations of the regression function is presented in Appendix Table A4.3.

The correlation between the explained indicator and the indicators selected from the regression for each period is presented in Appendix Table A4.4. For all three periods, the technology indicators (PMVAR and PIRRIG) and crop productivity indicator (LVYLD), were found to be significantly ($p<0.01$ and $p<0.05$) positively correlated to foodgrain output (GVFOOD) thereby reinforcing the confidence in the analysis.

4.1.4 Construction of the Weighted Standard Score

The next step is to utilize the information of the regression results and construct a composite index of weighted standard scores. These scores are then used to delineate the regions in descending orders of agricultural development levels. Composite weighted standard scores reflecting agricultural development levels for each of the periods were constructed applying Equation (3.6.1.3) on information provided by Table 4.2. The regions were then ranked in descending orders of development for each period. Threshold for the delineation of the regions falling into five levels of agricultural development, namely 'very high', 'high', 'medium', 'low', and 'very low' level is done using Equation (3.6.1.6) and varying the value of m[24] = 1 and 2.

The overall level of agricultural development index is then constructed by using the averages of the weighted standard scores of the three periods for each individual region and then finally ranked in descending order of development. The result of this exercise is presented in Table 4.3 and Figure 4.1, respectively.

4.1.5 Results

The last two columns of Table 4.3 provide the final outcome of this exercise. It provides the ranking of regions according to descending levels of development, which is based on the analysis of their relative standing in three selected periods, Period 1 (1973-75), Period 2 (1981-83) and Period 3 (1991-93), respectively. The result is further summarized in Figure 4.1. Table 4.3 reveals that Chittagong was ranked top for Period 1 and 2 and ranked third in Period 3. Therefore, as a whole it was ranked top with highest mean weighted standard score. In fact, the gross value of foodgrain production, the yield levels of local rice varieties, area

[24] Prior to using Equation (3.6.1.6), the weighted standard scores are adjusted using Equation (3.6.1.7). Regions with the value of adjusted standard score lying beyond two standard deviations above mean score is classified as 'very high', between one and two standard deviation above mean as 'high', within one standard deviation above mean as 'medium', within one standard deviation below mean as 'low', and beyond one standard deviation below mean as 'very low', respectively.

under modern varieties and area under irrigation for Chittagong region was highest in all three periods. All these factors together placed Chittagong at the 'very high' level of agricultural development. Dey and Evenson (1991), Hossain (1989), Ahmed and Hossain (1990), and Hossain *et al.* (1990) also identified Chittagong as the region with highest levels of modern variety diffusion and designated as the leading region.

Table 4.3 Grouping of regions into descending order of agricultural development.

Region	Weighted standard score						Final index (average scores of three periods)	
	Period 1 (1973-75)		Period 2 (1981-83)		Period 3 (1991-93)			
	Z-score	Rank/ Level	Z-score	Rank/ Level	Z-score	Rank/ Level	Z-score	Rank/ Level
Chittagong	4.40	1 VH	3.80	1 VH	1.98	3 H	3.39	1 VH
Comilla	2.06	2 M	2.11	2 H	2.24	2 H	2.14	2 H
Bogra	1.91	4 M	1.65	5 M	1.91	4 M	1.82	3 M
Dhaka	1.16	11 L	1.41	8 M	2.73	1 VH	1.77	4 M
Mymensingh	1.71	5 M	1.77	4 M	1.27	8 M	1.58	5 M
Noakhali	1.57	8 M	1.37	9 M	1.62	6 M	1.52	6 M
Sylhet	1.93	3 M	1.20	10 L	1.17	12 L	1.43	7 M
Dinajpur	1.61	7 M	1.42	7 M	1.09	14 L	1.37	8 M
Jamalpur	1.71	5 M	1.12	12 L	1.14	13 L	1.32	9 M
Barisal	1.21	10 L	1.14	11 L	1.21	10 L	1.19	10 L
Ch. Hill Tract	1.67	6 M	1.80	3 M	0.09	19 VL	1.18	11 L
Rangpur	1.38	9 M	1.44	6 M	0.68	17 L	1.17	12 L
Kushtia	0.78	15 L	0.96	15 L	1.66	5 M	1.13	13 L
Tangail	0.86	12 L	1.04	13 L	1.24	9 L	1.05	14 L
Rajshahi	0.85	13 L	1.03	14 L	1.20	11 L	1.03	15 L
Pabna	0.35	18 VL	0.82	16 L	1.38	7 M	0.85	16 L
Jessore	0.61	17 L	0.65	18 L	0.95	15 L	0.74	17 L
Patuakhali	0.76	16 L	0.76	17 L	0.61	18 L	0.70	18 L
Khulna	0.78	14 L	0.48	19 VL	0.04	20 VL	0.43	19 VL
Faridpur	0.05	19 VL	0.03	20 VL	0.81	16 L	0.30	20 VL
Mean score Standard dev.	1.37 (0.91)		1.30 (0.76)		1.25 (0.66)		1.31 (0.67)	
Adjustment factor	1.35		1.30		1.25			

Note: VH = very high, H = high, M = medium, L = low, and VL = very low.
Source: Computed.

It is worth noting from this analysis that only high gross value of foodgrain production is not necessarily the prime determinant for particular region to be classified as having 'very high' or 'high' level of agricultural development. For example, Dhaka in Period 3 is ranked top though its gross value of foodgrain production is not the highest. However, the modern variety rice yield of Dhaka is highest and percentage of area under modern varieties is also high coupled with highest road density. Characteristics of all these indicators together placed Dhaka at the top rank in Period 3.

Comilla region consistently held the second rank in all the three periods and therefore was placed in rank 2 with second highest mean weighted standard score. The region is characterized by high values for foodgrain output, local rice yield, area under modern varieties and area under irrigation. These factors together placed Comilla at the 'high' level of agricultural development. It should be noted that Comilla is commonly considered as the birthplace of modern technology diffusion as well as other well-known agricultural development initiatives. However, it could not reach the peak level due to high population density and relatively lower farm size. The average literacy in this region is also high leading to higher level of economic diversification since deriving total household income from agriculture is very competitive and often inadequate. This might be one important reason for Comilla region to consistently hold the second position over the 20-year period under consideration.

Seven regions, Bogra through Jamalpur with ranks 3 through 9, were categorized into 'medium' level of agricultural development. The inter-period standing of each of these regions has been variable. However, as a whole, these seven regions are grouped in a single category with Bogra reaching the upper limit and Jamalpur the lower limit. For each individual period, these regions have moderately varying values for foodgrain output, local rice variety yield, area under modern varieties and area under irrigation. Three regions, Bogra, Mymensingh and Noakhali, consistently maintained the 'medium' level throughout while others experienced a decline in relative ranks, except Jamalpur. This is consistent with the findings of *Bangladesh Agricultural Sector Review* (BASR, 1989) which identified Mymensingh, Bogra and Noakhali among the high crop growth regions (above 2.86 percent growth rate) during 1981-87 period and are not slowing down lately in terms of foodgrain production. BASR (1989), however, stressed mainly on differential irrigation coverage as the prime reason for having regional variation as it leads to rapid shifts in varieties from local to modern, increase in fertilizer use as well as change in crop composition, since irrigation induces an extra rice crop under *Boro* season.

Next nine regions, Barisal through Patuakhali with ranks from 10 to 18, were grouped into 'low' level of agricultural development. These regions are characterzed by low values for foodgrain output, local rice yield, area under modern varieties and area under irrigation. Most of the regions under this category remained stagnant in all the three consecutive periods. Regions such as Barisal, Tangail, Rajshahi, Jessore, and Patuakhali maintained the 'low' level throughout. However, the drastic decline in relative rank in this category was for Chittagong Hill Tracts region which ranked 19th in Period 3, declining from from rank 6 in Period 1 and rank 3 in Period 2. Rangpur region also revealed similar decline.

The remaining two regions, Khulna and Faridpur, were grouped into 'very low' levels of agricultural development. These two regions are characterized by lowest values for foodgrain output, local rice yield, area under modern varieties and area under irrigation. The decline is relatively sharp for Khulna region, declining from 14th in Period 1 to 19th in Period 2 and last (20th) in Period 3.

The phenomenon behind this stagnation for regions that are classified into 'low' or 'very low' levels for all three periods becomes clear once the agro-ecological and physical constraints of these regions are highlighted. For instance, Rajshahi region is the hardest hit region following the drying of the main river Padma (Ganges) and onset of the dessertification process largely owing to the building of Farakka barrage at the upstream of Padma river. Patuakhali is a low-lying riverine region with numerous *char* (delta) lands, which yields one rice crop only. Faridpur lies at the confluence of Jamuna and Meghna rivers and often faces severe river erosion and flooding. Khulna is a saline area wherein most of the prime agricultural lands are converted into shrimp culture area, thereby, destroying the productive capacity of the lands.

In order to verify whether regions grouped into various development levels differs from each other, variance analysis (ANOVA) across regions was conducted. Results confirm that significant ($p<0.05$) differences exist among regions grouped into five different levels of development (Table 4.4). This finding, therefore, nullify the first hypothesis (# H1) that agricultural development levels across regions are uniform in Bangladesh. Rather, it indicates that significant differences exist in development levels that are explained to a large extent by technological change (diffusion of modern rice and wheat varieties and level of irrigation development), crop productivity (yield levels of local rice varieties), rainfall, level of infrastructural development, and population density.

Table 4.4 Differences in agricultural development levels among regions.

Development levels	Number of regions corresponding to each level			
	Period 1	Period 2	Period 3	All period
Very high	1^{A}	1^{A}	1^{A}	1^{A}
High	-	1^{B}	2^{B}	1^{B}
Medium	9^{B}	7^{C}	5^{C}	7^{C}
Low	8^{C}	9^{D}	10^{D}	9^{D}
Very low	2^{D}	2^{E}	2^{E}	2^{E}
F-ratio for difference across levels	25.783^{a}	25.224^{a}	3.643^{b}	57.297^{a}

Note: F-test shows the difference across levels based on weighted standard scores of individual region.

Same uppercase letters in the superscript represents similarity in weighted standard scores of individual region based on LSD at 5 percent level of significance ($p<0.05$).

^{a} = significant at 1 percent level ($p<0.01$); ^{b} = significant at 5 percent level ($p<0.05$).

Source: Computed.

4.2 Technological Change and Aggregate Crop Production

A number of factors influence decision to adopt modern agricultural technology. In order to identify the influence of various factors in crop production, an aggregate production function of the Cobb-Douglas form is estimated using regionwise time series data for 29 years (1960/61 - 1991/92). A total of 19 regions excluding only the Chittagong Hill Tracts are covered in this regionwise analysis (for details please see Table A4.1 in the appendix). The following aggregate production function model is used for the estimation:

$$\ln CROP = \beta_0 + \beta_1 \ln LAND + \beta_2 \ln LABOR + \beta_3 \ln ANIMAL + \beta_4 \ln FERT + \gamma_1 HCAP + \gamma_2 ROAD + \gamma_3 PMVAR + \gamma_4 PIRRIG + \varepsilon \quad (4.2.1)$$

where

CROP	= value of rice (all varieties), wheat, jute, sugarcane, potato, pulses, oilseeds at 1984/85 prices of each region ('000 taka)
LAND	= area under all crops included in output (CROP) is considered as the land area under cultivation (ha)
LABOR	= agricultural labor force of the region (persons)
ANIMAL	= total draft animals of the region (number)
FERT	= total fertilizer (urea, phosphate, potash, and gypsum) use in the region weighted at 1984/85 prices (taka)
PMVAR	= area of all modern rice variety and wheat as percent of gross cropped area (%)
PIRRIG	= irrigated area (all types) as percent of gross cropped area (%)
ROAD	= road density per sq km of land area (km/km^2), a proxy measure of infrastructure
HCAP	= percent of literate population above 10 years (%), a proxy measure for human capital
β_i and γ_i'	= parameters to be estimated
ε	= the error term

4.2.1 The Data

The data used for this analysis is adapted from Deb (1995). The aggregate crop output includes all varieties of rice (Aus, Aman, and Boro), wheat, jute, sugarcane, potato, pulses, and oilseeds for each region. The output (CROP) is measured in values estimated at constant 1984/85 prices. The unskilled labor variable (LABOR) is constructed from census data using linear trend extrapolation model. The total area (LAND) in hectares under all crops included in output is considered as the land area under cultivation. The number of livestock (ANIMAL) is also estimated using linear trend extrapolation from livestock census data. The fertilizer data (FERT) is the total amount of fertilizers (urea, phosphate, potash, and gypsum) weighted by constant 1984/85 prices to convert it into value form. The average years of schooling of the rural male population above 10 years of age is used as a proxy for human capital (HCAP). The technological index (PMVAR) is measured as the proportion of total cultivable area under modern varieties of all rice and wheat crops. The irrigated area as a proportion of total cropped area is used as irrigation index (PIRRIG). The infrastructure variable is proxied by a measure of kilometers of paved road per unit cropped area (For details see Deb, 1995).

4.2.2 Estimation of theAggregate Production Function

Three alternative models were tried by varying the variable representing technology. Model 1 uses the irrigation index as the proxy for technology variable. Model 2 uses the proportion of area under modern varieties of rice and wheat as the technology variable. Since both the irrigation index and area under modern varieties are complements, the multiplication of irrigation index and area under modern varieties (PIRRIG*PMVAR) is used in Model 3. This would break the multicollinearity between these two variables to a large extent.

Table 4.5 presents the results of the estimation. The fit is remarkable for all the three specifications as indicated by the value of adjusted R^2 (0.91 in all three models) and significance of the variables (for details see Appendix Table A4.5). The coefficients are corrected for autocorrelated disturbances, which were found to be significant (p<0.01) in all three models. All the conventional inputs, land, labor, fertilizers, and animal power services, are significantly (p<0.01 and p<0.05) positively related to output as expected. The influence of land is highest in increasing crop production as indicated by the large coefficient in all the models. Animal power services also contribute largely to crop production followed by labor and fertilizers, respectively.

Table 4.5 Estimates of Aggregate Crop Output of Bangladesh, 1960/61 – 1991/92.

Variables	Model 1	Model 2	Model 3
	Estimated coefficient	Estimated coefficient	Estimated coefficient
Constant	7.565[a]	7.835[a]	7.615[a]
lnLAND	0.827[a]	0.744[a]	0.785[a]
lnLABOR	0.085[b]	0.113[a]	0.099[a]
lnANIMAL	0.132[a]	0.160[a]	0.134[a]
lnFERT	0.037[a]	0.051[a]	0.061[a]
HCAP	0.034[b]	-0.021	0.002
ROAD	0.738[a]	0.417[a]	0.471[a]
PIRRIG	0.748[a]	-	-
PMVAR	-	0.469[a]	-
PIRRIG*PMVAR	-	-	1.169[a]
Adjusted R^2	0.91	0.91	0.91
$F_{(7, 456)}$	665.978[a]	654.402[a]	664.505[a]
D.W. Statistic	2.05	2.06	2.05

Note: The estimates are corrected for first degree autocorrelated disturbances using Prais-Winsten method. D.W. Statistics is of the transformed residuals.
[a] = significant at 1 percent level (p<0.01); [b] = significant at 5 percent level (p<0.05).
Source: Computed from data of Deb (1995).

The technology variable is significant (p<0.01) in all the models irrespective of specification and the large coefficient indicates that technological change is a major factor in increasing aggregate crop production. The infrastructure variable is significantly (p<0.01) positively related to aggregate crop output in all the models indicating its importance in crop production. The human capital variable has mixed signs. It is significantly (p<0.05) positively related to aggregate crop output in Model 1 while it is negative in Model 2 and weakly positive in Model 3. However, precise inference can be drawn from the elasticities derived from the aggregate production function.

As the specification of the model is of Cobb-Douglas form, the coefficients of the conventional factor inputs are the output elasticities and can be read directly. However, since the non-conventional factor inputs, HCAP, ROAD, PIRRIG, and PMVAR are expressed in proportions the coefficients cannot directly reveal the elasticities. Therefore, the output elasticities of these inputs are computed at the mean levels of these variables. The output elasticities and the measure of returns to scale of crop production are provided in Table 4.6.

Table 4.6 Ouput elasticities and returns to scale in crop production in Bangladesh, 1960/61 – 1991/92.

Variable	Output elasticities		
	Model 1	Model 2	Model 3
Land	0.827	0.744	0.785
Labor	0.085	0.113	0.099
Animal power	0.132	0.160	0.134
Fertilizers	0.037	0.051	0.061
Human capital	0.069	-0.042	0.005
Road infrastructure	0.096	0.054	0.061
Irrigation index	0.087	-	-
Technology index	-	0.089	-
Irrigation * Technology	-	-	0.046
Returns to scale (conventional inputs)	1.081	1.068	1.079
Returns to scale (all inputs)	1.333	1.169	1.191

Source: Computed from data of Deb (1995).

The elasticity values reveal that land is the major factor in crop production followed by animal power services, labor, and fertilizers, respectively. Technological change as well as infrastructure development also has important impact on aggregate crop production. This finding is consistent with the results from the analyses of regional variation in Section 4.1.

The estimate of returns to scale using conventional inputs reveals that 'constant returns to scale (1.08 ≈ 1.00)' prevails in crop sector in Bangladesh. When non-conventional factors are incorporated in the estimation, it can be decisively stated that 'increasing returns to scale (1.17 > 1.00)' prevails in crop production. Deb (1995) also provided similar conclusion. This finding, therefore, provides the hope that crop production can be sustained in future by increasing input use intensity as the output response would increase by a constant or increased proportion. However, it should be borne in mind that such analyses do not incorporate the issue of environmental compatibility of this technological breakthrough in agriculture and nor does it indicate its impact on the environment which is a major concern of this study.

4.3 Technological Change and Sustainability of Food Production

It was already mentioned earlier that the major thrust of the agricultural development policies for the past four decades has been in achieving self sufficiency in food production, particularly, foodgrain production. The target has been mainly to keep up food production at par with population growth. However, the widespread observation on slowing down of modern variety yield levels (BASR, 1989; and Yano, 1986) raised concern over the sustainability of food production through technological progress. The estimated annual compound growth rates of yield levels of local and modern varieties of rice, wheat and potato for the study regions as well as Bangladesh for the 47-year period (1947/48 - 1993/94) is presented in Table 4.7. Three sets of average annual compound growth rate are estimated: the pre-technological change period (1947/48 – 1967/68), the post-technological change period (1969/70 – 1993/94), and the total period (1947/48 – 1993/94). It is alarming to note that though the productivity growth rate of all rice varieties is higher in the post-technological change period, the productivity growth rates of modern rice varieties is negative. The modern rice productivity declined from 3.6 mt/ha in 1968/69 to 2.4 mt/ha in 1993/94. This raises serious doubt on sustaining the foodgrain production in future. The reason for increase in the productivity growth of all rice varieties is due to shift in varieties from local to modern rice. Until today, the absolute yield level of modern rice variety is about twice the yield level of local rice, which offset the depressing effect of decline in modern rice productivity. The productivity of local rice variety increased slightly from 0.9 mt/ha in 1947/48 to 1.2 mt/ha in 1993/94. This phenomenon though results in overall gains in foodgrain productivity it casts illusion on the sustainability of food production in the future.

The productivity of modern varieties is declining continuously despite dramatic increases in input usage, such as, fertilizers, pesticides and irrigation which further reinforces the notion that soil fertility is on the decline (this issue dealt in detail in Chapter IX). It is encouraging to note the high productivity growth of wheat in the post-technological change period which further assisted in keeping the food production increasing. The productivity of wheat increased sharply due to total shift from local to modern varieties. The yield level of wheat increased three-folds from 0.6 mt/ha in 1947/48 to 1.8 mt/ha in 1993/94.

The productivity of potato also increased about two-folds from 5.1 mt/ha in 1955/56 to 11.0 mt/ha in 1993/94. However, the decline in the productivty growth rates of potatoes during the post-technological change period reveals that the ceiling productivity level for this crop have been achieved and it became stagnant indicating probable limitation in seeking crop diversification as a solution to food deficit. The scenario mentioned above shows similar trends for all the study regions as well as the country as a whole (Table 4.7). Dey and Evenson (1991) also noted that Bangladesh enjoyed major gains in yield performance in wheat and potato over the past four decades.

Table 4.7 Average annual compound growth rate in yield per gross hectare (mton/ha) of major food crops in the study regions for the period, 1947/48 – 1993/94.

Crops	Pre-technological change period (1947/48 – 1967/68)		Post-technological change period (1968/69 – 1993/94)		Total period (1947/48 – 1993/94)	
	Growth rate (%)	Adj. R^2	Growth rate (%)	Adj. R^2	Growth rate (%)	Adj. R^2
Jamalpur region						
All rice	1.08[b]	0.26	1.60[a]	0.41	1.54[a]	0.73
Local rice	1.08[b]	0.26	0.04	0.01	0.71[a]	0.31
Modern rice	-	-	-1.06[a]	0.34	-1.06[a]	0.34
Wheat	0.27	0.01	3.56[a]	0.33	3.52[a]	0.68
Potato	1.84	0.12	3.06[a]	0.81	1.99[a]	0.66
Jessore region						
All rice	1.07[a]	0.39	3.22[a]	0.84	1.38[a]	0.61
Local rice	1.07[a]	0.39	0.68[a]	0.51	0.72[b]	0.11
Modern rice	-	-	-1.17[a]	0.36	-1.17[a]	0.36
Wheat	1.28[a]	0.35	3.90[a]	0.57	3.59[a]	0.82
Potato	5.06[a]	0.56	2.43[a]	0.56	2.24[a]	0.67
Comilla region						
All rice	2.21[a]	0.56	1.18[a]	0.71	1.75[a]	0.81
Local rice	2.21[a]	0.56	0.67[c]	0.14	0.61[a]	0.26
Modern rice	-	-	-0.67[c]	0.13	-0.67[c]	0.31
Wheat	2.47[a]	0.38	3.46[a]	0.36	3.09[a]	0.83
Potato	4.49[a]	0.64	2.61[a]	0.75	3.39[a]	0.89
Bangladesh						
All rice	1.36[a]	0.56	2.05[a]	0.92	1.45[a]	0.89
Local rice	1.36[a]	0.56	0.71[a]	0.41	0.82[a]	0.44
Modern rice	-	-	-1.16[a]	0.40	-1.16[a]	0.40
Wheat	1.67[a]	0.31	3.63[a]	0.57	3.58[a]	0.84
Potato	3.87[a]	0.77	0.61[a]	0.38	1.26[a]	068

Note: Growth rates are estimated using semi-log trend function $\ln Y = \alpha + \beta t$ where t is time.

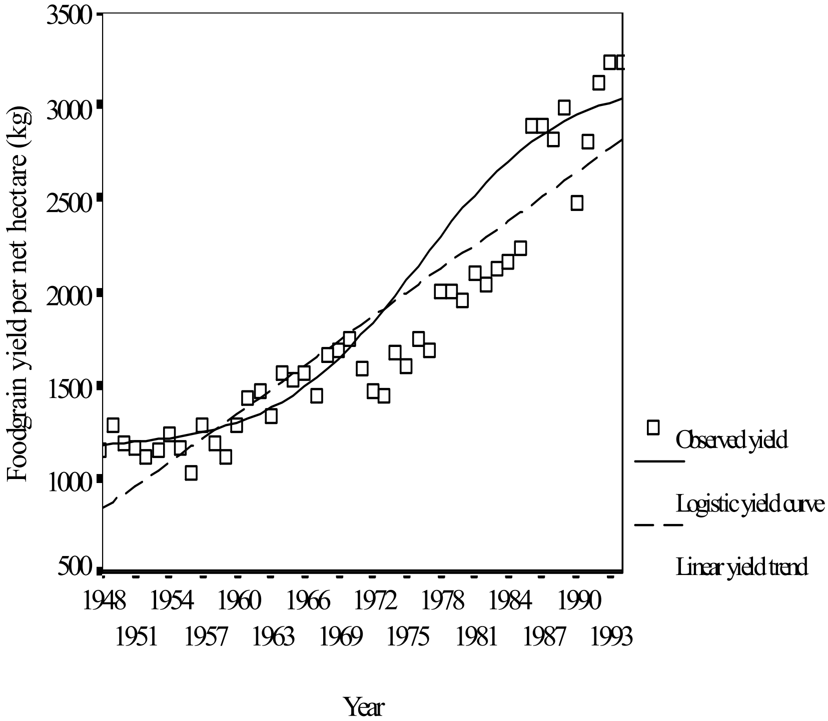
Data for local rice varieties and wheat is from 1947/48, for modern rice varieties from 1968/69, and for potato is from 1955/56, respectively.

a = significant at 1 percent level ($p<0.01$); **b** = significant at 5 percent level ($p<0.05$); **c** = significant at 10 percent level ($p<0.10$).

Source: Computed from Hamid (1991, 1993) and BBS (various issues).

Though it is clear from the aforementioned analyses that there is a potential threat to sustain future food production by diffusing modern rice technology alone, a further analysis on the issue of sustainability is presented in Figure 4.2.

Fig.4.2 Trends in foodgrain yield per hectare of net cropped area in Bangladesh, 1947/48 - 1993/94.



The fitted equations are as follows:

Linear function: FOODYLD = $785.520 + 43.057\ T$ (4.3.1)

($R^2 = 0.846$, t-ratio = 15.703^{a})

Logistic function: FOODYLD $= 1004.6 + (1185.96) / (1 + e^{-(-4.0500 + 0.1557T)})$ (4.3.2)

($R^2 = 0.970$, t-ratio = 37.987^{a})

The logistic function analysis reveals that foodgrain productivity is reaching a ceiling level of about 2,200 kg per net hectare of land area. This estimate is quite close to 2,300 kg per net hectare reported by Alauddin and Tisdell (1991) using a 37-year period data (1947/48 - 1983/84). An addition of another 10 years on the time-series resulted in a decline in productivity of 100 kg per net hectare of land, which further enforces the fact that soil fertility is sharply deteriorating in recent years, particularly, during the late 1980s and the 1990s.

The foregoing analysis suggests that the belief of food production growth to be tapering off in later years is valid to a large extent. On the other hand, overall growth rate in foodgrain productivity was observed to be higher during the post-technological change period largely due to widespread adoption of the modern technology. Also, the overall crop production growth is depicting 'constant return to scale'. Therefore, it may be unwise and overly pessimistic if one tends to conclude that sustainability in food production in Bangladesh may not be achieved at all. Selective farm-level large-sample surveys covering the period 1979/80 - 1995/96 reveals an upward trend in yield estimates for both local and modern varieties of rice (Table 4.8) indicating food production can be increased.

Table 4.8 Farm-level estimates of rice yield rates (mton/ha) in selective large-scale surveys conducted covering the period, 1980 – 1996.

Rice varieties	IFDC survey (1980-82)	IFPRI/BIDS survey (1981/82)	GOB Survey (1982-85)	BIDS/BRRI survey (1987)	BIDS/IFPRI survey (1991)	Present study (1996)
Local Aus	1.31	1.19	1.24	1.69	1.55	2.06
Modern Aus	3.16	3.24	3.26	4.23	3.63	3.56
Local Aman	1.90	1.73	1.85	2.63	2.10	2.85
Modern Aman	2.74	2.87	2.89	3.50	3.50	3.44
Local Boro	1.95	2.50	2.30	2.66	2.19	2.30
Modern Boro	3.73	3.73	4.10	5.07	4.34	4.67

Source: Field survey (1997); Mahmud *et al.*, (1994); Hossain *et al.*, (1990); Sanyal (1993); and Hossain (1989).

Also, the total factor productivity (TFP) growth for rice in Bangladesh is estimated at only 0.98 percent for the period (1952 – 1971) and 1.15 percent for the period (1973 – 1989), respectively. When all crops are included the TFP growth rate further declines to 0.72 percent and 0.96 percent for the aformentioned period (Dey and Evenson, 1991). However, the encouraging feature to note in these TFP estimates is that the growth rate of TFP is higher during the post-technological change period though the overall rate of increase is very low in absolute terms. Further, it should be mentioned that the TFP index estimate also fails to incorporate the environmental impacts associated with technological change in agriculture.

4.4 Inferences

Technological change has a profound influence on regional variation in agricultural development. The coefficient is significantly positively related to foodgrain output in all the three periods, implying that technological change significantly contribute to variation in foodgrain output. The second most important determinant of regional variation is the yield level of local rice varieties. In addition to these two factors, infrastructural, irrigation and demographic factors also influence regional variation. However, most of the regions in Bangladesh are underdeveloped in terms of agricultural development levels. Out of a total of 20 regions, 9 regions are classified under 'low' and two at 'very low' levels as compared to only one region each under 'very high' and 'high' level, respectively. Remaining seven regions are classified under 'medium' level. The agro-ecological and biophysical constraints are largely responsible for the stagnancy of 'very low' and 'low' regions.

Analysis of long-run trend in crop production using aggregate production function estimation with regionwise time-series data revealed that in addition to conventional factor inputs, technological and infrastructural factors significantly increases crop production. The role of human capital in increasing crop production is indecisive (significantly positive in only one model).

Computation of returns to scale revealed that 'constant returns to scale ($1.08 \approx 1.00$)' prevails in the long-run crop production when conventional inputs are considered. Inclusion of non-conventional inputs in returns to scale computation decisively revealed that 'increasing returns to scale ($1.17 > 1.00$)' prevails in crop production. This finding indicates that crop production can be sustained in the future by manipulating the non-conventional inputs, particularly modern agricultural technology, irrigation and infrastructures in addition to the conventional inputs of land and labor.

Sustainability analysis of foodgrain production revealed that though the productivity of food crops is increasing the productivity of modern varieties of rice is decreasing thereby casting doubt on sustaining foodgrain production in future through technological change alone. Further, result from the logistic function analysis suggested that the yield level of foodgrain seems to be tapering off towards a saturation value of 2,200 kg/ha which poses a threat to sustaining foodgrain production over a long time horizon.

CHAPTER V

FARM-LEVEL DECISION ANALYSIS OF ALTERNATIVE AGRICULTURAL TECHNOLOGIES: A 'META-PRODUCTION FUNCTION' APPROACH

Several studies on farm-level input demand estimations were made in the past two decades in Bangladesh. Demand relationships in these studies were typically estimated from a sample of farms in which a common variety of rice or wheat was planted. Such studies ignored the possibility that cultivators can respond to price changes not only by adjusting their use of variable inputs but also by switching to different rice and wheat seed varieties. Also, ignoring this choice factor results in bias in the estimated results (Pitt, 1983).

In a situation of rising costs of production and high competition in the market, Bangladeshi farmers would require to switch between seed varieties in order to bring higher profit and insure against crop losses. It was observed that for the past two decades, farmers were increasingly switching varieties of rice as well as wheat from local to modern one released by the Bangladesh Rice Research Institute (BRRI) and Wheat Research Centre of Bangladesh Agricultural Research Institute (BARI). Therefore, in this study, input demand at farm-level is jointly determined while allowing for the possibility of seed variety switching following a 'meta-production function' framework as discussed below.

The chapter is organized into following major sections. The first section provides the analytical framework. Second section provides concise analyses of nature of alternative crop production technologies and resource use patterns covering the overall cropping system practiced by the Bangladeshi farmers. The analyses of factor shares in crop production provide the relative profitability of major and minor crops. The final section provides the estimated parameters of the input demand and output supply elasticities of local and modern varieties of rice and wheat as well as non-cereal crops. These estimated parameters form the basis of policy analyses conducted in the final chapter of this dissertation.

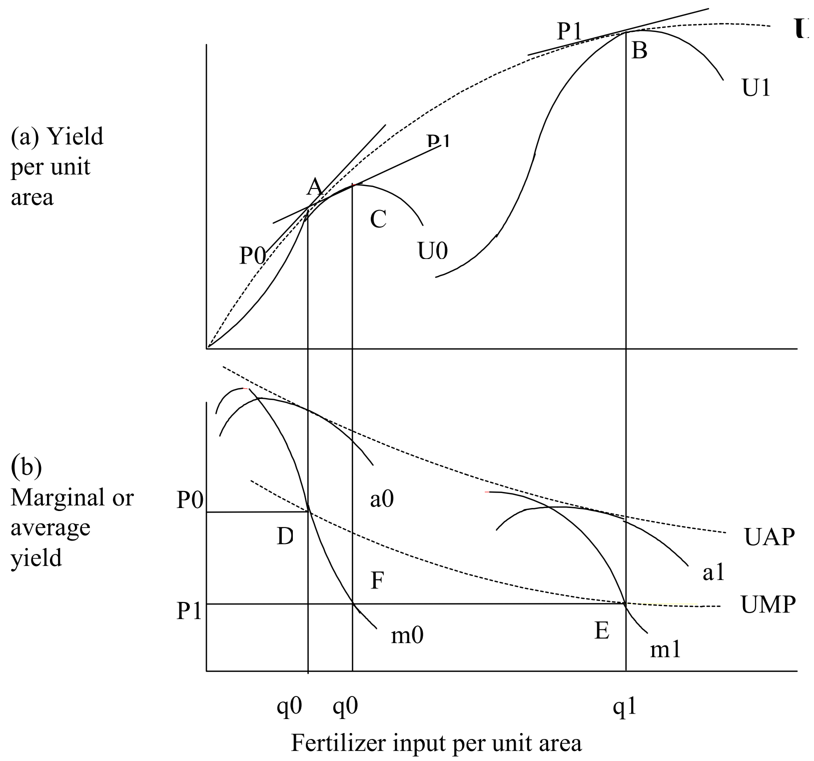
5.1 Analytical Framework: The 'Meta-Production Function' Hypothesis

Hayami and Ruttan (1985) asserted that a requisite for agricultural productivity growth is the capacity of the agricultural sector to adapt to a new set of factor and product prices. And this adaptation involves not only the movement along a fixed production surface but also the build up of a new production surface that is optimal for the new set of prices. For instance, take the example of fertilizer use. Hayami and Ruttan (1985) noted that 'even if fertilizer prices decline relative to the prices of land and farm products, increases in the use of fertilizer may be limited unless new crop varieties are developed which are more responsive to high levels of biological and chemical inputs than are traditional varieties'.

Stated in simpler terms, it implies that 'changes in the relative price of fertilizer will induce cultivators to switch to seed varieties of differing fertilizer intensiveness so as to maximize profits with respect to a 'meta-production function'. 'The meta-production' function is the envelope containing the production surfaces of all potential seed varieties, irrigation system and cultivation techniques' (Pitt, 1983). The concept can be best illustrated as follows.

Figure 5.1 illustrates a conceptual ‘meta-fertilizer response surface’ U, representing the locus of technically efficient fertilizer-output combinations for a particular agro-climatic environment and fixed level of other factors such as irrigation. It should be noted that different types of ‘meta-fertilizer response function’ are associated with each different combination of agro-climatic environment and factor inputs. The fertilizer response surface for the traditional varieties and the modern varieties can be drawn as U_0 and U_1 (Fig. 5a). The ‘meta-fertilizer response surface’ U, which is the envelope of many such response surfaces encompass the individual seed variety fertilizer response functions U_0 and U_1, each characterized by a different degree of fertilizer-responsiveness. UAP and UMP, a_0 and m_0, a_1 and m_1, in Fig. 5b, are the average and marginal product curves corresponding, respectively, to U, U_0 and U_1.

Figure 5.1. Fertilizer Response on a ‘Meta-production Surface’



Source: Adapted from Hayami and Ruttan (1985).

U_0 represents the optimal (profit maximizing) variety for the fertilizer/rice price ratio, P_0; and U_1 represents an optimum for P_1. With the fertilizer/rice price ratio of P_0, the profit maximizing farmer would be at A (or D) on the ‘meta-response function’ using variety 1. For a decline in the fertilizer/rice price ratio declines from P_0 to P_1, if the individual farmer is not allowed to switch seed varieties (or not permitted to move along the ‘meta-response surface’), the result will be an increase in use of fertilizer at C (or F), a point inside the ‘meta-production surface’. When allowed for seed variety switching, this problem is eliminated, since the new fertilizer-output combination will be at B (or E) with variety type 2 on the 'meta-response surface'. Point C represents equilibrium for response surface U_0 if undertaken by farmers, but a disequilibrium in terms of potential alternatives described by the 'meta-production function' U. It is worthy to note that fertilizer response to price is larger for movements along the 'meta-response surface' than along the seed variety specific surface (Hayami and Ruttan, 1985 and Pitt, 1983).

5.2 Nature of Alternative Crop Production Technologies and Resource Use

The term 'technology' generally refers to the application of knowledge to produce output by utilizing factor inputs. Technological change in this context refers to change in the process and combination of inputs to produce output. In this section, details of production technologies of foodgrains (local and modern varieties of rice and wheat of all three seasons), jute, potato, oilseeds, pulses, vegetables and cotton is outlined including their implications for cost of production, capital requirements, profitability of cultivation, and returns to factor shares. Thus far, most of the studies on nature and impact of 'Green Revolution' technologies concentrated in the analyses of rice only, such as Hossain (1989), Ahmed and Hossain (1990), Hossain *et al.* (1990), and Alauddin and Tisdell (1991). However, this study extends the scope by including similar details for modern wheat varieties as well as other non-cereal crops in order to cross-examine the viability of switching not only to modern varieties (MVs) of rice and wheat, but also to other crops. Moreover, data for the aforementioned studies dates back to 1982 and 1987 at the latest. Therefore, even a reassessment of similar issues seems justified. It should be noted that the main thrust of technological change in Bangladesh agriculture is confined to rice and wheat and negligible in potato, jute and oilseeds. This is possibly another reason for confinement of all major studies in rice alone.

5.2.1 Landuse and Cropping Intensity

Prior to the analyses of economics of various crops it would be worthwhile to highlight the cropping seasons and major crops grown therein. Rice occupies about 70 percent of the cultivated land and grown in all three seasons, Aus, Aman, and Boro, respectively (Appendix Table A5.1). Aman is the monsoon season while Boro and Aus fall in the dry season and overlap each other. Moreover, the modern Boro rice competes with modern Aus rice and has similar characteristics. And these modern varieties are grown by substituting land from local Aus rice, jute, broadcast Aman rice and minor dry season crops such as pulses and oilseeds (Hossain *et al.*, 1990). This is also evident in data of the present study where modern Boro rice areas are very high covering about 35 percent of gross cropped area.

The cropping intensity of the surveyed region is estimated at 172.8 and closely matches with the comparison study[25] of 174.5, thereby, rendering confidence in the

[25] In this chapter, three extensive survey based studies were used as comparison. These are: (a) Differential Impact Study (DIS) of Modern Rice Technology conducted jointly by Bangladesh Institute of Development Studies (BIDS) and BRRI covering 62 villages of 62 new districts. The data pertains to crop year 1987; (b) Farm Level Fertilizer Use Study (FLFUS) conducted by International Fertilizer Development Centre (IFDC) covering 56 locations in 30 new districts. Data pertains to crop years, 1990, 1991, and 1992, respectively; and (c) Agricultural Diversification Study conducted jointly by International Food Policy Research Institute (IFPRI) and BIDS. Data pertains to crop year 1990/91.

representativeness of the data (Appendix Table A5.1). Among the three regions, however, sharp differences exist in cropping intensity. The intensity of cropping is highest in Jamalpur (183.3) followed by Jessore (178.2). Comilla region has the lowest cropping intensity (148.2) largely due to the extensive rice monoculture in two seasons, Aman and Boro facilitated by the large scale Meghna-Dhonagoda Flood Control Drainage and Irrigation (FCD/I) project, which become operational in 1987.

The interesting point to note between the present study and comparison study is the changes in the proportion of local Aus rice area and modern Boro rice area while the total proportion of all rice area remains strikingly close (Appendix Table A5.1). The jute area remained the same while pulse area dropped sharply. As for the other crops, they remain comparable revealing little change has occurred in an attempt to diversify to non-cereal crops.

5.2.2 Yield Rates of Crops

Bangladesh agriculture is already operating at its land frontier and has very little or no scope to increase the supply of land to meet the growing demand for food required for the ever-increasing population. Moreover, owing to stagnation in industrial and services sector, rural people tend to cling to the agricultural land making the land market very thin. Therefore, only solution to increase food production lies in raising the productivity of land, either by increasing the yield levels of crops or by increasing cropping intensity. Table 5.1 provides the information on normal yield levels of all crops. The overall yield levels of crops are strikingly close to the estimates of comparison studies thereby rendering confidence in these estimates (Appendix Table A5.2).

It is clear from Table 5.1 that the yield levels of modern rice varieties are significantly ($p<0.01$) higher than the local varieties in all regions. This explains the phenomena of drastically declining local rice area in Bangladesh. Among the modern rice varieties of all three seasons, the modern Boro rice yield levels are highest (Appendix Table A5.2). This is because modern Boro rice requires complete mechanical irrigation while modern Aman rice and modern Aus rice is grown mainly under rainfed conditions. It is interesting to note that though there are significant differences in the yield levels of local varieties of rice across regions, the yield levels of modern rice varieties as well as modern wheat is similar. This finding is consistent with the analyses of regional variation in agricultural development levels done in Chapter IV which revealed that the difference in the yield levels of local rice varieties is an important factor in explaining regional differences.

Sharp inter-regional differences in yield levels are also observed for non-cereal crops (Table 5.1). Comilla region has intensive production practices for potato, which resulted in significantly ($p<0.05$) higher yield as compared to Jamalpur and Jessore regions. The reason is mainly due to differential access to infrastructures. Only, Comilla region has a large cold storage facility within 3-5 km from the study villages. Existence of cold storage is vital for storing potato in order to fetch higher prices during off-season since the potato price hits record low levels during harvest season. In case of spice production, Jamalpur region has significantly ($p<0.05$) higher yield levels as compared to Comilla region. This is largely due to the individual micro-climatic requirements for specific crops. This complex variability of agro-ecological features for non-cereal/commercial crops limits the scope for a general policy of crop diversification for the country as a whole. Rather, it demands careful analyses of soil as well as micro-climatic suitability for individual crops, particularly, non-cereals.

Table 5.1 Yield rate of crops by study regions, 1996.

Crops	Yield rates (mt/ha) in present study				F-ratio for regional difference
	Jamalpur region	Jessore Region	Comilla region	All region	
Foodgrain crops					
Modern wheat	2.14[A]	2.27[A]	2.12[A]	2.18	0.60
Local rice	2.59[A]	1.98[B]	2.10[BC]	2.32	5.29[a]
Modern rice	4.17[A]	4.16[A]	4.20[A]	4.18	0.03
t-ratio for rice variety difference	-8.72[a]	-4.49[a]	-11.12[a]	-14.98[a]	
Non-cereal crops					
Jute	1.63[A]	2.33[B]	1.74[A]	1.99	11.95[a]
Potato	11.56[A]	8.80[A]	16.04[B]	13.93	9.75[a]
Pulses	ng	0.72[A]	0.92[B]	0.76	5.59[b]
Oilseeds	1.18[A]	1.02[A]	1.29[A]	1.17	1.15
Spices	3.32[A]	2.85[AB]	1.55[B]	2.75	3.76[b]
Vegetables	8.84[A]	7.72[A]	ng	8.00	0.52
Cotton	ng	1.30	ng	1.30	-

Note: Same block letters in superscript represents similarity in yield levels across regions for individual crop based on LSD at 5 percent level of significance (p<0.05).
ng = not grown.
[a] = significant at 1 percent level (p<0.01); [b] = significant at 5 percent level (p<0.05);
[c] = significant at 10 percent level (p<0.10).
Source: Field Survey, (1997).

5.2.3 Fertilizer Use Rates for Crops

Fertilizer use has been widespread in Bangladesh since the diffusion of modern varieties of rice and wheat. Almost all of the farmers apply chemical fertilizers in modern rice, wheat, potato and vegetables. However, the intensity of fertilizer use varies sharply with higher levels of application on modern varieties grown during the dry season.

The fertilizer use rates for various crops are presented in Table 5.2. The intensity of fertilizer use for crops is quite comparable with the comparison studies, particularly for rice and wheat (Appendix Table A5.3). Fertilizer use rates are significantly (p<0.01) higher for all modern rice varieties across regions. This is expected as the new technology require intensive use of inputs, particularly, fertilizer, labor and irrigation, in order to realize the potential yield levels. Moreover, there is significant (p<0.01, p<0.05, and p<0.10) inter-regional variation in fertilizer use rates. Comilla region has the highest intensity of fertilizer use for most of the crops followed by Jamalpur region. This is consistent since the soil fertility status of Comilla and Jamalpur regions is tested to be poor as compared to Jessore region (see Chapter IX for detail analysis).

In case of non-cereal crops, significant ($p<0.05$) regional differences in fertilizer use rates are observed. The rate is highest for potato (348 kg/ha). The major reason is the use of modern varieties of potato, which requires high doses of fertilizers, particularly, in Comilla region. Cotton, a specialized crop, grown only in Jessore also consumes high doses of fertilizers (326 kg/ha). The use rates are high and similar for spices and vegetables with high inter-regional difference. Such sharp variation in use rates of fertilizers can also be attributed to differences in soil fertility status of the study villages (analyzed in detail in Chapter IX).

Table 5.2 Chemical fertilizer use rates by study regions, 1996.

Crops	Fertilizer use rates (kg/ha) in present study				F-ratio for regional difference
	Jamalpur region	Jessore Region	Comilla region	All region	
Foodgrain crops					
Modern wheat	218^A	225^A	239^A	230	0.38
Local rice	126^A	112^B	61^B	94	6.81^a
Modern rice	231^A	244^A	279^B	246	17.71^a
t-ratio for rice variety difference	-7.62^a	-3.44^a	-17.45^a	-16.11^a	
Non-cereal crops					
Jute	132^A	178^B	78^C	140	9.67^a
Potato	286^A	392^B	387^B	348	5.11^a
Pulses	ng	26^A	95^B	37	10.32^a
Oilseeds	175^A	117^A	122^A	125	0.73
Spices	301^A	223^A	230^A	271	1.16
Vegetables	175^A	286^B	ng	258	3.92^b
Cotton	ng	326	ng	326	-

Note: Same block letters in superscript represents similarity in yield levels across regions for individual crop based on LSD at 5 percent level of significance ($p<0.05$).
ng = not grown.
^{a} = significant at 1 percent level ($p<0.01$); ^{b} = significant at 5 percent level ($p<0.05$);

Source: Field Survey, (1997).

5.2.4 Irrigation and Pesticide Use Rates for Crops

The market of irrigation in rural Bangladesh is imperfect and varies widely (Hossain, 1989). Until recently, irrigation was used only for growing modern varieties of rice. However, due to erratic rainfall and to increase responsiveness of fertilizers, mechanical irrigation is provided for most of the crops. Table 5.3 reveals that the cost for irrigation is highest for modern rice varieties as expected. However, use of irrigation for other crops, including local varieties, is a new phenomenon. Irrigation cost for Comilla region is significantly lower as compared to other regions due to Meghna-Dhonagoda FCD/I Project, which supplies irrigation through canals free of cost for sample households within its command area. For the non-cereal crops, irrigation cost is also quite high, particularly, for vegetables, spices and potato with sharp inter-regional differences. Irrigation cost for potato is high in Jessore region because this is a dry region with less rainfall, thereby, requiring frequent irrigation.

Table 5.3 Irrigation and pesticide use rates by study regions, 1996.

Crops	Irrigation cost (Taka/ha)				Pesticides use rates (Taka/ha)			
	Jamalpur region	Jessore region	Comilla region	All region	Jamalpur region	Jessore region	Comilla region	All region
Foodgrain								
Mod. wheat	1,161	1,612	113	835	86	13	78	56
Local rice	724	504	0	365	45	121	171	110
Modern rice	2,257	2,047	1,118	1,929	182	397	1,022	439
Non-cereals								
Jute	494	1,011	0	612	71	123	0	78
Potato	1,319	3,118	518	962	1,029	94	1,347	1,159
Pulses	ng	232	0	196	ng	23	0	20
Oilseed	158	768	0	316	0	10	130	72
Spices	2,080	1,265	706	1,584	1,046	0	0	623
Vegetables	1,675	1,635	ng	1,645	498	1,687	ng	1,390
Cotton	ng	682	ng	682	ng	1,926	ng	1,926

Note: ng means not grown.
Source: Field Survey, 1997.

Use of pesticides in crops is dependent upon the disease and pest infestations and also the type of crops grown. Though, in the past, pesticides are rarely applied in local rice crops, its use rates substantially increased since the introduction of the modern varieties of rice and wheat. Also, for the non-cereal crops, pesticide usage became a must. The large expenses incurred for pesticides in modern rice, vegetables, and cotton is the evidence (Table 5.3). There are sharp inter-regional differences in pesticide usage for crops. Comilla region with its poor soil quality and intensive rice monoculture, use pesticides intensively as compared to other regions (Table 5.3). Except for vegetables and cotton production, pesticide use in Jessore region is generally lower. Few studies report explicitly the usage of pesticides. As such, comparison for the change in rate of pesticide use remains limited. However, it can be confidently stated that the current level of pesticide use is much higher than the previous levels (detail time-trend analysis is attempted in Chapter IX).

5.2.5 Human Labor and Animal Power in Crop Production

Traditionally, family-labor were the major sources of labor input in agricultural production. Since the diffusion of modern agricultural technology, the demand for hired labor increased substantially (Hossain, 1989; Ahmed and Hossain, 1990; and Hossain *et al.* 1990). Table 5.4 reinforces the fact that demand for hired labor increased from previous 1987 cropyear levels of 44 and 52 percent for local and modern rice varieties (Hossain *et al.*, 1990) to 56 and 61 percent, respectively, and spread evenly across all crops. This has profound implication for distribution of gains from modern agricultural technology as rural labor market is largely composed of landless and marginal farmers. There are sharp differences in proportion of hired labor use across regions for specific crops though a definite pattern cannot be ascertained. Since labor requirement for each crop is different, the proportion of hired labor varies sharply across regions as well as crops (for details of labor use see Chapter VII).

Table 5.4 Use of hired labor and hired animal power services by study regions, 1996.

Crops	Hired labor as percent of total (%)				Hired animal power as percent of total (%)			
	Jamalpur region	Jessore region	Comilla region	All region	Jamalpur region	Jessore region	Comilla region	All region
Foodgrain								
Mod. wheat	64.2	50.6	57.8	56.3	34.5	52.0	85.3	66.7
Local rice	56.3	70.8	52.9	55.5	38.9	57.1	89.3	64.1
Modern rice	59.6	60.5	62.8	60.6	45.2	58.4	75.5	55.9
Non-cereals								
Jute	60.0	60.0	72.1	63.1	26.9	47.8	79.3	52.0
Potato	51.2	78.6	46.2	49.4	58.1	30.8	94.3	59.3
Pulses	ng	50.0	39.5	47.6	ng	50.0	92.7	74.2
Oilseed	52.5	63.3	52.9	55.8	82.8	60.9	83.8	78.8
Spices	54.5	41.4	51.4	51.1	40.7	61.5	72.9	56.3
Vegetables	81.3	42.6	ng	52.4	42.9	33.3	ng	36.0
Cotton	ng	72.7	ng	72.7	ng	45.8	ng	45.8

Note: ng means not grown.
Source: Field Survey, 1997.

Until present time, use of mechanical power for agricultural operation, particularly for land preparation, land leveling and transportation of harvests from fields to home and market has been nascent. These activities are mainly performed by bullocks and cows, which are used in pairs. Since the diffusion of the modern varieties of rice and wheat, demand for hired animal power increased considerably (Table 5.4). Table 5.4 reveals that demand for hired animal power increased sharply from previous 1987 cropyear levels of 10 – 13 percent (Hossain *et al.*, 1990) to 56 – 64 percent for rice crops. Also the rate of increase in hired animal power services is much higher than the rise in hired labor indicating shortage of draft power resulting in a rapidly growing market for hired animal power services. However, the implication for gains from modern technology diffusion in this case is not the same as that of hired labor. Generally, the rich and medium farmers own one or more pairs of bullock and/or cows. Therefore, sharp increase in market for hired animal services implies that they gain from the modern technology diffusion on two counts, first by cultivating modern varieties and second by hiring out animal services in response to increased demand owing to technological change. It should be worth noting that each bullock pair includes a hired labor and as such, it will have a complementary effect on the market for hired labor demand but the extent of gain is much less.

5.2.6 Cost and Return Analyses of Crop Production

The estimates of costs and returns from crop production are computed at actual prices paid and received by the farmers. Prior to the analysis of costs, the cost components are discussed in details along with their justification.

Land is an important fixed asset and a source of wealth in rural setting. Therefore, the opportunity cost of land for the owner operator is imputed at the net rental cost of land incurred by the tenant farmer. The family supplied inputs of human labor and animal power services, seeds, and manures are imputed at their market rates. One cost element that has not been included is the opportunity cost of capital invested in crop production. Generally, farmers borrow from non-institutional sources, such as moneylender, friends and relatives. Interest rates for these sources are substantially higher than the bank rates for rural credit. Since these loans are mostly taken for a number of purposes, such as, consumption, crop production, education, health care and other services, and their duration being very short and diversified, apportioning the actual cost for individual crop production seems intractable.

The items included in the estimation of cost and return variables are:

Cost components	
Current inputs	= seeds, manures, fertilizers, pesticides, and irrigation charges.
Purchased inputs	= current inputs plus hired labor and hired animal power services.
Total cost of production	= purchased inputs plus imputed value of family labor and animal power services supplied from the household.
Land rent (opportunity cost of land)	= gross value of output share received by landowner minus value of input cost share paid by landowner.
Return components	
Gross return (gross value of output)	= value of total production plus value of by-product.
Farm family income	= gross value of output minus purchased input.
Value added	= gross value of output minus current inputs.
Profits (gross margin)	= gross value of output minus total cost.
Farm operator surplus (net of land rental cost)	= gross value of output minus total cost minus value of rent paid to landowner.
Farm operator surplus (Owner operator)	= gross value of output minus total cost.
Farm operator surplus (Part tenant farmer)	= gross value of output minus total cost minus rent paid to landowner for the portion of land rented-in.
Farm operator surplus (Tenant farmer)	= gross value of output minus total cost minus rent paid to landowner for the land rented-in.

The average profitability of producing various crops per unit of land area is presented in Table 5.5. The relative weights of land area devoted to individual crop groups indicate the dominance of the modern varieties of rice in the cropping system. Profits from modern varieties of rice is significantly ($p<0.01$) higher for all crop seasons and highest in Boro season (Tk.14,157/ha) followed by Aus (Tk.12,273/ha) and Aman (Tk.11,310/ha) seasons, respectively (Appendix Table A5.4). Among the non-cereals, vegetables, spices, and potato yields very high return per unit of land and the amount is at least twice the returns from modern rice varieties and about four times of returns from local rice varieties. Despite such high rates of return, these crops are grown selectively in specific regions largely due to high price and yield risk associated with these crops and also marketing bottlenecks. Return from jute is strikingly close to return from modern rice varieties while modern wheat yields much less (Tk.7,790/ha). Even then, the area under jute has been declining sharply all over Bangladesh mainly due to difficulty of jute retting in open water bodies, storing and marketing bottlenecks and availability of cheap substitutes, the plastics.

Table 5.5 Average cost and profitability of crop production (all regions), 1996.

Crops	Weights[1]	Yield (ton/ha)	Price (Tk/ton)	Gross value (Tk/ha)	Variable cost (Tk/ha)	Profits (Tk/ha)
Foodgrain crops						
Modern wheat	0.046	2.18	7,984	18,082	10,292	7,790
Local rice	0.092	2.32	5,452	13,952	7,347	6,515
Modern rice	0.700	4.18	5,637	24,809	11,983	12,826
t-ratio for rice variety difference	-	-14.98[a]	-3.72[a]	-13.50[a]	-12.16[a]	-8.70[a]
Non-cereal crops						
Jute	0.047	1.99	9,395	20,539	9,089	11,450
Potato	0.017	13.93	3,790	51,708	24,718	26,990
Pulses	0.038	0.76	19,559	14,650	6,138	8,512
Oilseeds	0.031	1.17	13,058	14,535	7,431	7,104
Spices	0.008	2.75	25,202	46,620	17,400	29,220
Vegetables	0.013	8.00	6,120	42,970	13,203	29,767
Cotton	0.008	1.30	23,546	30,139	11,720	18,419

Note: [a] = significant at 1 percent level ($p<0.01$)
[1] Weights as percent of gross cropped area.
Source: Field Survey, 1997.

Factor shares in crop production are estimated to analyze the distribution of gains from crop production. Comparison of factor shares of crops provides a first hand knowledge on the relative differences among crops with respect to the contribution of individual inputs to gross value of production and, therefore, possess distributional implications. The actual contribution of various factors in absolute terms may be largely different among crops depending on the gross value of output realized from specific crops and thus, limits the scope for comparison. The major argument in favor of modern agricultural technology is that it is labor intensive and as such utilizes more hired labor. Therefore, gains from modern technology diffusion indirectly reach to landless and marginal farmers who sell their labor in the rural labor market. The factor shares in crop production at the mean level of all three regions are presented in Table 5.6.

Factor shares of current input is higher for modern rice and wheat varieties as compared to local rice varieties thereby confirming the capital intensity argument of the modern agricultural technology (Table 5.6). The proportion of hired labor is similar between local and modern varieties, about 11 – 13 percent of gross value of production distributed in the form of wages for hired labor services, which presumably goes to landless and marginal farmers. The rate is similar for some non-cereal crops, such as, jute, oilseeds, spices and cotton.

The opportunity cost of land, the land rent ranges between 36 – 44 percent of gross value of output. This indicates the scarcity and importance of land, as the prime source of wealth in the rural region since for the owner operator, this cost component would be added as return. Also, this explains the extent of vulnerability of tenant farmers most of whom become bankrupt in case of crop failures and lose their meager landholdings to landlords and/or moneylenders, thereby, exacerbating the pauperization process. The estimates of land rent reported by Hossain *et al.* (1990) ranges between 43 – 45 percent of gross value of rice production which is very close to the current estimates thereby rendering confidence in results.

Table 5.6 Factor shares in crop production (all regions), 1996.

Factors	Factor shares as percent of gross value of production (%)									
	Local rice	Modern rice	Mod. wheat	Jute	Oil-seeds	Potato	Pulses	Spices	Vege-tables	Cotton
Current input	13.7	21.2	23.2	11.4	14.9	31.0	13.9	12.6	13.7	17.0
Family	4.0	4.0	3.7	1.7	2.0	11.9	3.3	1.6	1.1	0.8
Purchased	9.7	17.2	19.5	9.7	12.9	19.1	10.6	11.0	12.6	16.2
Animal labor	14.1	8.7	12.6	10.2	15.7	4.5	15.5	5.1	5.4	7.6
Family	5.5	4.2	4.6	5.3	4.4	1.1	6.3	2.4	3.5	4.3
Hired	8.6	4.5	8.0	4.9	11.3	3.4	9.2	2.7	1.9	3.3
Human labor	24.9	18.4	21.1	22.6	20.5	12.3	12.5	19.6	11.8	14.2
Family	11.7	7.3	9.3	8.5	8.9	6.2	6.5	9.2	5.9	3.9
Hired	13.2	11.1	11.8	14.1	11.6	6.1	6.0	10.4	5.9	10.3
Land rent	39.4	37.5	38.7	35.7	41.5	42.8	39.3	43.5	40.1	36.4
Gross value of output	13,952	24,809	18,082	20,538	14,535	51,708	14,650	46,620	42,970	30,139
Value added	86.3	78.8	76.8	88.6	85.1	69.0	86.1	87.4	86.8	82.9
Farm family income	64.5	63.2	56.9	69.6	62.2	59.5	71.0	74.3	78.9	69.3
Farm Operator surplus	8.0	14.2	4.4	20.0	7.3	9.4	18.8	19.2	29.5	24.7
Observations	117	829	103	92	71	59	70	47	44	16

Note: Figures in parentheses are percentages of gross value of output (return).
Source: Field Survey, 1997.

The value added from crop production is around 77 – 89 percent of gross value of output for all crops except for potato (69 percent only). The value added for modern rice varieties is estimated at 79 percent and is lower by 7 percent when compared to local rice varieties. This is largely due to high cost incurred for irrigation and/or water charge for modern rice varieties. The irrigation cost include two cost components: fuel cost which is an intermediate consumption, and depreciation cost of using the irrigation equipment which is a return to capital and should be included in value added. However, difficulty in disaggregation of the two cost components led to treat the entire water charge as the irrigation cost which is underestimation of value added. Since modern varieties use higher level of irrigation, the underestimation is higher thereby leading to lower value added.

Since land is scarce, farmers would tend to maximize the return from land. The return over family resources, the farm family income, in absolute term is 74 and 14 percent higher for modern rice and wheat varieties when compared to local rice varieties (Table 5.6). Hossain *et al.* (1990) estimated that the farm family income is 72 percent higher for modern varieties than for local varieties, which is strikingly close with the current estimate. The farm family incomes for potato, spices, vegetables and cottons are similar for oilseeds and pulses when compared to local rice varieties. This also explains the sharply declining trend of area under oilseeds and pulses in Bangladesh as it yields as low as the local rice varieties.

The net return from per unit of land (farm operator surplus) is 3.2 times higher for modern rice varieties as compared to local rice varieties when cost of land is included. The gap in net return per unit of land among the non-cereals and foodgrain is much narrower as compared to gap in farm family income for the same set of crops. The difference is largely due to the high land rent. The net return from jute and potato becomes closely comparable to modern rice varieties while spices, vegetables and cotton are significantly higher.

The labor productivity, estimated as value added per day of labor, was Tk. 190 for modern varieties, which is 36 percent higher than Tk. 140 estimated for local varieties. The labor productivity for modern wheat is Tk. 145. All these compare very favorably to the prevailing wage rate of Tk. 46 per day. Hossain *et al.* (1990) also reported 31 percent higher labor productivity for modern rice (Tk. 133) as compared to local rice varieties (Tk. 86) for the crop year 1987.

5.3 Infrastructure Level in the Study Area and Construction of Infrastructure Index

Infrastructure, in development literature, generally refers to services and facilities that are an integral part of human life. Infrastructure includes facilities for transportation, communications, power, water supplies, education, health care, irrigation, drainage, and all types of public utilities. The role of infrastructure in economic development is complex and its effects are indirect. Ahmed and Hossain (1990) noted that infrastructure drastically reduce the cost of marketing of agricultural products thereby exerting far reaching consequences for comparative advantage of a country to compete in the world market. They also indicated that the existence of interlocked labor market with land and credit markets is largely due to lack of opportunity of alternative jobs in non-farm sectors that are constrained due to poor access and infrastructural facilities. Also, infrastructure is critical in diffusion of modern agricultural technology as easy access to transportation and communication system could promote extension activities, marketing of products, and purchase of modern inputs. However, the crucial role of infrastructure and institutions in augmenting agricultural productivity has been felt only recently, in the mid-1980s, spurred by the observation of widespread stagnancy and sluggish growth in agricultural productivity. Evenson (1986) noted that investments in rural infrastructures, such as roads and rural electrification, is designed to change behavior of farmers. Mann (1992), drawing on experience from Pakistan, suggested that a realistic strategy to promote agricultural growth through national policies would be to repair the massive infrastructure of the agricultural system as the root cause of low farm productivity lies into biological, institutional, and social constraints.

In this study, one of the focuses is to measure the effects of rural infrastructure on agricultural production and household economy in rural areas. As such, the urban and first-order infrastructures such as national highway, ports, airports, etc. were excluded. Ahmed and Donovan (1989) demonstrated that there is a gap in the methods of empirically measuring effects of infrastructure. Ahmed and Hossain (1990) developed a composite measure of infrastructure development using a cost-of-access approach, which is then successfully employed as an explanatory indicator in subsequent quantitative analyses. In this study, the composite index of infrastructure development is constructed using the same cost-of-access approach while including a wider range of elements as compared to Ahmed and Hossain's (1990) index.

The infrastructure index for this study is constructed from village level information. A total of 14 elements of infrastructure are selected. These are: primary markets (haat), growth centers or secondary markets, high school (secondary school), college, post office, thana headquarter, bus stop, paved road, bank, storage facilities, agricultural extension office, rice mill, union council office, and health center. The railway and water transportation stations were excluded because, only Comilla region use the Meghna river in addition to road, the Jamalpur region use only the railway in addition to road, and Jessore region does not use any of these two. The data includes distances in km, common mode of transport used and total cost of travel in taka. The index formulation is shown in Section 3.7.1.5 of Chapter III.

In order to assess the representativeness of the infrastructure index so constructed using the aforementioned procedure, rotated factor analysis is applied to the infrastructure variables. The first three factors, agricultural extension office, bank, and bus stop explained about 83 percent of total variation (Appendix Table A5.5). The rank correlation among the two sets of weights, the communality and correlation coefficients (of IC_i with TC) is 0.43 and is significant at 5 percent level ($p<0.05$). This indicates that the index constructed using cost-of-access approach represents satisfactorily the index constructed using factor analytic approach. However, for the present purpose, the infrastructure index constructed by using cost-of-access is utilized throughout as an independent explanatory variable in subsequent analyses. However, it should be noted that this is a village level index and, as such, households from a single village will have the same index value.

Information on mean distances and inter- and intra-regional differences in distances of 14 elements of infrastructure from the study villages is provided in Appendix Tables A5.6 and A5.7, respectively. Except paved road, union office and highschool, significant ($p<0.01$ and $p<0.05$) regional differences exists in distances of these infrastructures from the study villages. Observations of homogeneity among regions revealed that Comilla and Jessore are similar while Jamalpur region is different (Appendix Table A5.7). The constructed infrastructure index confirmed this intuition (Table 5.7). The distinction between developed and underdeveloped villages is based on the value of index number below and above the mean score of infrastructure index. The mean score of the index is estimated at 31.2. It is clear from Table 5.7 that all six villages of Jessore region, five out of seven villages of Comilla region is classified under developed infrastructure category as compared to only one village out of eight of Jamalpur region, thereby, confirming the intuition reflected from Appendix Table A5.7. The intra-regional classification also revealed that about half of Jamalpur villages are in the underdeveloped category. The lower index value implies cheaper cost-of-access to the infrastructural facilities indicating develop infrastructure. Therefore, the higher the index the less developed the infrastructure. In other words, the index can be termed as 'the index of underdevelopment of infrastructure' (Ahmed and Hossain, 1990).

Table 5.7 Infrastructure index numbers of 21 study villages, 1996.

Developed villages			Underdeveloped villages		
Region	Name of village	Index number	Region	Name of village	Index number
Jessore	*Taherpur*	14.87	Jamalpur	*Karanipara*	31.98
Comilla	*Dhakirgaon*	16.32	Jamalpur	*Rupshi*	35.74
Jessore	*Mohanpur*	16.37	Jamalpur	*Sapleja*	36.63
Jessore	*Subalkati*	17.18	Jamalpur	*Deuliabari*	39.37
Comilla	*Uddamdi*	18.81	Comilla	*Sonaterkandi*	41.89
Jessore	*Juranpur*	19.28	Jamalpur	*Sonakata*	47.01
Comilla	*Silmondi*	21.22	Jamalpur	*Munshipara*	47.78
Comilla	*KhasUddam*	21.96	Jamalpur	*Jaliarpar*	49.32
Jamalpur	*Manikbari*	24.71	Comilla	*Begumpur*	73.55
Jessore	*Chandipur*	24.83			
Jessore	*Monaharpur*	26.14			
Comilla	*Fatehpur*	30.05			

Note: The higher the infrastructure index the less developed the infrastructure.
Source: Computed from Field Survey, 1997.

5.4 Soil Fertility Status of the Study Area and Construction of Soil Fertility Index

Soil fertility refers to the inherent capacity of soil to supply plant nutrients in proper amount, forms, and proportions required for the maximum plant growth (Uexkull, 1988). The inherent capacity of supplying nutrients itself is a function of the type and nature of the minerals present and the organic matter content in soils. And both the minerals and organic components determine the amount of nutrients reserved in the soil and the rate at which these nutrients are released to plants in available form (Dahal, 1996). However, it should be mentioned that though fertility can be measured in terms of compounds or ions it does not reflect the nature of crop productivity. This is because fertile soil may not necessarily be a productive soil as all productive soil*s* are not fertile (Dahal, 1996). This call for the concept of nutrient availability closely associated with the concept of soil fertility. The nutrients, either in soluble or exchangeable ions, become available to the plant root system once is in direct contact. However, it is the capacity of the soil to release the unavailable minerals to the plant in the required form that determines the crop productivity.

In this study, an attempt has been made to evaluate the existing soil fertility status of the study villages. A total of ten soil fertility parameters, namely, soil reaction (pH), available nitrogen (N), available phosphorus (P), available potassium (P), available sulfur (S), and available zinc (Zn), organic matter content (OM), cation exchange capacity (CEC), electrical conductivity (EC), and textural class are analyzed. Table 5.8 provides the summary results.

It is evident from Table 5.8 that the soil nutrient content largely varies across regions. A test of homogeneity is performed in order to get a detailed grasp of the regional differences in soil fertility status which revealed that Jamalpur and Comilla region have more or less similar soil fertility levels while Jessore is largely different. The sharp difference is in organic matter content of soils (Table A5.8 in the appendix).

Table 5.8 Summary of soil test results of the study regions, 1996.

Soil variable	Jamalpur region		Jessore region		Comilla region		All region		Difference (F-value)
	Mean	CV	Mean	CV	Mean	CV	Mean	CV	
pH	6.0	9	7.8	3	7.2	7	7.0	13	20.11[a]
OM (%)	2.0	39	6.5	44	1.5	24	3.3	85	12.96[a]
N (μg/g)	16.0	42	19.1	43	25.5	29	20.2	40	2.11
P (μg/g)	26.7	24	22.3	71	20.4	10	23.1	41	0.53
K (μg/g)	32.2	52	52.4	26	20.2	30	34.9	52	7.89[a]
S (μg/g)	7.8	20	10.2	36	5.5	13	7.8	37	5.08[b]
Zn (μg/g)	5.0	74	7.6	42	4.1	73	5.5	62	1.51
Sand (%)	19.9	28	8.7	64	3.5	49	10.7	78	16.19[a]
Silt (%)	57.7	14	52.2	17	74.9	6	61.6	20	12.70[a]
Clay (%)	22.4	30	39.1	36	21.7	24	27.7	44	5.43[b]
EC (μS/cm)	75.0	40	176.2	19	112.5	28	121.2	43	12.81[a]
CEC (meq/100g)	10.9	32	26.2	33	15.8	29	17.6	49	8.52[a]

Note: CV = coefficient of variation expressed as $(\sigma / \bar{x}) * 100$.
[a] = significant at 0.01 level ($p<0.01$); [b] = significant at 0.05 level ($p<0.05$).
Source: Field survey, 1997.

In addition to the analysis of infrastructural factors, another focus of this study is to evaluate and measure the effects of soil fertility factor in agricultural production and household economy. For this purpose, a composite index of overall soil fertility status of the study villages is constructed. In deriving the mean index, nine soil test parameters are considered. The soil texture parameter is excluded since it is quite similar across villages. The index is constructed following the procedure adopted by Motsara (1994) and Dahal (1996). First, the number of samples falling in each soil nutrient class (high, medium, and low) is identified. The range of soil nutrient values used for classifying the samples in each class is adopted from the 'Soil Guides for Crop Production' (in Bangla) published by Soil Resource Development Institute (SRDI, 1990 and 1991) of Bangladesh. The detail of soil fertility index of individual soil parameter is presented in Appendix Tables A9.1 – A9.9. Table 5.9 presents the composite index value of soil fertility for the study villages.

It is clear from Table 5.9 that the soil fertility level is consistently low in Jamalpur and Comilla region and medium in Jessore region. It should be noted that this index is also a village level index and, therefore, households from a single village will have the same index number representing overall soil fertility. This evaluation is particularly useful in the context of the study because the inferences drawn from the analyses of productivity performance and resource use efficiency of farmers of the study regions will incorporate this knowledge of bio-physical limitation faced by them.

Table 5.9 Soil fertility index of 21 study villages, 1996.

Medium quality soil (index value 1.67 – 2.33)			Low quality soil (index value < 1.67)		
Region	Name of village	Index number	Region	Name of village	Index number
Jessore	*Subalkati*	2.00	Jamalpur	*Rupshi*	1.38
Jessore	*Mohanpur*	1.88	Jamalpur	*Karanipara*	1.50
Jessore	*Taherpur*	1.88	Jamalpur	*Munshipara*	1.50
Jessore	*Juranpur*	1.88	Jamalpur	*Jaliarpar*	1.50
Jessore	*Monaharpur*	1.88	Jamalpur	*Sapleja*	1.50
Jessore	*Chandipur*	1.88	Jamalpur	*Deuliabari*	1.63
Jamalpur	*Sonakata*	1.88	Jamalpur	*Manikbari*	1.63
			Comilla	*Dhakirgaon*	1.38
			Comilla	*Shilmondi*	1.50
			Comilla	*Fatehpur*	1.63
			Comilla	*Sonaterkandi*	1.63
			Comilla	*Begumpur*	1.63
			Comilla	*Uddamdi*	1.50
			Comilla	*Khas uddamdi*	1.63

Note: Index = $\{(n_1 * 1) + (n_2 * 2) + (n_3 * 3)\}/ n$
where $n_1 \ldots n_3$ are respective number of sample in each class, and 1, 2, 3 are the weights for low, medium, and high class and n is the sample size. The range of available nutrient contents for each soil parameter for each class is taken from 'Soil Guide for Crop Production' (in Bangla) of the Soil Resource Development Institute, Bangladesh. The index value rated as **< 1.67 = low, 1.67 – 2.33 = medium,** and **> 2.33 = high** following Motsara (1994) and Dahal (1996)
Source: Field survey, 1997.

5.5 Farm-Level Input Demand Estimation Using 'Meta-Production Function' Approach

Section 5.2 elaborated on the nature of alternative production technologies, level of input use, and relative profitability of major and minor crops comprising of the entire cropping system of Bangladesh. Also Sections 5.3 and 5.4 elaborated on the construction of two special indices, index of underdevelopment of infrastructure and index of soil fertility level of the study villages that are to be incorporated as independent arguments in decision-making models.

The present section is set to empirically estimate the input demand and output supply elasticities within a 'meta-production function' framework (elaborated in Section 5.1) which allows for technology choices reflected in switching between modern and local varieties of seed.

Such analysis required to be conducted in two stages utilizing the Two-stage Switching Regression procedure. The first stage is the estimation of reduced-form seed selection equation which will enable us to compute the probability that any farm has information on modern variety profit function (regime 1) or the local variety profit function (regime 2) using Probit Maximum Likelihood Estimation procedure. It also shows how prices and fixed factors affect the probability of choosing modern seed varieties. The second stage is the joint estimation of the normalized restricted translog profit function and the variable factor share equations for the two separate regimes using the Zellner's Seemingly Unrelated Regression Estimator[26] (SURE).

5.5.1 Specification of the Model

The generalized translog profit function model and the i<u>th</u> share equation was developed in Chapter III. From the general function (3.7.1.1), the normalized restricted translog profit function for the farms can be specified in actual variables as:

$$\begin{aligned}\ln \pi' = {} & \alpha_0 + \alpha_W \ln P'_W + \alpha_F \ln P'_F + \alpha_M \ln P'_M + \tfrac{1}{2}\gamma_{WW} \ln P'_W \ln P'_W + \tfrac{1}{2}\gamma_{FF} \ln P'_F \ln P'_F \\ & + \tfrac{1}{2}\gamma_{MM} \ln P'_M \ln P'_M + \gamma_{WF} \ln P'_W \ln P'_F + \gamma_{WM} \ln P'_W \ln P'_M + \gamma_{FM} \ln P'_F \ln P'_M \\ & + \beta_L \ln Z_L + \beta_A \ln Z_A + \beta_I \ln Z_I + \beta_S \ln Z_S + \beta_E \ln Z_E + \delta_{WL} \ln P'_W \ln Z_L + \delta_{WA} \ln P'_W \ln Z_A \\ & + \delta_{WI} \ln P'_W \ln Z_I + \delta_{WS} \ln P'_W \ln Z_S + \delta_{WE} \ln P'_W \ln Z_E + \delta_{FL} \ln P'_F \ln Z_L + \delta_{FA} \ln P'_F \ln Z_A \\ & + \delta_{FI} \ln P'_F \ln Z_I + \delta_{FS} \ln P'_F \ln Z_S + \delta_{ML} \ln P'_M \ln Z_L + \delta_{MA} \ln P'_M \ln Z_A + \delta_{MI} \ln P'_M \ln Z_I \\ & + \delta_{MS} \ln P'_M \ln Z_S + \delta_{ME} \ln P'_E \ln Z_E + \tfrac{1}{2}\psi_{LL} \ln Z_L \ln Z_L + \tfrac{1}{2}\psi_{AA} \ln Z_A \ln Z_A + \tfrac{1}{2}\psi_{II} \ln Z_I \ln Z_I \\ & + \tfrac{1}{2}\psi_{SS} \ln Z_S \ln Z_S + \tfrac{1}{2}\psi_{EE} \ln Z_E \ln Z_E + \omega_{LA} \ln Z_L \ln Z_A + \omega_{LI} \ln Z_L \ln Z_I + \omega_{LS} \ln Z_L \ln Z_S \\ & + \omega_{LE} \ln Z_L \ln Z_E + \omega_{AI} \ln Z_A \ln Z_I + \omega_{AS} \ln Z_A \ln Z_S + \omega_{AE} \ln Z_A \ln Z_E + \omega_{IS} \ln Z_I \ln Z_S \\ & + \omega_{IE} \ln Z_I \ln Z_E + \omega_{SE} \ln Z_S \ln Z_E + \sigma_{iu} MR + \upsilon \qquad (5.5.1)\end{aligned}$$

where π' is the restricted profit from foodgrain (rice and wheat) production per farm: total revenue less total costs of labor, chemical fertilizer, manures, irrigation, pesticides, and animal power services normalized by the price of foodgrain; P_W' is the money wage rate of labor per day normalized by the price of foodgrain; P_F' is the money price per kg of fertilizer materials normalized by the price of foodgrain; and P_M' is the money price of animal power per hectare normalized by the price of foodgrain.

Five fixed inputs are included in the specification of the profit function. Z_L is the land input per farm measured as hectare of foodgrain (all rice and wheat varieties) grown in one year; Z_A is the value of the non-farm fixed capital assets used for foodgrain production per farm measured as taka of total stock value; Z_I is the index of underdevelopment of infrastructure measured at the village level; Z_S is the soil fertility index measured at the village level; and Z_E is the level of education of the farmer measured as years of schooling completed. The variable MR represents the Mill’s Ratio to be obtained from the first stage probit estimate of the reduced-form seed selection equation. The parameters α_0, α, β, γ, δ, ψ, ω and σ are to be estimated and subscripts W, F, and M stands for the variable inputs of production, viz., labor, chemical fertilizer, and animal power, respectively.

[26] LIMDEP Version 6 (1992) is used for the purpose.

Following the development of (5.5.1), the S_i functions of labor, chemical fertilizer and animal power is obtained by differentiating the normalized restricted translog profit function (5.5.1) as follows:

$$-\frac{P'_W.X_W}{\pi'} = \alpha_W + \gamma_{WW}\ln P'_W + \gamma_{WF}\ln P'_F + \gamma_{WM}\ln P'_M + \delta_{WL}\ln Z_L + \delta_{WA}\ln Z_A + \delta_{WI}\ln Z_I + \delta_{WS}\ln Z_S + \delta_{WE}\ln Z_E \qquad (5.5.2)$$

$$-\frac{P'_F.X_F}{\pi'} = \alpha_F + \gamma_{FW}\ln P'_W + \gamma_{FF}\ln P'_F + \gamma_{FM}\ln P'_M + \delta_{FL}\ln Z_L + \delta_{FA}\ln Z_A + \delta_{FI}\ln Z_I + \delta_{FS}\ln Z_S + \delta_{FE}\ln Z_E \qquad (5.5.3)$$

$$-\frac{P'_M.X_M}{\pi'} = \alpha_M + \gamma_{MW}\ln P'_W + \gamma_{MF}\ln P'_F + \gamma_{MM}\ln P'_M + \delta_{ML}\ln Z_L + \delta_{MA}\ln Z_A + \delta_{MI}\ln Z_I + \delta_{MS}\ln Z_M + \delta_{ME}\ln Z_E \qquad (5.5.4)$$

where X_W, X_F, and X_M are the quantities of variable inputs of labor, chemical fertilizer and animal power, respectively.

This sets of equations (5.5.1), (5.5.2), (5.5.3), (5.5.4) will be jointly estimated for each regime in the second stage after incorporating the selectivity variable to be obtained from the first stage probit estimation of the reduced-form seed selection equation.

5.5.2 The First Stage Estimation: Probit Maximum Likelihood Model

In order to adjust the selectivity bias in the final stage estimation of the profit functions and to see how prices and fixed factors affect the probability of choosing modern varieties, a reduced-form seed selection equation is estimated

$$I'_i = \theta_0 + P_i\theta_1 + Z_i\theta_2 - \varepsilon'_i$$

as a typical probit equation because this is not directly observable. What we observe is a dummy variable that takes the value of 1 if a plot is planted with modern varieties, 0 otherwise: that is

$I_i = 1$ if $I_i' \geq 0$,
$= 0$ otherwise.

The maximum likelihood estimate of the probit reduced-form seed selection equation is presented in Appendix Table A5.9. It should be noted that the right-hand side of the reduced form probit equation is the difference in the modern foodgrain and local foodgrain variety profit functions. Since both profit functions have identical sets of regressors and parametric restrictions, conceptually, the coefficients on the reduced-form regressors can be regarded as the differences between the modern foodgrain and local foodgrain variety profit function coefficients for the same regressors (Pitt, 1983).

Thirteen of the total forty-five estimated coefficients are statistically significant at 10 percent level at the least (Appendix Table A5.9). About 89 percent of the observations are accurately predicted and the McFadden's R-squared[27] was 0.23. The coefficients of probit reduced form seed selection function cannot directly reveal the sign or magnitude of the change in the probability of cultivating modern foodgrain varieties in response to change in the exogenous variables. The probit estimation is used mainly to obtain the selectivity variable (or Mill's ratio) to be incorporated in the second stage of estimation and to check the accuracy of prediction. Information on the magnitude and direction of factors affecting seed selection is provided as elasticities in Table 5.10.

The following procedures were used to obtain the probit elasticities: the derivative of the probabilities with respect to a particular exogenous variable for the probit model is given by:

$$\frac{\partial F(\phi_i)}{\partial X_{ik}} = f(\phi_i)\beta_k \qquad (5.5.5)$$

where F is the distribution function and f is the density of the standard normal; β_k is the coefficient attached to the exogenous variable X_{ik} (Maddala, 1987). Therefore, the elasticity of the probability of *i*th exogenous variable is:

$$\varsigma_h = \frac{\partial F(\phi_i)}{\partial X_{ik}} . \frac{X_{ik}}{p_i} = f(\phi_i)\beta_k . \frac{X_{ik}}{p_i} \qquad (5.5.6)$$

where p is the probability.

Seven of the nine elasticities (at the sample means) are significantly different from zero at 1 percent level ($p<0.01$) suggesting that seed selection is highly responsive to changes in prices and fixed factors (Table 5.10). The highly elastic response to foodgrain price change reflects the responsiveness of the farmers to increase their stagnant income through operating in the output market. The elasticity of probability with respect to land area is positive, though small, suggesting that farm size, is positively related with modern foodgrain production.

Table 5.10 Elasticity of probability of planting modern foodgrain varieties, 1996.

Exogenous variables	Estimated coefficients	t-ratio
Rice price	2.425	65.899[a]
Labor price	-0.366	- 5.097[a]
Fertilizer price	-0.045	- 1.405
Animal power price	-0.486	-18.489[a]
Land area	0.005	0.838

[27] McFadden's R^2 is not comparable to the R^2 in the OLS regression. McFadden's R^2 lies in the range of 0.20 to 0.40 in this type of model (Sonka *et al.*, 1989).

Farm capital	0.354	44.279[a]
Underdevelopment of infrastructure	0.086	4.072[a]
Soil fertility	0.635	20.238[a]
Education of farmer	-0.152	-23.498[a]

Note: [a] = significant at 1 percent level ($p<0.01$).
Source: Computed.

The significant ($p<0.01$) influence of non-conventional factors in increasing probability of planting modern varieties is an indication of the bottlenecks existing in the present foodgrain production system. The positive coefficient of index of underdevelopment of infrastructure indicates that modern technology adoption is higher in the underdeveloped regions. This finding is apparently in contrast with the expectation, which however, becomes clear when all other factors are considered in details. In an underdeveloped region, the choices open to farmers are highly limited. Also, access to non-farm activities is limited. It was also shown in Section 5.2 that though the profitability of modern rice and wheat is significantly higher than the local rice varieties but it is not higher than most of the non-cereal crops, particularly, potato, vegetables, spices and cotton. Therefore, in a rural region with underdeveloped infrastructure, limits to produce commercial crops and poor access to non-farm activities would induce farmers to adopt modern foodgrain technology because it would ensure significantly higher income than growing traditional foodgrain at the minimum. The argument will be clearer in the subsequent analyses.

The soil fertility index has a large positive value indicating that diffusion of modern agricultural technology will increase significantly with improvement in soil fertility status as expected. However, the education level of farmer has a negative influence in increasing modern technology diffusion. Deb (1995) also reported negative influence of education level in modern technology adoption citing that the education system in Bangladesh is not agriculture oriented and therefore pulls people out of agriculture and induce them to engage in non-farm activities that are more rewarding in general.

5.5.3 The Second Stage Estimation: Maximization of the Profit Function

From the first stage probit estimation, we defined the Mill's ratio or selectivity variable which are used as identifiability restriction to adjust the selectivity bias and force the separation of the translog profit function of the two regimes (1) and (2). One of the interesting properties of the Mill's ratio is that, the higher the value of the ratio, the lower is the probability that an observation is having data on $I_i = 1$ (Heckman, 1976).

The final specification of the reduced-form of the translog profit function with the inclusion of the selectivity variable are restated as:

$$\pi_{hi} = P_i\beta_h + Z_i\gamma_h + \sigma_{1'_\varepsilon}\left(\frac{-f(\phi_i)}{F(\phi_i)}\right) + \xi_{hi} \quad \textit{for modern foodgrain varieties}$$

$$\pi_{li} = P_i\beta_l + Z_i\gamma_l + \sigma_{2'_\varepsilon}\left(\frac{f(\phi_i)}{1-f(\phi_i)}\right) + \xi_{li} \quad \textit{for local foodgrain varieties}$$

These translog profit functions and the corresponding three share equations for each regimes were jointly estimated by using Zellner's Seemingly Unrelated Regressions Estimator (SURE).

The joint restricted parameter estimates of the normalized restricted translog profit function and labor, fertilizer, and animal power share equations adjusted for selectivity bias for modern foodgrain and local foodgrain varieties are presented in Appendix Table A5.10. The Wald Test satisfies the validity of the estimation of two functions and are highly significant (see bottom of Appendix Table A5.10). This proves, among other things, that the sample farms, on an average, maximize profits with respect to normalized prices of the variable inputs, thus supporting empirically the assumption of profit maximization. Evidence of profit maximizing behavior of the Bangladeshi farmers were also noted by Hossain (1989), Hossain *et al.*, (1990) and Ahmed and Hossain (1990).

Fifty-four and thirty-five coefficients of the total 73 coefficients in each set of functions are statistically significant at 10 percent level at the least (Appendix Table A5.10). The adjusted R-squared is 0.64 and 0.43 in modern foodgrain and local foodgrain functions, respectively. This is quite satisfactory as it maintains the validity of including large number of fixed factors along with interaction terms in each of the functions.

At the bottom of the profit function in Appendix Table A5.10, the coefficients of the selectivity variables appear, $-f(\phi_i)/F(\phi_i)$ for the modern foodgrain variety function and $f(\phi_i)/[1 - F(\phi_i)]$ for the local foodgrain variety function. The selection variable is significantly different from zero at 1 percent level of significance ($p<0.01$) in the modern foodgrain profit function. This is the evidence of pronounced selection bias in estimating equations from a subsample of cultivators (Pitt, 1983). On the other hand, there appears to be no significant selection bias in the estimation of the local foodgrain variety function. Therefore, single stage estimation of this function from a subsample of local variety cultivators should be unbiased[28].

Most of γ_{ij} coefficients are of negative signs in both the regimes as expected. The negative cross-price coefficients imply a complementarity in inputs. Land coefficient (β_L) is small but positive in modern variety regime implying profitability would increase with increase in land while it is negative for local variety regime implying that planting more land with local varieties will incur loss. This is consistent with the analysis of factor shares in rice and wheat production which, revealed that the net income from growing local varieties of rice is negative for Aus and Boro season for many farmers. The positive farm capital coefficients (β_A) in both function implies that increase in capital endowment would increase profitability. The large positive soil fertility coefficient implies that profitability will increase with improvement in soil quality, which

[28] In general, the selectivity variable may be significant in any or both of the equations (Lee, 1978 and Pitt, 1983).

is consistent with our a priori expectation. The infrastructure coefficient is positive implying that profitability will be higher in underdeveloped regions. This is due to increase in return from foodgrain production in case of shortage in supply and with little scope for bringing in foodgrain from other areas owing to underdeveloped infrastructure. The education coefficients are small, non-significant and have mixed signs, positive for modern variety regime and negative for local variety regime.

The coefficients are generally found to be larger in magnitude for local foodgrain function. This is because the profitability in local foodgrain variety production is significantly lower as compared to modern foodgrain. As such, variations in input prices and exogenous factors would lead to larger decreases in profitability in absolute terms. On the other hand, smaller coefficient in modern foodgrain function implies that the extent on reduction would be lower for an equivalent change in input prices and exogenous factors. However, firm conclusions can be drawn only from the elasticities to be computed using these profit function coefficients, factor demand functions and input prices.

5.5.4 Input Demand and Output Supply Elasticities

The estimates presented in Appendix Table A5.10 form the basis for deriving elasticity estimates for foodgrain supply and demand for the variable inputs of labor, fertilizer, and animal power services. These elasticity estimates for individual varieties were first obtained by using equation (3.7.1.18), (3.7.1.19), (3.7.1.20), (3.7.1.23), (3.7.1.24), and (3.7.1.25) of Chapter III. As noted earlier, the elasticities are functions of variable input ratios, variable input prices, level of fixed inputs, and the parameter estimates of the translog profit function presented in Appendix Table A5.10. These elasticities are evaluated at simple averages of the S_i variable input prices and fixed inputs. This provides the basis of using equation (3.7.1.27), which uses these estimates from each regime plus the elasticities of the probabilities presented in Table 5.10. The total elasticity of demand after allowing for seed switching adjustments (or permitting movements along the 'meta-response surfaces') are presented in Table 5.11.

Table 5.11 Input demand and output supply elasticities of foodgrain crops with variety switching adjustments, 1996.

	Output price	Labor price	Fertilizer price	Animal price	Land	Farm capital	Infra-structure	Soil quality	Educa-tion
Output supply	0.6470 (30.0)	-0.2357	-0.0759	-0.1384	0.5997	0.5746	4.8706	7.7288	-0.3175
Labor demand	0.4229	-0.5322 (18.9)	0.0399	0.1186	0.4495	0.4631	5.1172	6.7776	-0.2500
Fertilizer demand	0.7832	-0.1396	-0.5951 (6.2)	-0.1845	0.7164	0.6902	5.1812	7.9856	-0.3228
Animal demand	1.0626	0.2154	-0.1063	-0.9770 (0.7)	0.5966	0.4275	4.7235	7.1266	-0.2097

Note: Figures in parentheses represents percent of improvement due to variety switching adjustments.

Source: Computed.

In the translog function, unlike Cobb-Douglas, the impact across variable input demand functions for labor, fertilizer, and animal power of a given change in any of the exogenous variables is not symmetric. It varies across demand equations, which is consistent with a priori theoretical expectations (Sidhu and Baanante, 1981). All the own-price elasticities of demand are less than one except for labor in local variety regime indicating an inelastic response of factor utilization (Appendix Table A5.11). The total own price elasticity for labor was estimated at -0.45 and the seed switching adjustments increases the elasticity by about 18 percent to -0.53. The improvement in own price elasticity of fertilizer is about 6 percent, from -0.56 to –0.60. The highest level of increase is in the output supply elasticity. The total own price elasticity of supply changes from 0.50 to 0.65, a 30 percent increase. Rahman and Sriboonchitta (1995) reported that allowance for seed switching between high quality aromatic rice and low quality glutinous rice in Chiang Mai valley of Thailand improved the elasticity estimates by 16, 49, 42, and 58 percent for fertilizer, labor, tractor power and rice output, respectively. Pitt (1983) reported that allowance for seed switching between modern and local varieties of rice in Java, Indonesia improve the elasticity of fertilizer demand by 11 percent.

The fixed inputs appear to be important in influencing foodgrain supply. Their influence, however, is not uniform on labor, fertilizer and animal power demand functions. The exogenous increases in land quantities and expansion in farm capital increases output supply and demand for all variable inputs of production. The elasticities of output supply with respect to land size and value of fixed farm assets are estimated at 0.60 and 0.57, respectively. This indicates that a one percent increase in land size would increase output supply by 0.60 percent while a one percent increase in the value of fixed farm assets would increase output supply by 0.57 percent.

The influence of soil fertility status is very high. The elasticity value indicates that 1 unit increase in the index of overall soil fertility (which is almost a movement from one class to another class in such a composite index) would increase output supply by 7.7 units and increase input demand by 6.7 to 7.9 units. The influence of infrastructure is also very high. Both output supply as well as input demand will increase in underdeveloped region, as increasing demand for input may not be adequately supplied owing to underdeveloped infrastructure. On the other hand, the supply of output will be higher due to marketing bottlenecks in underdeveloped region. All price effects are quite reasonable, and nonsymmetrical nature of their impact, contrary to the Cobb-Douglas case, is as expected and more natural.

At an individual variety level, the own-price elasticity of fertilizer input is relatively higher (-0.52) for modern varieties and is consistent with the expectation (Appendix Table A5.11). Few farmers expressed interest to expand local foodgrain area, as the existing level of production is enough for consumption and market opportunities for local foodgrain is uncertain. Price elasticity of labor is higher in local foodgrain function. In Section 5.2, it was revealed that relatively less hired labor was used in local foodgrain production implying farmers' responses would be higher to changes in labor price. Also, since the profit margin in local rice is significantly lower as compared to modern foodgrain, farmers tend to response actively to price increases because it would result in larger cuts in absolute profits than modern foodgrain for an equivalent rise in prices. On the other hand, changes in output price have higher response in local foodgrain function as compared to modern foodgrain because of its preference for consumption and could be inherent attachment to tradition and culture as well.

The cross-price effects for both regimes are not different from each other, due to the inelastic nature of overall response to price changes. Output supply and input demand elasticities with respect to fixed farm assets were, however, largely different between two functions. The influence of soil fertility in local variety function is more than double to that of modern variety function implying that farmers would like to grow local varieties if soil fertility status increases. This is because producing local varieties will exert less pressure on capital requirements and increase in soil fertility would raise productivity to a desired level. Also, the education variable has a larger negative effect indicating that farmers with higher level of education discards growing local varieties to a larger extent.

5.5.5 Maximization of Profit Function for Non-cereals: One Stage Estimation

Since most of the farmers interviewed in this survey also produced a wide variety of non-cereals, an attempt has been made to evaluate their response to prices and fixed factors with respect to non-cereal production by utilizing a farm-level aggregate profit function framework. The reason for aggregation is largely due to the limitation posed by few observations on individual non-cereal crops, such as oilseeds, pulses, vegetables, potatoes and cotton. An aggregate profit function for non-cereals with the same set of variables used for foodgrain function is estimated. Appendix Table A5.12 provides the joint restricted parameter estimates of the normalized restricted translog profit function and labor, fertilizer, and animal power share equations. The Wald Test satisfy the validity of the estimation of function and is highly significant (see bottom of Appendix Table A5.12). This proves, among other things, that the sample farms, on an average, maximize profits with respect to normalized prices of the variable inputs, thus supporting empirically the assumption of profit maximization for the non-cereal crops as well.

Twenty-six coefficients of the total 73 coefficients of the functions are statistically significant at 10 percent level at the least (Appendix Table A5.12). The adjusted R-squared is 0.38 which can be considered as satisfactory since the function includes a diverse range of crops while still maintains the validity of a large number of fixed factors along with interaction terms.

Most of γ_{ij} coefficients are of negative signs as expected. The negative cross-price coefficients imply a complementarity in inputs. Land coefficient (β_L) is large and positive implying that profitability would increase with increase in land. This is consistent with the analysis of factor shares in non-cereal crop production, which reveal that the net income from growing non-cereal crops is very high. The small but positive soil fertility coefficient implies that profitability will increase with improvement in soil quality consistent with a priori expectation.

The infrastructure coefficient is negative indicating that profitability from commercial crop production is higher in developed region, a finding exactly opposite to that of foodgrain production. However, this is expected since development of infrastructure is intricately linked with the marketing and storage facilities which is vital for realizing profits from these crops. Also, as explained earlier that developed infrastructure offers more choices to farmers. The education coefficient is also positive indicating that educated farmers chose to grow non-cereal crops which provides higher profitability as shown in Section 5.2. However, firm conclusions can be drawn only from the elasticities to be computed using these profit function coefficients, factor demand functions and input prices.

5.5.6 Input Demand and Output Supply Elasticities of Non-cereal Crops

The price elasticities for non-cereal crops are presented in Table 5.12. All the own-price elasticities of demand are greater than one except for fertilizer indicating highly elastic response of factor utilization. A finding opposite to foodgrain production where farmers are more or less showed inelastic response to factor utilization. The output supply elasticity is also highly elastic (1.33) indicating that farmers respond sharply to output price changes. The own price elasticities for labor, fertilizer and animal power services are estimated at -1.55, -0.72 and -1.22, respectively.

The fixed inputs also seem to be important in influencing output supply as well as input demand. The elasticities of output supply with respect to land size is 0.23 indicating that a one percent increase in land size would increase output supply by 0.23 percent. The influence of soil fertility status is quite high and positive indicating that improvement in soil quality will increase non-cereal output supply and input demand.

Table 5.12 Input demand and output supply elasticities of non-cereal crops, 1996.

	Output price	Labor price	Fertilizer price	Animal price	Land	Farm capital	Infra-structure	Soil quality	Educa-tion
Output supply	1.3370	-0.6928	-0.1761	-0.4072	0.2349	-0.0715	-1.3889	0.6067	0.3295
Labor demand	2.6050	-1.5524	-0.4286	-0.6240	0.2026	-0.0654	-1.2787	0.2787	0.3121
Fertilizer demand	2.4649	-1.7981	-0.7221	0.0554	0.3784	-0.1079	-1.0989	0.4634	0.4221
Animal demand	2.4063	-1.2106	0.0256	-1.2213	0.3217	-0.0985	-1.3480	1.0708	0.3248

Note: Non-cereal crops include jute, potato, pulses, oilseeds, spices, vegetables, and cotton.
Source: Computed.

The influence of infrastructure is also very high. The negative elasticity values of this variable indicates that both non-cereal output supply as well as input demand is higher in developed region, a finding opposite to that of foodgrain production and is expected. Also, the education variable has a positive coefficient indicating that farmers with higher level of education chose to grow non-cereal crops, which yields higher profitability. All price effects are quite reasonable, and nonsymmetrical nature of their impact, contrary to the Cobb-Douglas case, is as expected and more natural.

5.5.7 Indirect Estimates of Production Elasticities

The usual approach for estimating production elasticities or the output elasticities is by estimating the production function directly. However, farm-level estimation of production function suffers from a number of limitations, particularly the multicolliniarity problem. A profit function approach is considered a superior technique and avoids the multicollinearity problem and thus, utilized in this study. However, if one wishes, the production elasticities can be indirectly derived from the information of price elasticities.

The indirect estimate of output elasticities of input i can be obtained by utilizing the following identities (Puapanichya and Panayotou, 1985):

$\gamma_i^* = -\gamma_i (1 - \mu)^{-1}$, i = W, F, M. (5.5.7)

$\beta_i^* = -\beta_i (1 - \mu)^{-1}$, i = L, A, E, I, S. (5.5.8)

where,

$$\mu = \sum_{i=1}^{3} \gamma_i$$

γ_i = production elasticities of variable input i
β_i = production elasticities of fixed input i

Summing up (5.5.7) we obtain:

$$\sum_{i=1}^{3} \gamma_i^* = -\mu(1-\mu)^{-1} \qquad (5.5.9)$$

$$\mu^* = \sum_{i}^{3} \gamma_i^* \qquad (5.5.10)$$

And by substituting eq. (5.5.10) into eq. (5.5.9), we obtain

$\mu^* = -\mu(1-\mu)^{-1}$

Therefore

$(1-\mu) = (1-\mu^*)^{-1}$ (5.5.11)

Finally substituting eq. (5.5.11) in eq. (5.5.7) and (5.5.8), we obtain

$\gamma_i = -\gamma_i^* (1 - \mu^*)^{-1}$, i = W, F, M. (5.5.12)

$\beta_i = -\beta_i^*(1 - \mu^*)^{-1}$, i = L, A, E, I, S. (5.5.13)

Now, the computation of production elasticities of inputs is straightforward as eq. (5.5.12) and eq. (5.5.13) are expressed in terms of price elasticities of inputs that are available from Tables 5.11 and 5.12 for foodgrain crops and non-cereal crops, respectively. Table 5.13 presents the indirect estimates of production elasticities.

The role of fertilizer in modern varieties of rice and wheat is distinct from Table 5.13. The output elasticity is almost double to that of elasticity of local rice varieties. The elasticity of fertilizer for non-cereal crop is also very high. It is interesting to note that the production elasticities of variable inputs are much higher than the fixed inputs, land and farm capital. The effect of education level of farmers has a negative impact on foodgrain production indicated by the negative coefficient of education variable while it is positive for non-cereal crop production. Soil fertility has a very high elastic response to crop production which, is expected. The elasticity of underdeveloped infrastructure indicates that foodgrain production is higher in underdeveloped regions while for non-cereal crop it is higher in developed regions.

The estimate of the returns to scale of conventional inputs, that is, labor, animal power, fertilizers, land and farm capital reveals that 'increasing returns to scale ($1.13 > 1$)' prevails in local rice production while modern rice and wheat production is characterized with 'constant returns to scale ($0.98 \approx 1$)' (Table 5.21). The overall foodgrain production is very likely to be characterized by 'constant returns to scale ($1.04 \geq 1$)'. The non-cereal crop production, however, depicts 'decreasing returns to scale ($0.82 < 1$)' which is quite disturbing as this might limit any scope for crop diversification. It should be noted that this aggregate non-cereal crop model incorporates a diverse set of crops in which returns to scale for individual crops may be variable. Therefore, it would be desirable to empirically estimate individual non-cereal crop elasticities which, is beyond the scope of this study due to the focus of the study in one hand, and the small sample size of individual non-cereal crops grown by these predominantly rice farmers on the other.

Table 5.13 Indirect estimates of the production elasticities, 1996.

Factors/inputs	Name of the crops for which the elasticities are estimated			
	Local varieties of rice	Modern varieties of rice and wheat	All foodgrain crops	Non-cereal crops
Conventional inputs				
Labor	0.3431	0.1472	0.1741	0.3453
Animal power	0.2634	0.3294	0.3147	0.2717
Fertilizer	0.0950	0.1795	0.1917	0.1606
Land	0.1874	0.1944	0.1902	0.0633
Farm capital	0.2428	0.1314	0.1736	-0.0191
Non-conventional inputs				
Education	-0.2542	-0.0688	-0.0886	0.0772
Infrastructure	0.5240	1.6321	1.6021	-0.2844
Soil fertility	4.3282	2.3416	2.3853	0.1345
Returns to scale (Conventional inputs)	1.13	0.98	1.04	0.82

Note: The infrastructure variable is defined as underdevelopment of infrastructure, therefore, positive elasticity means negative response on output.
Source: Computed.

5.6 Inferences

Input-output analysis of crop production revealed that yield per unit of land area for modern rice varieties is significantly higher than the local varieties in all crop seasons. The yield levels for modern and local rice varieties are estimated at 4.18 ton/ha and 2.32 ton/ha, respectively. The estimates for crops seasons for modern rice variety yields are 3.6 ton/ha, 3.5 ton/ha, and 4.8 ton/ha for Aus, Aman and Boro season while local rice varieties are 1.99 ton/ha, 2.38 ton/ha, and 2.60 ton/ha, respectively. No significant regional differences in yield levels of modern rice varieties are observed contrary to local rice varieties. The fertilizer use rates per unit of land (kg/ha) is significantly higher for modern rice varieties (246 kg/ha) than local rice varieties (94 kg/ha).

The profit (gross margin) per ha for modern rice varieties are estimated to be significantly higher than the local rice varieties. The profit per ha of land area is estimated at Tk. 12,822, Tk. 7,790, and Tk. 6,515 for modern rice, modern wheat and local rice, respectively. Highest modern rice variety profit per ha of land area is estimated at Tk.14,157 during Boro season followed by Tk.12,273 for Aus and Tk. 11,310 for Aman season, respectively. Among the non-cereal crops, highest gross profit per ha is estimated at Tk. 29,767 for vegetables followed by spices (Tk. 29,220) and potato (Tk. 26, 990).

The net return (farm operator surplus) for modern rice varieties is estimated at 14 percent of gross value of output (Tk. 3, 529) while it is 8 percent (Tk. 1,111) for local rice varieties. The highest net return is estimated at Tk. 12,608 (29 percent of gross value of output) for vegetables followed by Tk. 8, 938 (19 percent of gross value of output) for spices, respectively.

With respect to infrastructural development, all villages of Jessore region and five out of seven villages of Comilla region was classified as developed villages while all but one villages of Jamalpur region was classified as underdeveloped villages. With respect to soil fertility status, villages of Jessore region was classified under ‘medium’ level while villages of Jamalpur and Comilla are classified under ‘low’ level.

Farm-level decision analysis of alternative technologies revealed that farmers are profit maximizers and their response to variation in input prices and changing environment is high. Probit analysis revealed that farmer’s probability of switching from local to modern foodgrain varieties will increase with an increase in output price and decrease in input prices. Among the fixed inputs, availability of land and farm capital, and improved soil fertility will increase probability of planting modern varieties while infrastructural development and education will decrease the probability.

Estimation of price elasticities for foodgrain crops revealed inelastic response to price changes. Allowance for seed switching improved the input and output price elasticity estimates. On the contrary, highly elastic response to changes in soil fertility status and infrastructural development for foodgrain crop is observed. The sign of elasticity estimates reveal that input demand and output supply will increase with improvement in soil fertility status and decrease with infrastructural development.

For the non-cereal crops, elastic response to factor utilization was observed, except for fertilizers, which is at the upper end of the inelastic range. Also, response to infrastructure and farmer's education level is in contrast. The sign of elasticity estimate reveal that input demand and output supply will increase with infrastructural development and higher education level of farmers. Improvement in soil fertility status will also increase input demand and output supply.

Indirect estimation of production elasticities from price elasticity information revealed the dominant role of variable inputs as compared to the fixed inputs of land and farm capital for all crops. Constant returns to scale prevails in foodgrain production while decreasing returns to scale is observed in the non-cereal crop production.

CHAPTER VI

ADOPTION OF MODERN AGRICULTURAL TECHNOLOGY

Major criticism of the modern agricultural technology relates to its equity implications and a crucial factor determining this is the extent and intensity of modern technology adoption by all groups of farmers (Hossain, 1989). Moreover, relationship between specific individual factors and adoption decision cannot be determined a priori. Adoption decision may be influenced by a number of factors, such as, technical, infrastructural, soil quality, and socio-economic factors. In general, qualitative techniques, such as preference rankings, farmers' own perceptions, motives and attitudes facilitate our understanding of the decision making process. However, qualitative analysis alone cannot be considered as complete. Quantitative techniques, on the other hand, reconfirms conclusions and enable us to predict on farmers' responses, hence, their decision making process with respect to economic variables, through testing various hypotheses developed from a priori knowledge of the situation. Therefore, one strategy to analyze the issues is to use a combination of methods. The present chapter attempts to provide a detailed understanding of the diverse factors influencing adoption of modern agricultural technology utilizing both qualitative and quantitative analytical techniques.

6.1 Issues Related to Modern Agricultural Technology Adoption

Decision making process is a complicated issue dealing with which calls for substantial evidences to support the notions. A number of socio-economic issues relating to land ownership, farm size, and tenurial structure may influence adoption decision and their relationship varies widely depending on specific circumstances. For instance, relationship between farm size and modern technology adoption cannot be determined a priori. This is because, farm size is surrogate for a number of factors that may have an important bearing in adoption decision (Hossain, 1989). Impact of tenurial structure on adoption decision is another major issue with substantial controversy. Bhaduri (1973), using Indian experience, revealed that it is the interest of the landlords, who derive income from land rent and money lending, not to allow tenants to adopt new technology, as it would reduce their indebtedness and dependence. Bardhan (1971) argued that the new agricultural technology would induce higher incidence of tenancy. On the other hand, risk aversion theory implies that share tenancy may be a preferred arrangement for modern technology adoption as the risk can be shared by both, the tenants and the landlords (Hossain, 1989).

Availability of working capital and farm assets may be an important determinant in adoption decision. As shown in Chapter V that modern rice varieties requires substantially higher capital investments. Therefore, access to capital source, that is the financial institutions (formal or informal) may influence adoption decision. Access to information and sources of inputs and knowledge of new technology relating to its optimal and efficient use is another important factor. Farmers' education can be taken as a proxy measure for this variable. As modern agricultural technology involves higher labor input, availability of family labor may also be a crucial factor in adoption decision. Also, the consumption unit of the family in relation to the production unit (land and working member) may be another factor.

At the technical level, availability of inputs, such as fertilizers, pesticides and irrigation facilities, are vital factors in influencing adoption decision. Agro-ecological suitability, for instance, soil fertility status, may also be an important determinant. The infrastructural facilities that facilitate the availability of inputs and marketability of outputs, may also be an important element in adoption decision.

6.2 Farmers' Motivation and Modern Agricultural Technology Adoption

As mentioned earlier, decision making is a complicated process and is influenced by a number of factors. In this section, the qualitative features particularly, the farmers' motivation behind cultivating/not cultivating modern/local varieties of rice and wheat is presented. For this purpose, a set of motives, determined during pre-testing of questionnaire, was read to the farmers who ranked them on a five-point scale.

Modern agricultural technology has been diffused in the study region more than a decade ago (Appendix Table A6.1). Majority of Comilla farmers (57 percent) reported that modern rice varieties were introduced more than 10 years ago followed by Jamalpur (55 percent) and Jessore (47 percent), respectively. Modern wheat was also introduced earlier in Comilla. This result is expected since Comilla region is considered as the birthplace of most of the agricultural innovations since 1960s. Therefore, it is clear that modern agricultural technology was introduced in the study regions at an early stage, prior to the 1980s. As such, a clear understanding of the long-term or delayed consequences of modern technology adoption can be expected from the study regions.

It is interesting to note that, though farmers are growing modern varieties for more than 10 years, their perception with respect to trends in productivity varies widely across regions. While about 60 percent of sample farmers in Jamalpur and Jessore consider that the productivity level is somewhat increasing, 57 percent of farmers in Comilla considers that it remained unchanged and 31 percent considers that productivity is rather declining (Appendix Table A6.2). This finding indirectly supports the hypothesis of declining soil fertility, one of the major delayed consequences of modern agricultural technology adoption. Since majority of farmers in Comilla region adopted modern rice technology more than a decade ago, the effect is more profound in the region as compared to Jessore where intensity of modern variety cultivation increased only in recent years. It is worthy to mention that mean fertilizer use rate per ha for modern rice varieties is significantly higher in Comilla region (279 kg/ha) as compared to Jamalpur (231 kg/ha) and Jessore (244 kg/ha) while mean yield rates are same (4.2 ton/ha) in all these regions. Also, soil fertility analysis revealed that Comilla has the poorest soil fertility status followed by Jamalpur. Soil fertility status of Jessore, however, is relatively better.

6.2.1 Farmers' Motives behind Growing Modern Varieties of Rice and Wheat

Information on farmers' motive behind growing modern varieties of rice and wheat is presented in Table 6.1. A total of six motives were elicited, out of which 'high yield' of modern varieties of rice and wheat came as the prime motivation followed by 'ready marketability' of the product. It is interesting to note that comparatively lower proportion of farmers cited 'higher profit' as their motive to grow modern varieties of rice and wheat. The implication is further strengthened when the relative ranking among motives to grow modern varieties of rice and wheat are considered. As a whole, 'high yield' was ranked one followed by 'ready marketability' while 'high profit' is ranked lowest (Table 6.1). For individual regions, the relative strength of motives drops sharply after the first rank, except in Jessore region, where the level of decline is lower. As indicated by the index value, the motive is strongest in Jessore region followed by Jamalpur and Comilla, respectively. Though there are differences in relative ranks against each motive across regions, the pattern of motive behind growing modern varieties of rice and wheat is quite clear. The strength of such ranking is validated by estimation of rank correlation coefficients among regions. Table 6.2 reveals that relative ranking of Jessore and Comilla region is significantly ($p<0.01$ and $p<0.05$) correlated with ranking of all the regions. For Jamalpur region, though the correlation is not significant, the value is quite high. The inter-regional rank correlation coefficients are, however, weak implying diversity in secondary motives while the primary motive (high yield levels) is uniform across all regions (Table 6.2).

Table 6.1 Ranking of farmers' motives in growing modern varieties of rice and wheat by study regions, 1996.

Motives for growing modern varieties	Jamalpur region			Jessore region			Comilla region			All region		
	%[a]	Index[b]	R[c]	%[a]	Index[b]	R[c]	%[a]	Index[b]	R[c]	%[a]	Index[b]	R[c]
High yield	99	0.97	1	97	0.96	1	94	0.82	1	97	0.93	1
Ready market	70	0.47	2	91	0.73	2	54	0.32	3	70	0.49	2
Short maturity period	46	0.37	4	58	0.52	3	72	0.31	4	57	0.39	3
High quality of grain	52	0.31	6	66	0.42	5	42	0.45	2	53	0.38	4
High price	50	0.35	5	56	0.43	4	43	0.28	5	50	0.35	5
Higher profit	58	0.39	3	40	0.35	6	34	0.16	6	46	0.31	6
All motives[d]	63	0.48	2	68	0.57	1	57	0.39	3	62	0.48	

Note: [a] Multiple responses. Indicates the percent of farmers responding in the affirmative.
[b] Index = $\{R_{VH}(1.0) + R_H(0.8) + R_M(0.6) + R_L(0.4) + R_{VL}(0.2) + R_0(0.0)\} / N$
where R_{VH} = farmers giving very high rank, R_H = high rank, R_M = medium rank, R_L = low rank, R_{VL} = very low rank, and R_0 = farmers responding in the negative, respectively; and N = sample size.
The higher the index the stronger is the motive.
[c] R = Rank.
[d] Overall rank computed across three regions.
Source: Field Survey, 1997.

Table 6.2 Rank correlation among regions on motives behind growing modern varieties, 1996.

	Jamalpur region	Jessore region	Comilla region	All region
Jamalpur region	1.00			
Jessore region	0.66	1.00		
Comilla region	0.26	0.66	1.00	
All region	0.60	0.94[a]	0.83[b]	1.00

Note: [a] = significant at 1 percent level ($p<0.01$); [b] = significant at 5 percent level ($p<0.05$).

Source: Field Survey, 1997.

6.2.2 Farmers' Motives behind Growing Local Varieties of Rice and Wheat

Since, farmers still grow local varieties of rice, if not wheat, similar questions relevant for choosing local varieties were asked to the respondents. Out of nine motives, 'reliability of yield' and 'low labor intensity' were reported as the main reason behind growing local varieties of rice (particularly in Aman season when irrigation is not generally used) followed by 'high fodder output' and 'ready marketability' (Table 6.3). The 'yield reliability' of local rice varieties stands out as the prime motive behind farmers when relative ranking of each motive is considered. The second most important reason is the 'low labor intensity'. As shown in Chapter V that local variety cultivation requires less labor. The value of each index is very low because few farmers actually grow local varieties of rice. Relative strength of these inter-regional ranking is comparatively weaker than ranking done for modern varieties. However, the rank correlation is significant ($p<0.01$ and $p<0.05$) for Jamalpur and Jessore region with the overall ranking of regions (Table 6.4).

Table 6.3 Ranking farmers' motives behind growing local varieties of rice and wheat by study regions, 1996.

Motives for growing local varieties	Jamalpur region			Jessore region			Comilla region			All region		
	%[a]	Index[b]	R[c]	%[a]	Index[b]	R[c]	%[a]	Index[b]	R[c]	%[a]	Index[b]	R[c]
Reliable yield	26	0.20	2	48	0.46	1	6	0.06	3	25	0.22	1
Low labor intensity	31	0.26	1	20	0.25	5	14	0.11	1	25	0.21	2
High fodder output	21	0.18	3	39	0.30	2	7	0.02	7	21	0.16	3
Higher profit	21	0.15	6	34	0.27	3	6	0.04	5	20	0.15	4
Ready market	26	0.16	5	38	0.26	4	-	-	9	21	0.14	5
Don't need irrigation	23	0.17	4	18	0.16	9	14	0.08	2	19	0.13	6
High price	19	0.13	7	25	0.19	7	2	0.05	4	15	0.11	7
Disease resistant	14	0.12	8	18	0.17	8	7	0.03	6	13	0.10	8
High quality	17	0.11	9	26	0.20	6	1	0.01	8	14	0.09	9
All motives[d]	22	0.17	2	31	0.25	1	6	0.05	3	19	0.15	

Note: [a] Multiple responses. Indicates the percent of farmers responding in the affirmative.
[b] See explanation in Table 6.1.
[c] R = Rank.
[d] Overall rank computed across three regions.
Source: Field Survey, 1997.

Table 6.4 Rank correlation among regions on motives behind growing local varieties, 1996.

	Jamalpur region	Jessore region	Comilla region	All region
Jamalpur region	1.00			
Jessore region	0.46	1.00		
Comilla region	0.67[b]	-0.07	1.00	
All region	0.89[a]	0.79[b]	0.50	1.00

Note: [a] = significant at 1 percent level ($p<0.01$); [b] = significant at 5 percent level ($p<0.05$).
Source: Field Survey, 1997.

6.2.3 Farmers' Reasons behind Not Growing Local Varieties of Rice and Wheat

Reasons cited for not growing local varieties of rice and wheat may not necessarily reflect the motives for growing modern varieties. Therefore, in order to pinpoint farmers' motives behind decision to adopt modern agricultural technology, questions relevant for not choosing local varieties of rice and wheat were asked to the respondents. Out of seven reasons, 'low yield levels' of local varieties followed by 'poor quality of output' were reported as the main reasons (Table 6.5). Next reason is the 'long maturity period' as compared to modern varieties. 'Low level of yield' of local varieties of rice and wheat was ranked one followed by 'poor quality of output' and 'low output price' when relative ranking is considered. Individual index value drops sharply after the first ranking implying the relative weakness of the other reasons in influencing decision making. Though there are some variation in the relative ranks of reasons across regions, the pattern of reason is quite clear. This is further strengthened by rank correlation coefficients among regions (Table 6.6). As evident from the Table 6.6, the overall ranking is significantly ($p<0.01$) correlated to individual regions. Also, the inter-regional rank correlation coefficients are significant ($p<0.01$, $p<0.05$ and $p<0.10$).

Table 6.5 Ranking farmers' reasons behind not growing local varieties of rice and wheat, by study regions, 1996.

Motives for not growing local variety	Jamalpur region			Jessore region			Comilla region			All region		
	%[a]	Index[b]	R[c]	%[a]	Index[b]	R[c]	%[a]	Index[b]	R[c]	%[a]	Index[b]	R[c]
Low yield	69	0.67	1	68	0.65	1	72	0.64	1	70	0.66	1
Poor quality	26	0.17	4	28	0.14	5	75	0.52	2	42	0.27	2
Low price	28	0.19	3	38	0.23	3	34	0.24	3	32	0.22	3
Long maturity period	33	0.23	2	35	0.24	2	32	0.19	4	33	0.21	4
Require fertilizers	25	0.16	5	31	0.12	6	18	0.06	5	24	0.12	5
No one grow these	10	0.05	7	24	0.19	4	3	0.03	7	11	0.08	6
Requires pesticides	15	0.07	6	21	0.07	7	10	0.05	6	15	0.07	7
All motives[d]	29	0.22	3	35	0.24	1	35	0.23	2	33	0.23	

Note: [a] Multiple responses. Indicates the percent of farmers responding in the affirmative.
[b] See explanation in Table 6.1
[c] R = Rank.
[d] Overall rank computed across three regions.
Source: Field Survey, 1997.

Table 6.6 Rank correlation among region on motives behind not growing local varieties, 1996.

	Jamalpur region	Jessore region	Comilla region	All region
Jamalpur region	1.00			
Jessore region	0.96[a]	1.00		
Comilla region	0.78[b]	0.71[c]	1.00	

All region	0.97[a]	0.94[a]	0.90[a]	1.00

Note: [a] = significant at 1 percent level ($p<0.01$); [b] = significant at 5 percent level ($p<0.05$).
[c] = significant at 10 percent level ($p<0.10$).
Source: Field Survey, 1997.

Therefore, a cross-examination of motives behind growing modern varieties and reasons behind not growing local varieties clearly reveal that it is the 'yield advantage' of modern varieties which is the prime determinant of adoption of modern agricultural technology. The 'ready marketability' and 'short maturity period' of modern varieties of rice and wheat is also important in adoption decision. However, though modern varieties yield higher returns per unit of land, 'higher profitability' do not seem to be the prime determinant implying that other crops, particularly the non-cereal cash/commercial crops, yield higher profit as compared to modern varieties of rice and wheat (for details see Chapter V).

6.3 Patterns of Modern Agricultural Technology Adoption

It was mentioned earlier that socio-economic and technical factors may influence adoption decision and their relationships cannot be determined a priori. In this section, influence of major socio-economic factors such as farm size classes and tenurial status, and technical factors such irrigation technology in decision to adopt modern varieties is analyzed. The proportion of farmers using modern varieties of rice or wheat in at least one season appears to be highest in Jessore region followed closely by Jamalpur region and substantially lower in Comilla region, irrespective of size classes and tenurial status (Table 6.7).

Table 6.7 Adoption of modern agricultural technology by farm size and tenurial status by study regions, 1996.

Farmers	Percent of farmers using modern varieties				Percent of area under modern varieties[1]			
	Jamalpur	Jessore	Comilla	All region	Jamalpur	Jessore	Comilla	All region
Land ownership categories[2]								
Landless	83.7	94.4	69.8	82.1	87.3	69.9	69.0	77.3
Marginal	86.1	95.5	71.9	83.3	85.9	72.2	77.3	80.0
Small	86.0	93.7	62.2	78.1	89.1	52.8	67.8	75.7
Medium	89.7	100.0	42.9	81.3	84.4	62.5	62.6	74.1
Large	83.3	93.3	na	88.9	78.8	61.2	na	69.3
Tenurial status[3]								
Own-oper.	87.0	95.4	64.8	82.6	83.7	61.5	68.6	73.3
Part tenant	85.7	91.3	67.5	80.4	88.2	65.7	74.0	79.4
Tenant	80.8	100.0	60.0	81.0	83.7	70.1	57.7	72.2
All	**85.7**	**95.2**	**65.1**	**81.8**	**84.8**	**62.8**	**69.0**	**74.7**

Note: na means not applicable.
[1] As percent of gross cropped area.
[2] Landless = less than 0.20 ha of owned land, marginal = owned land 0.21 – 0.40 ha, small = owned land 0.41 – 1.00 ha, medium = owned land 1.01 – 2.00 ha, and large = owned land above 2 ha.

[3] Owner operator = operates owned land; part tenant = operates own land and rent-in additional land, tenant = do not operate owned land but rent-in land for crop production.

Source: Field Survey, 1997.

There is a moderate declining trend in proportion of farmers adopting modern varieties with increasing farm size for Comilla region. However, when the proportion of gross cropped area devoted to modern varieties of rice and wheat is considered, Jamalpur region stands out highest while Jessore and Comilla regions become closely comparable, irrespective of size classes and tenurial status. This is due to the fact that Jessore region has diverse cropping system as compared to Comilla region. Therefore, even though very high proportion of farmers in Jessore region grow modern varieties of rice and wheat, the land they allocate for this purpose competes with non-cereal crops, particularly, pulses, oilseeds, jute and cotton. Table 6.7 further reveals that though there are some variations in absolute proportions, no definite pattern between decision to adopt and size classes or tenurial status can be observed. This indicates that size classes and tenurial status do not adversely impact on adoption decisions, and therefore, not a constraint in modern agricultural technology diffusion in Bangladesh. It is evident from Table 6.7 that landless and marginal farmers are higher adopters who in turn operate mostly on rented-in lands, a notion also supported by Hossain *et al.* (1990). This finding, therefore, supports the argument of Bardhan (1971) who noted that modern technology would increase tenancy, which is implied from the observation of higher adoption intensity by landless and marginal farmers operating mostly as tenants.

Water control is one of the major pre-requisites for modern rice cultivation. Without assured supply of water, the yield levels of modern varieties could be even lower than the local varieties. Table 6.8 reveals that 60 percent of farmers in Comilla region is using irrigation in at least one season followed by Jessore and Comilla region. Substantially high proportion of farmers using irrigation in Comilla region is due to their location within Meghna-Dhonagoda FCD/I project command area. However, there is no major difference in area under irrigation between Jessore and Jamalpur regions while Comilla has comparatively lower proportion of land under irrigation (Table 6.8).

Table 6.8 Adoption of irrigation technology by farm size and tenurial status by study regions, 1996.

Farmers	Percent of farmers using irrigation				Percent of area under irrigation[1]			
	Jamalpur	Jessore	Comilla	All region	Jamalpur	Jessore	Comilla	All region
Land ownership categories[2]								
Landless	43.6	50.0	65.1	52.2	63.7	60.7	56.6	60.8
Marginal	22.2	36.4	62.5	40.0	56.6	62.6	61.9	59.7
Small	20.9	56.3	51.4	38.5	62.1	53.1	48.5	55.7
Medium	51.7	43.8	64.3	52.5	67.9	64.1	52.7	64.1
Large	50.0	53.3	nil	51.8	73.3	64.3	nil	68.5
Tenurial status[3]								
Own-oper.	35.0	44.6	56.3	44.1	67.4	61.6	54.2	62.9
Part tenant	30.6	52.2	67.5	48.2	60.1	65.6	58.2	61.1

Tenant	46.2	52.9	60.0	51.7	67.3	63.6	41.4	57.4
All	**35.4**	**47.6**	**60.3**	**46.3**	**65.8**	**62.4**	**53.9**	**62.1**

Note: na means not applicable.
[1] As percent of gross cropped area.
[2] Landless = less than 0.20 ha of owned land, marginal = owned land 0.21 – 0.40 ha, small = owned land 0.41 – 1.00 ha, medium = owned land 1.01 – 2.00 ha, and large = owned land above 2 ha.
[3] Owner operator = operates owned land; part tenant = operates own land and rent-in additional land, tenant = do not operate owned land but rent-in land for crop production.
Source: Field Survey, 1997.

The reason for such contrasting observation could be due to the degree of scatteredness of plots under individual ownership. Land owned by an individual farmer in Jamalpur and Jessore tend to be in close proximity as compared to Comilla region where the scatter is wider. Therefore, for an individual farmer, a certain portion of the land is within command area of the surface irrigation system. Also, due to the existence of a large-scale irrigation system, the minor irrigation installations, such as shallow tube wells are not developed for drier pockets within the command area of the irrigation project, thereby reducing the overall proportion under irrigation. Also, there is sharp variability in proportion of farmers using irrigation and area under irrigation across regions with respect to size classes and tenurial status. Therefore, no definite pattern of adverse effect of size classes and tenurial structure in accessing modern irrigation can be observed from Table 6.8.

6.4 Determinants of Modern Technology Adoption: A Multivariate Analysis

The aforementioned sections attempted to provide a sketch of the motives for adopting modern agricultural technology as well as patterns of adoption across farm size classes and tenurial categories. Though considerable amount of information is provided in these analyses, a complete picture of factors determining adoption behavior cannot be ascertained from them. Therefore, in order to explain the extent of modern agricultural technology adoption and factors determining decision to adopt, the following equation is fitted at the household level:

PMVAR = f (OWNLND, PIRRIG, PTNC, AMLND, FPR, WAGER, ANIMPR, LBR, CAPL, AGCR, NAGI, EDUCH, FAMILY, WORK, WORKW, INFRA, SOIL)

PMVAR = proportion of cultivated land under modern varieties of rice and wheat (%)
OWNLND = amount of land owned by the household (ha)
PIRRIG = proportion of cultivated land under irrigation (%)
PTNC = proportion of cultivated land rented-in (%)
AMLND = amount of land cultivated by the household (ha)
FPR = fertilizer price relative to price of rice and wheat at farm-level
WAGER = labor wage relative to price of rice and wheat at farm-level
ANIMPR = animal power price relative to price of rice and wheat at the farm-level
LBR = amount of land cultivated per agricultural worker (ha)
CAPL = value of farm capital excluding land asset ('000 taka)

AGCR	= amount of agricultural credit borrowed by the household ('000 taka)
NAGI	= income from non-agricultural sources of the household ('000 taka)
EDUCH	= completed years of formal schooling of the head of household (years)
FAMILY	= number of family members in the household (persons)
WORK	= number of working members in the household (persons)
WORKW	= number of female working members in the household (persons)
INFRA	= index of underdevelopment of infrastructure
SOIL	= index of soil fertility

Justification for incorporating the variables is as follows. As mentioned earlier, land ownership and farm size are surrogates for a large number of factors. Also, there are considerable debate relating to tenurial status and adoption of modern technology. Availability of irrigation is a major complementary factor in adoption decision. Therefore, all these variables are incorporated to test their influence in adoption decision.

As the modern agricultural technology is input intensive the relative profitability of growing modern varieties of rice and wheat may depend on the prices of these inputs. The labor variable defined as amount of land cultivated per unit of labor is a measure of labor scarcity and is assumed to influence adoption decision. Farm capital may also influence adoption decision as higher availability of farm capital lowers borrowing cost. Capital constraint is also an important factor that may influence adoption decision adversely. As such, availability of agricultural credit serves as a major means to liquidate this constraint. Also, availability of non-agricultural income may influence farmers to switch away from labor intensive agricultural production to non-farm activities. Therefore, the non-agricultural income variable is incorporated to test this influence. Access to information and ability to utilize inputs optimally and/or opportunity to switch away from agriculture to higher income earning non-agricultural activity may also influence adoption decision. Farmers' education is incorporated to capture this effect.

According to Chayanovian theory of peasant economy, the consumption unit of the family in relation to the production unit may be an important determinant of modern technology adoption (Hossain, 1989). Family size is incorporated to capture the effect of subsistence pressure. The number of working members in the family might ease the labor constraint and reduce hired labor requirement. As such this variable is added to capture its influence. There has been considerable debate relating to gender equity and technological change. It was increasingly observed that modern agricultural technology largely displaced women from the rural labor market, particularly, in post-harvest operations. Number of working female members is incorporated in the function to observe whether women have any influence in adoption decision. One of the major objective of this study is to highlight the role of non-conventional factors: infrastructural and soil fertility factors in influencing decision-making. The two variables, the index of underdevelopment of infrastructure and index of soil fertility are incorporated to test their influence in adoption decision.

<u>Estimation:</u>

As data of the dependent variable is observed in the range between 0 and 100, the values are censored at both tails. The most appropriate estimation technique for such case is the Tobit (two limit probit) procedure (Hossain, 1989; Ahmed and Hossain, 1990; and Hossain *et al.*

1990). For the present study, both OLS (Ordinary Least Squares) and Tobit estimation procedures were applied to the data[29]. The estimated parameters of the model are presented in Table 6.9 with asymptotic t-ratios. Table 6.9 reveals that both OLS and Tobit model provide similar results. The most significant ($p<0.01$) factor that influences modern technology adoption is the irrigation variable reflected by highest t-value. This is expected, as irrigation is a major complementary input in growing modern varieties. Tenurial status measured by amount of land rented-in is positively related with adoption. The value is close to be significant at 10 percent level. Therefore, the argument that modern technology increases intensity of tenancy (Bardhan, 1971) is validated. The signs of land ownership and farm size variables are negative, the later being significant ($p<0.01$). The negative coefficient for farm size indicates that modern technology is adopted more in areas with poor land endowments. That is the smaller the farm size the higher the intensity to adopt modern technology in order to earn more income from limited resource base. This further implies that, contrary to the expected a priori hypothesis, economically unfavorable areas may have benefited more from the adoption of modern technology (see Chapter V). This finding was first supported by Hossain *et al.* (1990) in contrast to the earlier conclusion by Hossain (1989). The present study seems to reinforce this argument, however, the equity implication can be judged only by analyzing the issue of income distribution and poverty (dealt in detail in Chapter VIII).

Input prices seem to have positive relation with adoption rate. This can be explained in the context of relative profitability between modern and local varieties. As shown in Chapter V, profitability from local variety is significantly lower than modern varieties. Therefore, in a situation of increasing input prices, particularly, price of animal power services, which is invariant to growing either local or modern varieties, it would be better to chose a high income yielding crop to cover the increasing costs, leading to the adoption of modern varieties.

Table 6.9 Determinants of modern agricultural technology adoption, 1996.

Variables	OLS estimate		Tobit estimate	
	Coefficients	t-ratio	Coefficients	t-ratio
Intercept	0.115	0.89	-0.090	-0.40
OWNLND	-0.001	-0.04	0.031	0.66
PIRRIG	0.372	9.90[a]	0.542	8.23[a]
PTNC	0.044	0.98	0.129	1.62
AMLND	-0.037	-1.86[c]	-0.088	-2.64[a]
FPR	-0.040	-0.90	0.005	0.07
WAGER	0.009	0.89	0.004	0.22
ANIMPR	0.008	1.65[c]	0.017	2.11[b]
LBR	-2.686	-1.22	-1.844	-0.47
CAPL	0.002	1.81[c]	0.002	1.28
AGCR	-0.001	-0.99	-0.001	-0.37
NAGI	-0.001	-2.45[b]	-0.001	-1.73[c]
EDUCH	-0.004	-1.36	-0.008	-1.38
FAMILY	-0.003	-0.59	-0.005	-0.57
WORK	0.004	0.29	0.005	0.22

[29] LIMDEP Software Version 6 (1992) is used for the analysis.

WORKW	-0.037	-1.86[c]	-0.089	-2.36[b]
INFRA	0.006	7.49[a]	0.009	6.43[a]
SOIL	0.117	1.89[c]	0.125	1.18
Adj.R-squared	0.36	-	-	-
$F_{(17, 388)}$	14.47[a]	-	-	-
Log-likelihood	-	-	-201.42	-

Note: [a] = significant at 1 percent level ($p<0.01$); [b] = significant at 5 percent level ($p<0.05$).
[c] = significant at 10 percent level ($p<0.10$).
na means not available.
Source: Computed, 1997.

Farm capital positively influence adoption decision as expected. The coefficient is significant ($p<0.10$) in the OLS function. Non-agricultural income has significant ($p<0.10$) negative influence in adoption decision. This implies that farmers who are not able to adopt modern technology due to technical constraints (not necessarily the capital constraint) can augment their household incomes from non-agricultural sources. This finding was also supported by Hossain (1989).

Education level of the household head negatively influences adoption. The coefficient is significant at 10 percent level. The indication is that higher level of education provides greater opportunity to the farmer for switching either to non-cereal crops that yield higher income or to non-farm income generating activities. It is interesting to note that though total number working members in a household is positively related with modern technology adoption, number of working female members is significantly ($p<0.05$) negatively associated with adoption decision. The t-value is third highest, just after irrigation and infrastructure index. This reveals the discriminatory access of women in decision making.

As mentioned earlier, one of the major objectives of this study is to analyze the role of infrastructural and soil fertility factors in influencing adoption decision. The highly significant ($p<0.01$) positive coefficient for index of underdevelopment of infrastructure imply that adoption intensity is higher in underdeveloped regions. This might be due to constraints imposed by the underdeveloped infrastructure constraining farmers to switch to other non-farm income generating activities. This notion is supported by the other indicator, the non-agricultural income of the household, which is significantly ($p<0.10$) negatively related with modern technology adoption. In the OLS model, the soil fertility index is significantly ($p<0.10$) positively related with adoption indicating that better the soil quality, higher is the adoption of modern varieties, which conform to the a priori expectation. The implication is that biophysical constraints also have important bearing in decision making.

6.5 Support Services for Modern Agricultural Technology Diffusion

Agricultural extension service is vital for successful dissemination of new technologies developed in the research and academic institutes. In the developing countries, extension service is generally poor and inefficient. The constraints are many ranging from lack of skilled manpower, budgetary allocation, and infrastructure to stiff bureaucracy and ineffective field administration. Analysis of constraints faced by the agricultural extension system is beyond the scope of this study. However, few open ended questions relating to visits of agricultural extension officials and training received by farmers were asked to the respondents in order to assess the current level of inter-relationship among farmers and field level agricultural extension officials in the study regions.

The distance of nearest agricultural extension office from the study villages across regions is highly variable (Appendix Table A6.3). About 77 percent of the respondents reported that the nearest agricultural extension office is within three kms from their households in Comilla region, an infrastructurally developed area. The distance of the office is above five kms for 42 percent and 79 percent of respondents in Jessore and Jamalpur region, respectively. It should be noted that almost all villages in the Jamalpur region were categorized as underdeveloped villages in terms of infrastructure (see Chapter V).

Table 6.10 clearly reveals that the exchange of ideas and knowledge between farmers and agricultural extension officials are almost negligible. The number of visits made by the agricultural extension officials to the village is less than 10 percent in each region. Similarly, the visits made by farmers to the nearest agricultural extension office are less than 10 percent. This is an indication of the level of extension support provided for technology transfer in Bangladesh. It should be noted that agricultural extension official here refers to Thana Agricultural Extension Officer and higher, not the Block Supervisor who usually stays in any of the village within his/her command area.

Table 6.10 Number of visits of agricultural extension office to villages and farmers' visits to agricultural extension office during last one year by study regions, 1996.

Number of visits made in the last one year	Number and percent of households (%)			
	Jamalpur region	Jessore region	Comilla region	All region
Agricultural extension officer making visits to the village				
Once	10 (5.7)	3 (2.9)	2 (1.6)	15 (3.7)
Between two to three times	2 (1.2)	6 (5.8)	2 (1.6)	10 (2.4)
Between four to ten times	1 (0.6)	3 (2.9)	-	4 (0.9)
No visits by AEO to village	162 (92.5)	93 (88.4)	122 (96.8)	377 (92.1)
Farmers making visits to agricultural extension office				
Once	5 (2.9)	5 (4.8)	2 (1.6)	12 (3.0)
Between two to three times	2 (1.1)	5 (4.8)	-	7 (1.7)
Between four to twenty times	3 (1.7)	2 (1.9)	-	5 (1.2)
No visits by farmers to office	165 (94.3)	93 (88.6)	124 (98.4)	382 (94.1)
Total households	175 (100.0)	105 (100.0)	126 (100.0)	406 (100.0)

Note: Figures in parentheses are percentages of total households.
Source: Field Survey, 1997.

An inquiry on whether the farmers had received any training related to agricultural production in past seven years revealed that except Jessore region, negligible number of farmers received any formal training (Table 6.11). This is another indication of persistent lack of support for modern technology transfer to and from the research centers.

Table 6.11. Types of training received by farmers in past seven years by study regions, 1996.

Type of training received by farmers in past seven years	Number and percent of households			
	Jamalpur region	Jessore region	Comilla region	All region
Farmers received training	7 (4.0)	16 (15.2)	3 (2.4)	26 (6.4)
Seed bed preparation	1 (0.6)	1 (0.9)	1 (0.8)	3 (0.8)
Crop production	6 (3.4)	8 (7.7)	2 (1.6)	16 (3.9)
Fertilizers/pesticides application	-	7 (6.9)	-	7 (1.3)
Farmers not received training	168 (96.0)	89 (84.8)	123 (97.6)	380 (93.6)
Total households	175 (100.0)	105 (100.0)	126 (100.0)	406 (100.0)

Note: Figures in parentheses are percentages of total households.
Source: Field Survey, 1997.

Further, a breakdown of sources of training revealed that the government agencies, particularly, the agricultural extension office network provided training in Jessore and Comilla region, while the non-governmental organizations (NGOs) provided training in Jamalpur region (Table 6.12). This reflects the differential focus of government agencies and NGOs in their approach to rural development in Bangladesh. While the government with its minimal support tends to stick to agricultural development *per se*, the NGOs focuses on building up capacities and skills in small-scale cottage industries and trading activities. Also, spread of NGOs across all regions of the country is highly variable. The concentration of NGOs working at the grassroots is highly concentrated in the upper northern Bangladesh and selective central regions located in closer proximity from the capital Dhaka. Among the study regions, the extent of NGOs are relatively abundant in Jamalpur region followed by Jessore and Comilla. This might be another reason for dominance of NGOs training farmers in Jamalpur.

Table 6.12 Organizers of the training programs received by farmers by study regions, 1996.

Organizers of the training programs	Number and percent of households (%)			
	Jamalpur region	Jessore region	Comilla region	All region
Government agencies	1 (0.6)	16 (15.2)	3 (2.4)	20 (4.9)
Non-governmental organizations	6 (3.4)	-	-	6 (1.5)
Total households	175 (100.0)	105 (100.0)	126 (100.0)	406 (100.0)

Note: Figures in parentheses are percentages of total households.
Source: Field Survey, 1997.

An inquiry into the reasons for not receiving training in past seven years revealed that majority of the farmers did not deem it necessary (Table 6.13). Only few reported that they did not get the opportunity to receive training. However, 33 percent farmers in Comilla and 11 percent farmers in Jamalpur region reported that no one ever came to offer training, indicating their desire to receive training if offered (Table 6.13).

Table 6.13 Reasons cited by farmers who did not receive any training by study regions, 1996.

Reasons cited by farmers who did not receive any training	Number and percent of households (%)			
	Jamalpur region	Jessore region	Comilla region	All region

Did not get the opportunity	19 (11.3)	3 (3.4)	1 (0.8)	23 (6.0)
No one came to offer training	18 (10.7)	4 (4.5)	40 (32.5)	62 (16.3)
Did not think it as necessary	88 (52.4)	76 (85.4)	60 (48.8)	224 (58.9)
Non response	43 (25.6)	6 (6.7)	22 (17.9)	71 (18.7)
Farmers not received training	168 (100.0)	89 (100.0)	123 (100.0)	380 (100.0)

Note: Figures in parentheses are percentages of total households.
Source: Field Survey, 1997.

Since knowledge on modern agricultural technology can come from a variety of sources, such as model farmers, field demonstrations, audio-visual media and neighbors, and the perception on technology can be many, farmers were asked to provide examples which they consider represents modern agricultural technology. Table 6.14 reveals the broad group of these technologies. As evident from Table 6.14 that the concentration is in fertilizer and pesticide application techniques followed by cost reduction options and modern variety use. Land preparation by tractor is mentioned only in Comilla region indicating the diffusion of mechanized tillage equipment. This is perhaps due to increasing cost of tillage by using bullock-pairs and shortage of cattle in this region. As mentioned earlier, Comilla region is classified as developed in terms of infrastructure, which might have facilitated the diffusion of mechanization as compared to other areas.

Table 6.14 Knowledge of modern agricultural technology by study region, 1996.

Type of technology	Percent of households			
	Jamalpur region	Jessore region	Comilla region	All region
Farmers citing technology				
Fertilizer application technique	21.7	23.8	21.2	22.2
Pesticides application technique	14.8	20.8	29.0	20.2
General advise/cost reduction	14.2	27.5	3.9	14.4
Use of modern varieties	17.2	19.5	3.2	14.3
Planting technique	8.1	9.1	7.3	8.2
Land preparation by tractor	-	-	9.8	2.5
Irrigation system	2.1	0.4	0.5	0.4
Farmers citing none	23.8	22.5	1.0	17.6
Total households	100.0	100.0	100.0	100.0

Note: Multiple response.
Source: Field Survey, 1997.

6.6 Inferences

Analysis of farmers' motives revealed that it is the higher yield (ranked one), ready marketability (ranked two) and short maturity period (ranked 3) of the modern varieties that induces them to grow while profitability is ranked lowest. On the other hand, low yield (ranked one), poor quality of grains (ranked two) and low output price (ranked three) are the major reasons cited for not growing local varieties of rice and wheat.

Farm size and tenurial status do not seem to affect adversely to modern technology adoption decisions. The landless and marginal farmers are observed to be higher adopters who in turn mainly operate as tenants. Irrigation was found to be the major determining factor in influencing adoption decisions. Farm size, number of female family labor, non-agricultural income, and infrastructure development negatively influence adoption decisions. Soil fertility has positive influence in adoption decisions.

The support services for agricultural extension is very weak. There is a serious lack of interaction among agricultural extension officials and farmers. Knowledge of modern agricultural technology is mainly confined to application techniques of fertilizers and pesticides only while dissemination of relevant information for crop diversification, variety screening, health hazards of pesticide uses, and adverse impacts of modern agricultural technology is non-existent.

CHAPTER VII

TECHNOLOGICAL CHANGE AND ITS IMPACT ON EMPLOYMENT, RURAL LABOR MARKET AND FACTOR MARKETS

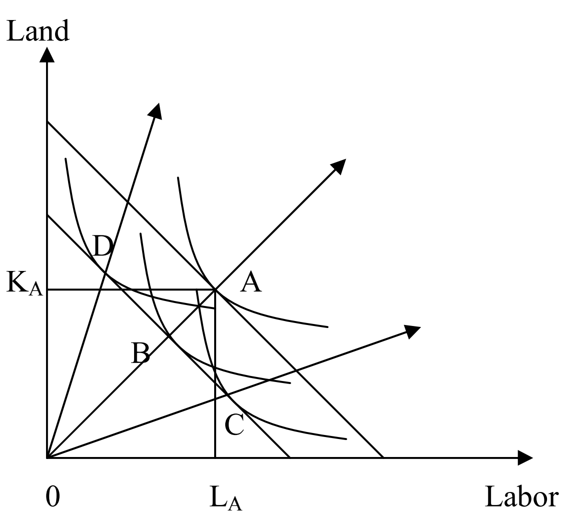
The literatures analyzing impacts of modern agricultural technology mostly emphasized on the direct effects on income distribution and geographical regions with a basic argument that the technology is not scale neutral and benefited most in areas endowed with favorable agro-ecological conditions (Lipton and Longhurst, 1989). However, Hossain *et al.* (1990) argued that modern agricultural technology may also have indirect effect that operates through factor markets and enables transfer of income across socio-economic groups as well as regions. This could occur from a change in the nature of operation of the land, labor and other input markets thereby indirectly smoothing income disparity across socio-economic groups through an adjustment process.

The present chapter analyzes the direct and/or indirect effects of modern technology diffusion on employment, rural labor market and other factor markets. The employment effect of the modern agricultural technology is analyzed with particular reference to its effect on gender distribution of labor, which is a major source of controversy. It also provides a systematic estimation of the women's participation in agricultural operations. The other factor markets on which the impact of technological change is analyzed include fertilizer, pesticide, land, agricultural credit, and output markets.

7.1 Employment Effects of Technological Change: Analytical Framework

Prior to the analysis of the employment effects, a brief on the theoretical framework of the labor use effect of technological change would be worthwhile. Figure 7.1 shows the impact of three basic types of technological change and their impact on labor use. In Figure 7.1 point A is the combination of factor used with the old technology. The three new isoquants D, B, and C represent labor-saving, neutral and labor-using technologies that are capable of producing the same level of output utilizing cost minimization principles. Though, labor productivity increases in all these three cases, due to the variation of factor proportions, the demand for labor also varies (Unnevehr and Stanford, 1985).

In a situation of growing supply of labor, they will only benefit from productivity increases if it is accompanied by increased demand for their labor. Figure 7.2 shows impact of labor demand from three types of technological change at an individual household level. Under a given set of prices of inputs and output, L_O amount of labor is used for the traditional (old) technology. With either a neutral or labor-using shift in the production function, it will be profitable for the household to employ additional labor to produce more output. If this additional demand for labor were to be absorbed by women then only the women will benefit from this technological change.



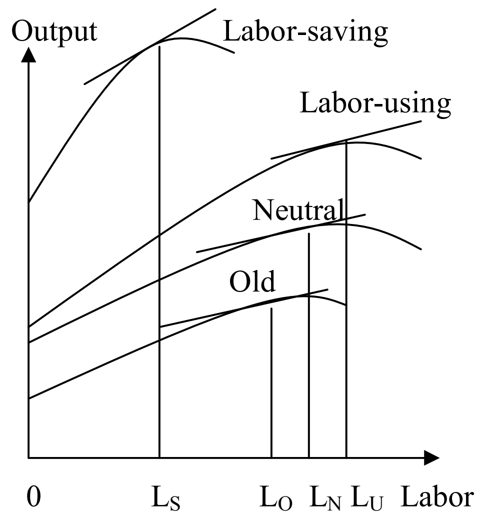


Figure 7.1 Technological change and factor proportion

Figure 7.2. Technological change and labor use.

Source: Adapted from Unnevehr and Stanford (1985).

7.2 Issues Related to Impact of Modern Agricultural Technology on Employment

Nearly one third of rural households in Bangladesh do not own any cultivable land and about half of them own less than 0.2 ha of land making farming as only a marginal source of income (Hossain, 1989). Due to such low access to land, the main source of livelihood of these households depend on the condition of the rural labor market, that is, the extent and duration of employment and the wage rate. Technological change in agriculture is expected to change the condition of rural labor market by increasing the labor use intensity through increased cropping intensity and productivity of labor thereby influencing the wage rate. Since the supply of labor is likely to be fixed in the short-run, increased demand will result in rise in wages, provided that shortage is not met by in-migration of labor from other regions. Also, as the rural labor market is largely composed of landless and marginal farmers, the upward pressure in wages would entail redistribution of gains from modern agricultural technology through a process of income transfer from producer farmers to hired laborers. Hossain *et al.* (1990) argued that, even if increased demand for labor were met by rural-rural in-migration, then the shortage of labor in non-adopting villages would cause an upward pressure in wages. Eventually the wage differential between adopter and non-adopter villages will narrow down at a higher wage level. Technological change may also indirectly affect the non-agricultural labor market as the expenditure of increased agricultural income would generate additional demand for non-agricultural goods and services (Hossain, 1989).

Alauddin and Tisdell (1995), observing historical data for Bangladesh, claimed that though significant employment gains has resulted from the 'Green Revolution' technologies in Bangladesh, however, the employment generating effect of the 'Green Revolution', in recent years, is slowing down showing little prospect for increased absorption. Also, there is little prospect of having a major turning point in labor absorption in non-farm sector to lead a successful industrialization as observed in East Asian regions, thereby providing a gloomy future for Bangladesh. Similar conclusion has also been arrived by Osmani (1990). He noted that the drastic fall in total labor force in agriculture is not an indication of a turning point[30] but rather the consequence of increasing work-sharing arrangement and consequent decline in average productivity per worker. He claimed that the true nature of shift gets revealed in areas where technological change has opened up new opportunities for gainful employment in agriculture. In these areas, a reverse flow of surplus labor from non-farm sectors to farm activities, are observed.

7.3 Technological Change and Employment Opportunities for Women

Rural women in Asia play a major role in agricultural sector particularly in the post harvest processing. With the advent of 'Green Revolution' there was an increased demand for labor owing to increased cropping and labor intensity of modern varieties. The scope of mechanization in the production arena remained only within provision of water for irrigation and to some extent for land preparation. However, a major shift in technology occurred in the post harvesting processing sector, the introduction of rice mills, which dramatically displaced employment opportunities of rural women involved in manual husking operation of rice grains. Ahmed (1982) estimated that rice mills displaced 29% of the total husking labor and almost all hired labor displaced were women who have limited alternative employment opportunity. His crude nationwide estimate reveals that, if rice mills are made adequately available throughout the country, a total of 45 million person-days of hired labor would be displaced leading to a reduction of rural poor's income of about Tk.450 million at its 1982 level estimates.

As the employment opportunities of rural women are closing in the post harvesting processing sector and non-farm sector is being highly stagnant, the alternative lies in actively involving them directly in crop production activities. In this respect, it is worth mentioning that gender division of labor in Bangladesh agriculture is strictly demarcated with women being responsible for most of agricultural work within the household and are not generally allowed to undertake field or market work (Begum, 1985; and Abdullah, 1985). However, contrasting version is also evident. Zaman (1995) observed that village women are working in fields with men as agricultural wage laborers. Women not only participate in rice crop production and processing but also involved in the production and processing of other major crops such as sugarcane, jute, wheat, and other winter crops.

Large number of studies were undertaken in evaluating impact of 'Green Revolution' in Bangladesh agriculture (e.g., Hossain, 1989; Ahmed and Hossain, 1990; Hossain *et al.* 1990; and Alauddin and Tisdell, 1991). Though these studies explicitly examined the employment effects of modern agricultural technology, however, they did not incorporate any gender dimension in their analyses. Furthermore, there is a dearth of knowledge about employment effect of modern agricultural technology for rural women and studies dealing with the issue remained confined in the post harvesting processing activities only (e.g.,

[30] The notion is that the slow growth rate of agricultural labor force implies a movement towards a priori expectation of reaching a turning point in the growth of agricultural labor force. Such an occupational shift from agriculture to non-agriculture and/or modern sector implies the onset of a Lewisian transition of labor surplus economy.

Begum, 1985; and Abdullah, 1985). As such, no systematic estimate of gender division of labor use for agricultural crops is available for Bangladesh. Also, the time-use approach used by almost all the studies dealing with gender roles examined daily workloads by activities, but did not provide the total labor input used for specific crops by gender.

A Note on Data Sources for Analyzing Gender Dimension of Employment Effects

In addition to the Field Survey 1997, the primary data for this section of the study comes from another intensive farm-survey conducted in crop year 1989 covering the same villages of Jamalpur and Jessore regions[31]. Therefore, total sampled households for the crop year 1989 stands at 1,755 in two regions (BRAC-VSP Survey, 1990). Though details of crop input-output data were collected in both surveys, only the BRAC-VSP Survey (1990), i.e., the survey of crop year 1989, contains labor input data for each agricultural operation and for specific crop production activities classified by men and women. Therefore, the analytical results for this section relates to the results of both surveys.

7.4 Participation of Sample Households in Economic Activities

In this study a worker is defined as a person who is available for work in income earning activities or expenditure saving activities during the week of the survey period and also identified as working member by the respondent. The activities include both agricultural and non-agricultural activities. Table 7.1 presents the labor force participation rate.

Table 7.1 Labor force participation by study regions, 1996.

Region	Average family member	Average working members	Participation rate in economic activity	Male worker as proportion of family size	Female worker as proportion of family size
	(persons)	(persons)	(percent)	(percent)	(percent)
Jamalpur region	5.27	1.88	38.49	25.81	12.68
Jessore region	6.24	2.47	40.78	29.44	11.34
Comilla region	6.90	1.88	29.31	27.88	1.43
All region	6.02	2.03	36.23	27.39	8.84

Note: na means not applicable.
Source: Field Survey, 1997.

The average family size is highest in Comilla (6.9 persons) followed by Jessore (6.2 persons) and Jamalpur regions (5.3 persons), respectively (Table 7.1). The average number of workers per household is estimated at 1.9 persons for both Comilla and Jamalpur and 2.5 for Jessore region, respectively. The number of workers in Comilla is less despite highest family

[31] These data were collected by BRAC (one of the largest national non-governmental organization) to serve as base-line information for a ten-year longitudinal study project, called as Village Study Project (VSP). As such, a census of all the 14 villages were conducted on virtually all types of information prevailing in a rural setting, for the cropyear 1989. The base-line data collection took about 6 months engaging 16 field researchers who were stationed in the core village of each thana. The first author of this study was responsible for coordinating the data collection.

size is due to non-participation of female as working members. There is an increasing trend in family size with land size categories for all regions (Appendix Table A7.1). Similar trend is observed for the average number of working members in the family as well as the labor force participation rate. Though the relative proportion of male working members is around 25 – 30 percent the proportion of female working members is much lower in all regions. In Bangladesh there is a social stigma against women working in the field or work as wage laborer (Hossain, 1989). The strikingly lower proportion of female workers in Comilla region reflects that the social stigma in labor use pattern is strongest in that region. However, women members from very poor family supply labor in all regions in order to raise subsistence.

7.5 Gender Distribution of Labor Input in Crop Production

Gender based human labor input for crop production by sources of supply is presented in Table 7.2. It is clear from Table 7.2 that women's labor input varies substantially across crop groups. Women's involvement in rice production is less than 13 percent, while for wheat and other non-cereal crops, such as pulses, oilseeds, spices, cotton and vegetables the range is above 13 percent. Their highest involvement is in vegetable production (about 48 percent of total labor requirement). This finding, therefore, proves that the claim that women labor is actively utilized only at post harvest processing stage in Bangladesh is an underestimation. A comparison of labor input data of present study with other evaluation studies of 'Green Revolution' reveals that inclusion of women labor separately in labor accounting does not distort the total labor requirements of crop production (Table 7.2). Rather, the estimates are strikingly close. However, leaving women labor in labor accounting seriously under-mine their important role in agricultural production.

Limiting the analyses of labor use only at this point can lead to serious misleading conclusion if one wish to predict the market for hired women labor requirements. A close look at the columns of hired labor input in Table 7.2 will clarify the matter by revealing the dismal scenario of hired women labor. The figures for hired women are practically zero for rice and less than 3 percent for wheat and non-cereal crop production except cotton. Only cotton production, a specialized crop grown in Jessore region, involves large amount of hired women labor. This proves that the theoretical framework within which this analyses is performed remains true only for men labor since the proportion of hired labor is substantially higher for modern varieties of rice and wheat. In other words, the increased demand for labor owing to the rapid technological progress in the foodgrain production was totally absorbed by hired men labor alone.

Breakdown of women labor input by agricultural operations reveals that though a major portion of women labor input goes into threshing operation for foodgrain crops, about 5 - 10 percent is involved in harvesting operations, weeding, and fertilizing, respectively (Appendix Table A7.2). For the non-cereal crops, the extent of involvement is wider, practically, in all types of agricultural operations, such as, in potato, spices, and vegetables production which again challenges the claim that women are involved only in post harvest processing of agricultural crops.

Table 7.2 Labor input in crop production by gender (all regions), 1989.

Crops/ seasons	Proportion of labor use per hectare of land							Comparison study
	Family labor		Hired labor		Total labor			
	Men	Women	Men	Women	Men	Women	Total labor	Total labor
Aus season (early monsoon)								
L Aus rice	43.1	11.1	45.1	0.7	88.2	11.8	100 (153)	152[a]
M Aus rice	35.0	11.5	52.9	0.6	87.9	12.1	100 (174)	185[a]
Jute	38.3	5.3	55.5	0.9	93.8	6.2	100 (227)	245[b]
Aman Season (monsoon)								
L Aman rice	40.0	11.0	48.4	0.6	88.4	11.6	100 (155)	160[b]
M Aman rice	35.6	9.2	54.6	0.6	90.2	9.8	100 (174)	189[b]
Boro Season (dry winter)								
L Boro rice	39.9	12.4	47.2	0.5	87.1	12.9	100 (178)	152[a]
M Boro rice	39.6	10.8	48.6	1.0	88.2	11.8	100 (212)	203[a]
L wheat	46.2	16.1	35.6	2.1	81.8	18.2	100 (143)	146[b]
M wheat	44.1	13.2	41.2	1.5	85.3	14.7	100 (136)	159[b]
Potato	52.4	12.5	33.8	1.3	86.2	13.8	100 (311)	295[b]
Pulses	41.3	25.7	31.2	1.8	72.5	27.5	100 (109)	82[b]
Oilseeds	38.5	18.3	40.4	2.8	78.9	21.1	100 (109)	118[b]
Spices	50.4	18.8	27.8	1.0	78.2	21.8	100 (276)	321[b]
Vegetables	34.9	46.5	17.4	1.2	52.3	47.7	100 (186)	217[c]
Cotton	50.1	15.3	23.1	11.5	73.2	26.8	100 (295)	211[b]

Note: Figures in parentheses are total number of labor used per hectare of land.
[a] Selected from Hossain *et al.* (1990).
[b] Selected from Mahmud *et al.* (1994).
[c] Selected from Sanyal (1993).
Source: BRAC-VSP Survey, 1990.

7.6 Technological change and Operation of the Labor Market

Though it is widely recognized that modern technology adoption directly influences the distribution of income across all classes of farmers and geographical regions, the scale neutrality of modern technology has been seriously criticized resulting in diversified evaluations. This is evident in the conclusion drawn by Freebairn (1995) from his analyses of 307 evaluation studies. However, researchers (e.g., Hossain, 1989; Hossain *et al.*, 1990; and Ahmed and Hossain, 1990) argue that modern technology adoption may also have indirect effect through operation of factor markets, particularly, the hired labor market. There those discriminated by the advent of modern technology would benefit from a redistribution of income through increased wages owing to increased labor demand.

7.6.1 Demand for Hired Agricultural Labor

Demand for hired labor is significantly ($p<0.01$) positively related with amount of land owned by households (Table 7.3). The correlation coefficients are estimated at 0.75, 0.87, and

0.71 for Jamalpur, Jessore and Comilla region, respectively. The level of hired labor use consistently increases with increasing size of land owned in all regions as indicated by significant ($p<0.01$) value of F-ratio. The pattern of hired labor use between the landless and marginal households are, however, not significantly different (as indicated by similar letters for LSD test values at five percent level). The difference in hired labor use becomes significantly ($p<0.05$) different across small, medium, and large farmers (as indicated by different letters for LSD test values). This is expected, as there is no major difference in socio-economic status between landless and marginal farmers, who mostly operate as tenants as well as hired labor.

Table 7.3 Hired labor as proportion of total agricultural labor by study regions, 1996.

Landownership categories[1]	Hired labor as proportion of total agricultural labor per household (%)			
	Jamalpur region	Jessore region	Comilla region	All region
Landless	46.56^{A}	43.67^{A}	52.47^{A}	47.68^{A}
Marginal	49.81^{AB}	56.25^{A}	64.89^{A}	56.75^{B}
Small	63.54^{B}	63.67^{A}	66.74^{B}	64.79^{C}
Medium	78.03^{C}	72.48^{B}	75.41^{C}	75.90^{D}
Large	83.63^{D}	72.97^{C}	na	77.71^{E}
All categories	59.16	57.93	62.37	59.84
F-ratio for mean diff.	44.41^{a}	31.06^{a}	23.56^{a}	84.76^{a}
Degree of freedom	4, 170	4, 100	3, 122	4, 401
Correlation coefficient	0.75^{a}	0.87^{a}	0.71^{a}	0.77^{a}

Note: Same block letters in superscript represents similarity in hired labor use levels across landownership categories based on LSD at 5 percent level of significance ($p<0.05$).
[a] = significant at 1 percent level ($p<0.01$).
[1] Landless = less than 0.20 ha of owned land, marginal = owned land 0.21 – 0.40 ha, small = owned land 0.41 – 1.00 ha, medium = owned land 1.01 – 2.00 ha, and large = owned land above 2 ha.
na means not available.
Source: Field Survey, 1997.

Table 7.4 presents the trend in hired labor use over time for local and modern rice. Though it is encouraging to note the increasing trend in hired labor component in production of rice crops in recent years, as compared to the 1982 period, it leaves little for the growing mass of landless rural women as only men are hired to meet the increased demand (Table 7.2). Practically, most of the past evaluation studies of labor market effects of technological change in Bangladesh agriculture (e.g., Hossain, 1989; Ahmed and Hossain, 1990; Hossain *et al.* 1990; and Alauddin and Tisdell, 1991) bypassed this notion of persistent gender inequality in reaping the benefits of the 'Green Revolution' technology. On the other hand, Table 7.2 reveals that increased labor requirement for growing modern varieties is met by either increased involvement (in terms of actual labor days) of women members of the family implying their increased workload or hiring male labor. The reduction in proportion of male labor from the family in growing modern varieties reinforces the notion (Table 7.2). For example, from a total of 153 days of labor input, about 43 percent and 11 percent are supplied by men and women member from the family in local Aus rice cultivation. On the other hand, for modern Aus rice cultivation, from a total of 174 days of labor input, 35 percent and 12 percent of total is supplied by men and women members from the family implying that less men and more women are involved from the family.

Table 7.4 Trends in hired labor input for crop production (all regions), 1989 and 1996.

Crops/ Seasons	Proportion of hired labor as percent of total labor			
	Present study		Comparison study	
	Field Survey 1997	BRAC-VSP 1990	BIDS 1987	BIDS/IFPRI 1982
Local Aus rice	67.5	45.8	44.1	29.0
Modern Aus rice	59.7	53.4	52.7	41.0
Local Aman rice	50.6	49.0	42.4	41.0
Modern Aman rice	62.0	55.2	50.3	41.0
Local Boro rice	46.8	47.8	43.4	24.0
Modern Boro rice	59.6	49.5	52.7	34.0

Note: ng means crop not grown.
na means not available.

Source: Field Survey (1997), BRAC-VSP Survey (1990), Hossain *et al.* (1990), and Hossain (1989).

7.6.2 Wage Rate Distribution by Gender

The present study is not only set to identify the validity of this indirect effect argument of technological change on employment generation but also attempts to analyze the influence of women in the hired labor market. As a first step towards such an attempt, actual farm-level wages paid for hired labor for both men and women for the crop year 1989 is presented in Table 7.5. It should be noted that the mean wage rate appearing under men's column includes influence of women's wages as households who used both men and women hired labor reported the total labor cost only. However, the mean wage rate under women's column are for households hiring only women workers, thereby, revealing the actual wage paid to women (though such cases are very few). Table 7.5 clearly demonstrates the level of discrimination in wage payments for women. The mean difference in wages between men and women is about Tk. 11 per day and is 30 percent lower than men's wage. Though there is a significant wage differential for men across region the rate of discrimination against women remains constant. Hossain (1989) also noted different wages for men and women.

Table 7.5 Wage differentials by gender and region, 1989.

Regions	Wage rate per day (taka)		Mean difference between gender	t- ratio
	Men	Women		
All region	31.6	20.1	11.5	16.36[a]
Jamalpur region	32.8	21.4	11.4	7.41[a]
Jessore region	30.6	19.6	11.0	15.13[a]
Mean difference between region	2.2	1.8	-	-

F-ratio	713.36[a]	1.45	-	-
Degree of freedom	1, 5012	1, 183	-	-

Note: [a] = significant at 1 percent level ($p<0.01$).
Source: Computed.

7.6.3 Determinants of Labor Demand: A Multivariate Regression Analysis

It is already evident from Table 7.2 that modern varieties of rice and wheat production utilize more hired labor than the local varieties. In order to rigorously test this hypothesis and identify the influence of factors affecting labor demand, a multivariate analysis is performed at the household level. The following equation is fitted to the data:

LABOR = f (AMLND, MVAR, TNC, WAGE, INFRA, SOIL, SUBP, WORK, WORKW, EDUCH)
where:
LABOR = number of days of total labor used in crop production (days)
AMLND = amount of land cultivated by the household (ha)
MVAR = amount of cultivated land under modern varieties of rice and wheat (ha)
TNC = amount of cultivated land rented-in (ha)
WAGE = labor wage at the farm-level (taka/day)
INFRA = index of underdevelopment of infrastructure
SOIL = index of soil fertility
SUBP = subsistence pressure measured as number of family members (persons)
WORK = number of working members in the household (persons)
WORKW = number of female working members in the household (persons)
EDUCH = completed years of formal schooling of the head of household (years)

It was observed that some farmers in the sample did not hire-in labor indicating that the dependent variable takes a zero value. For such cases, the problems of estimation when the dependent variable takes a zero value can be avoided by applying Tobit estimation procedure. Therefore, the household level data on hired labor use is estimated using both Tobit as well as OLS (Ordinary Least Squares) procedures. For the total labor use at the household level, however, only OLS procedure is used. The estimated parameters are presented in Table 7.6.

The fit is remarkable for both models for hired as well as total labor demand indicated by values high adjusted R-squared, F-ratio, and significance of variables. Also, the results are closely comparable to a similar estimate of Hossain (1989) using survey data for the cropyear 1982 (Appendix Table A7.3). It is clear from Table 7.6 (and Appendix Table A7.3) that, despite a span of 15 years between these two surveys, the nature of labor demand remains strikingly similar. This reveals the stagnant and tradition bound nature of agricultural production in Bangladesh.

Labor wage remains an important factor in determining labor demand with its strong negative influence ($p<0.01$), both for hired labor as well as total labor (Table 7.6). The cultivated area and area under modern varieties are significantly ($p<0.01$) positively associated with labor demand. However, the tenancy variable is significantly ($p<0.05$ and $p<0.01$) negatively associated with hired labor but positively with total labor. This is because, land rent in Bangladesh ranges from 40 – 45 percent of gross value of agricultural production (see Table 5.5) therefore, hiring more wage labor would seriously depress any profit from crop production. The situation is same 15 years ago as evident from the comparison study.

The index of under development of infrastructure also operates in similar way. The higher the level of infrastructural development the higher will be the demand for hired labor as the members of the households are expected to engage more in non-farm activities leading to shortage of family labor available for crop production. Education level of the household head is positively associated with hired as well as total labor demand. The comparison study also revealed the same results (Appendix Table A7.3).

Table 7.6 Determinants of labor use in crop production, 1996.

Variables	Demand for hired labor		Demand for total labor
	OLS estimate	Tobit estimate	OLS estimate
Intercept	162.780[a]	170.900[a]	155.420[a]
AMLND	35.253[a]	35.981[a]	57.668[a]
MVAR	29.231[a]	29.694[a]	16.000[a]
TNC	-15.560[b]	-14.502[c]	29.185[a]
WAGE	-1.007[a]	-1.065[a]	-1.502[a]
INFRA	-0.197	-0.238[c]	0.267[b]
SOIL	-54.030[a]	-57.608[a]	-41.744[a]
SUBP	-2.646[b]	-3.027[a]	-2.794[b]
WORK	-5.780[a]	-6.083[a]	-0.248
WORKW	1.218	1.575	-3.717
EDUCH	0.942[b]	1.096[a]	0.541
Adjusted R-squared	0.73	-	0.80
F-value (10, 395)	111.43[a]	-	163.36[a]
Log likelihood	-	-1886.42	-

Note: [a] = significant at 1 percent level ($p<0.01$); [b] = significant at 5 percent level ($p<0.05$); [c] = significant at 10 percent level ($p<0.10$).
Source: Computed.

Soil fertility appears to influence labor demand significantly ($p<0.01$). The higher the soil quality, the lower will be the demand for hired as well as total labor. This is expected, as high soil quality would require less labor input for all operations. The subsistence pressure and total number of working members is negatively associated with hired and total labor demand consistent with the a priori expectation.

Total number of working female in the family negatively influences the total demand for labor. A finding also observed in Hossain (1989). This reveals the consistency of important role that women play by substituting for hired labor from the family in agricultural production in Bangladesh.

7.6.4 Impact of Modern Agricultural Technology on Labor Wage

In order to determine the optimum wage rate, both demand and supply factors are to be determined. This would require information on in-migration of labor as well. Also, seasonality of labor supply and demand factors require that the data collection period should be spread over a calendar year which is beyond the scope of this study both in terms of time and fund. Therefore, the supply aspect of labor is avoided in this study. However, past studies (Hossain 1989; and Hossain *et al.* 1990) revealed that technological progress is an important variable affecting wage rate. In the present study, the following wage equation is fitted to the plot level data:
WAGE = f (LABOR, OWNLND, MVAR, INFRA, SOIL)

where:

WAGE	= labor wage at the farm-level (taka/day)
LABOR	= number of days of total labor used in crop production (days)
OWNLND	= amount of land owned by the household (ha)
MVAR	= amount of cultivated land under modern varieties of rice and wheat (ha)
INFRA	= index of underdevelopment of infrastructure
SOIL	= index of soil fertility

OLS model was fitted separately for rice crops (all varieties of rice) foodgrain crops (all varieties of rice and wheat) and all crops (foodgrain plus non-cereal crops). Regression results show that the price quantity relationship has the expected signs and is highly significant (p<0.01) in all equations (Table 7.7). Also see Appendix Table A7.4 for details.

Table 7.7 Determinants of labor wage, 1996.

Variables	Rice crops	Foodgrain crops	All crops
	OLS estimate	OLS estimate	OLS estimate
Constant	36.297[a]	25.147[a]	18.822[a]
LABOR	-0.046[a]	-0.030[a]	-0.023[a]
OWNLND	0.978	0.153	0.613[b]
MVAR	9.770[a]	8.749[a]	6.465[a]
INFRA	0.062[b]	0.086[a]	0.083[a]
SOIL	3.737[a]	9.293[a]	13.125[a]
Adj. R^2	0.09	0.10	0.14
F-ratio	9.19[a]	13.10[a]	28.02[a]
Degrees of freedom	5, 391	5, 491	5, 843

Note: [a] = significant at 1 percent level (p<0.01); [b] = significant at 5 percent level (p<0.05); [c] = significant at 10 percent level (p<0.10).
Source: Computed.

Land ownership status is positively related to wage rates and is significant (p<0.05) when all crops are considered indicating that wage rates are higher in areas with large landowners. The technology variable, the area under modern varieties, is one of the most important variable which is significantly (p<0.01) positively related with wage rates indicating that labor wages are higher in areas with high level of diffusion of modern agricultural technology.

The effect of the state of infrastructure as well as soil fertility status on labor wages is also very pronounced. The positive significant ($p<0.05$ and $p<0.01$) coefficient for underdevelopment of infrastructure indicates that labor wages are higher in underdeveloped areas. This is expected given the structure of production in the underdeveloped areas explained in earlier chapters. It was observed that intensity of modern technology adoption is higher in underdeveloped regions and also labor requirement is higher for modern rice cultivation. The joint operation of these factors will lead to increase in demand for labor that will eventually push up wages given limited supply of labor within the village and lower level of labor in-migration owing to underdeveloped infrastructure. The positive significant ($p<0.10$ and $p<0.01$) coefficient of soil fertility variable indicates that wages are higher in areas with higher soil fertility status largely due to increased cropping intensity and land use. All the three regression estimates show similar results, thereby, reinforcing confidence in the estimated functions.

7.7 Issues Related to Impacts of Modern Agricultural Technology on Factor Markets

As the increased diffusion of modern agricultural technology will increase the supply of foodgrains, the price of foodgrain is likely to remain low relative to other crops. This will lead to rise in real wages for agricultural laborers for both adopting as well as non-adopting regions. This notion of relatively lower and/or stagnant price of foodgrain, particularly rice, was already observed in the study region. However, this phenomenon will adversely affect the farmers not adopting modern agricultural technology who will lose out in the pursuit of subsistence. One of the many responses to combat the situation would be to switch from local varieties of rice and wheat to high income generating non-cereal crops, which would largely compensate income loss from non-adoption of modern technology or even raise income than the adopter farmers. However, it should be noted that foodgrain crop still covers more than 80 percent of gross cropped area in Bangladesh.

Historically, agriculture in Bangladesh has been dominated by rice monoculture. With the increased diffusion of modern varieties of rice and wheat, there will be a concentration of foodgrain crop production in regions with favorable irrigation as well as agro-ecological features. This will lead to specialization in foodgrain crop production and increase in marketable surplus thereby transforming consumption oriented subsistence farmers into market oriented foodgrain farmers. In the long run, this will spur growth of non-agricultural activities in the region with consequent increase in employment in the non-agricultural sector.

Apart from the indirect favorable impact of modern agricultural technology on the labor and output market, similar adjustment of income transfer can occur through the operation of the land market, particularly through change in tenurial arrangements, rental income from land and increased transactions in buying and selling operations. The prime effect of modern agricultural technology is increase in land productivity. Also, the short maturity of modern varieties of rice lead to an increase in cropping intensity, which complements to increased land productivity. As supply of land is relatively inelastic as compared to any other rural asset and wealth, the increased productivity per unit of land will raise its prices in the land market. Also, the rental income from a given piece of land will increase. As seen in Table 5.5, the factor share for land is within 40-45 percent of gross value of production while for hired labor the share is less than 20 percent. This implies that the gain derived from modern agricultural technology is much higher for landowners than for the laborers. However, increased land productivity would induce farmers from low productive regions to in-migrate through purchase of land. In the long run the effect would be the reduction of farm size in high adopter regions and an increase in farm size for low adopter regions. This notion is already observed in the study regions, since there are no farmers in the large farmer category (land owned > 2.00 ha) in Comilla region. While in Jessore region 16 percent of sample farmers fall in this category with average holding of 3.0 ha followed by 7 percent in Jamalpur region with average holding of 2.75 ha. It is needless to mention that Comilla region is categorized as representative of highly developed agricultural region, followed by Jamalpur region at the lower margin of medium developed region and Jessore at the lower end of low developed region (see Table 4.3).

Since the cultivation of modern varieties of rice and wheat is input intensive, the historically existing tenurial arrangement is likely to be changed. For example, in the past the most common form of sharecropping system was 50-50 crop sharing arrangement with no input costs shared by the landowner. Though a number of legislations were passed to change the land rental arrangement to 33-67 crop sharing arrangement between landowner and sharecropper, the implementation has been ineffective. However, with the increased diffusion of modern agricultural technology, a change was observed in the land rental arrangement, particularly, the input sharing arrangement between the landowner and the tenant farmer, which are detailed in subsequent analyses.

7.8 Technological Change and Fertilizer Market Operations

Fertilizer is a major input required for the cultivation of modern varieties of rice and wheat. Fertilizer subsidies have been a major component of government policy with a guaranteed distribution system since the early stages of modern agricultural technology diffusion, the late 1960s. However, with an increase in the use of fertilizers, the cost of subsidy became very high and made it difficult to be afforded by the government. Moreover, the primary policy of fertilizer subsidy was to promote use of fertilizers and diffusion of modern varieties of rice which were largely successful as the yield rates doubled in a span of 30 years. It should be noted that the rate of subsidy used in fertilizer distribution underwent major changes within this period. In later years, during the 1980s, the level of subsidy was gradually reduced and finally the subsidy was formally removed on December 1992 (Baanante *et al.*, 1993). The removal of subsidy incorporated the privatization of the delivery and marketing system as well. An evaluation study on the impact of removal of fertilizer subsidy conducted by International Fertilizer Development Centre (IFDC) showed that the increase in fertilizer prices as the consequence of removal of subsidy have a very small negative impact on rice yield. For instance, the 30 percent increase in fertilizer/rice price ratio is estimated to cause a decrease of only 1 percent in the increment of rice yield associated with the use of nitrogen and phosphate fertilizers in Aman season. The impact is even lower for Boro and Aus seasons. However, the effect of the subsidy removal on farmer’s income and profitability is much higher. The authors argued that this will be offset by developing an efficient marketing system since the reduction of rice price has a much higher impact than increase in fertilizer prices, and therefore, opted for removal of fertilizer subsidy (Baanante *et al.*, 1993).

It was shown in Table 5.2 that fertilizer use rates are significantly higher for modern varieties as compared to local varieties. The fertilizer use rates are also very high for non-cereal crops, such as potato, vegetables and cotton (Table 5.2). Table 7.8 shows that there is significant ($p<0.01$) differences in farm specific prices of all types of fertilizers across regions. The sharp variation is in the price of phosphate fertilizers (TSP) followed by potash fertilizers. This shows the effect of subsidy removal and liberalization of delivery system of fertilizers. The rise in prices during peak season is much higher than anticipated due to ineffective marketing system and hoarding by limited number of fertilizer dealers. The sharp price difference of TSP fertilizers across regions is the example of imperfect market liberalization. Therefore, the results of the impact study on fertilizer removal, which was conducted only a year after the subsidy removed formally (1992), remains quite questionable.

Table 7.8 Fertilizer prices by study regions, 1996.

Type of fertilizers	Farm specific mean prices of fertilizers (Tk/kg)				F-ratio for mean regional difference
	Jamalpur region	Jessore region	Comilla region	All region	
Urea	5.77	5.61	6.61	5.96	34.66[a]
TSP	7.44	12.32	8.00	9.22	402.86[a]
MP	6.87	7.20	8.00	7.29	28.29[a]
Gypsum	3.26	3.16	4.71	3.51	40.16[a]
All types	6.08	7.32	7.26	6.80	81.99[a]

Note: Urea = 46 percent nitrogen (N); TSP (Triple Super Phosphate) = 46 percent potash (P_2O_5); MP (Muriate of Potash) = 60 percent of potassium (P_2O); and Gypsum = zinc (BBS, 1994).
[a] = significant at 1 percent level ($p<0.01$)
Source: Field Survey, 1997.

The primary markets, in other words the village markets, serves as the major source for fertilizer supply with the exception of Comilla region where the secondary market is very close to the sample villages (Appendix Table A7.5). A negligible portion of farmers in the Jamalpur region reported city market as the primary source. An inquiry on the distance of buying places of fertilizers revealed that majority of farmers can buy their fertilizers within three kms from the village (Appendix Table A7.6). About 40 percent of them reported that the distance of fertilizer buying place is within one km, implying negligible transport costs incurred for fertilizer purchases.

In an attempt to identify problems related to purchase of fertilizers after the removal of subsidy and liberalization of the delivery and marketing system, it was revealed that the problems and/or effects are not uniform across regions. For example, about 57 percent of farmers in Jamalpur region reported problems as compared to only 36 percent in Comilla and 11 percent in Jessore. The major problems cited are high price of fertilizers and shortage in supply. Cheating in weight also came up as third major reason in Jamalpur region (Appendix Table A7.7). It is already known from Chapter V that Jamalpur region is characterized with underdeveloped infrastructure relative to Comilla and Jessore, respectively.

7.8.1 Impact of Modern Agricultural Technology on Fertilizer Prices

As mentioned earlier that fertilizer is an integral component of the modern agricultural technology. Hence, a positive association between fertilizer demand and area cultivated under modern variety of rice and wheat is expected. The increased demand for fertilizer might put an upward pressure to fertilizer prices. Also, since each single region is very small compared to the overall fertilizer demand of the country, the fertilizer prices is most likely to be determined exogenously with no influence of technological change in affecting its prices. In order to identify factors affecting fertilizer prices, the following fertilizer price equation is fitted to the plot level data.

FP = f (FERT, OWNLND, MVAR, INFRA, SOIL)

where:

FP	= price of fertilizer at the farm-level (taka/kg)
FERT	= amount of fertilizer used by the household (kg)
OWNLND	= amount of land owned by the household (ha)
MVAR	= amount of cultivated land under modern varieties of rice and wheat (ha)
INFRA	= index of underdevelopment of infrastructure
SOIL	= index of soil fertility

Reason for using land endowment, as one of the arguments is obvious. Availability of land is intricately linked with crop production. As such, the area under modern variety is used to capture the impact of technological change on fertilizer prices. Higher soil fertility status implies favorable physical condition for agricultural production thereby increases cropping as well as landuse intensity. This in turn would increase the demand for inputs as well as supply of outputs. As soil fertility varies from region to region, farmer’s response pattern relating to use of land will vary. As such the soil fertility factor is incorporated in the model to capture this effect of soil quality on fertilizer prices.

Under the assumption of competitive market, prices of inputs and outputs are expected to be exogenous. Infrastructural factors, in terms of better transportation and marketing facilities would affect prices through transport costs and profit margin of traders. The prices farmers pay for inputs and receive for outputs includes this transportation cost as well as traders margin which is likely to vary across farms and regions, depending on the state of development of infrastructure. This effect will be captured by the index of underdevelopment of infrastructure variable.

Ordinary Least Square (OLS) model was fitted separately for rice (all varieties of rice) foodgrain crops (all varieties of rice and wheat) and all crops (foodgrain plus non-cereal crops). Regression results show that the price quantity relationship has the expected signs though the coefficient is not significant (Table 7.9, also see Appendix Table A7.8 for details). The low adjusted R^2 indicates the exogenous nature of prices (Ahmed and Hossain, 1990). This finding conforms to our expectation.

Land ownership status and area under modern varieties also have positive relationship with fertilizer price indicating prices are higher in areas with large landowners and high level of diffusion of modern agricultural technology. However, the effect is not significant resulting in weak conformity to our a priori expectation. The effect of the state of infrastructure as well as soil fertility status on fertilizer prices is very pronounced. The negative significant ($p<0.01$) coefficient for underdevelopment of infrastructure indicates that fertilizer prices are higher in developed areas. This is expected due to the fact that in developed regions, there are more choices open to the farmers, particularly, in growing non-cereal crops that uses higher doses of fertilizers (see Table 5.2). The positive significant ($p<0.01$) coefficient of soil fertility variable indicates that fertilizer price is higher in areas with higher soil fertility status largely due to increased cropping intensity and land use. All the three regression estimates show similar results, thereby, reinforcing confidence in the estimated functions.

Table 7.9 Determinants of fertilizer prices, 1996.

Variables	Rice crops	Foodgrain crops	All crops
	OLS estimate	OLS estimate	OLS estimate
Intercept	5.100[a]	5.936[a]	6.321
FERT	-0.001	-0.001	-0.001
OWNLND	0.092	0.031	0.002
MVAR	0.015	0.119	Na
INFRA	-0.013[a]	-0.017[a]	-0.023[a]
SOIL	1.341[a]	0.901[a]	0.805[a]
Adj. R^2	0.07	0.06	0.09
F-ratio	7.08[a]	7.33[a]	18.56[a]
Degrees of freedom	5, 391	5, 491	5, 843

Note: [a] = significant at 1 percent level ($p<0.01$).
na means not applicable.
Source: Computed.

7.9. Technological Change and Pesticide Market Operations

Though pesticide has not been considered as a complementary input to be used in conjunction with new seeds, fertilizers, and irrigation while promoting diffusion of modern agricultural technology, it nevertheless, became a major input in present day agriculture. Pesticide use has a number of adverse effects, ranging from toxification of soil and water bodies to human health effects. The pesticides used for agriculture may be broadly classified in four categories: (a) organophosphate, (b) organochlorine, (c) carbamate, and (d) pyrithroid. According to World Health Organization (WHO), pesticides of organophosphate and organochlorine group are highly hazardous for human health (WHO, 1984). Table 7.10 presents the type of pesticides used in the study regions.

Table 7.10 Type of pesticides used by farmers by study regions, 1996.

Types	Percent of total households (%)			
	Jamalpur region	Jessore region	Comilla region	All region
Organophosphate	86.1	76.5	53.3	69.4

Carbamate	1.8	10.5	36.7	19.2
Organochlorine	5.5	9.1	6.2	6.8
Pyrithroid	6.6	3.9	3.8	4.6
Total number of households	100.0 (175)	100.0 (105)	100.0 (126)	100.0 (406)

Note: Figures in parentheses are percentage of total households.
Source: Field Survey, 1997.

It is clear from Table 7.10 that the chemical composition of pesticide used differs very sharply across regions. Though no information on human health component is collected in this study, one can get an indication of the potential human health hazard by observing the type and level of pesticide use (for details see Chapter IX). The concentration of pesticides of organophosphate group is highest in Jamalpur region followed by Jessore region while it is substantially less in Comilla region. However, the organophosphate pesticides, ranging from extremely to highly hazardous category, dominates pesticide use in the study regions followed by carbamates which is less hazardous to human health. The lower use of organophosphate chemicals in Comilla may be linked to the early adoption of modern agricultural technology in this region as compared to Jamalpur and Jessore. As such the hazards of pesticide use might have been realized early leading the farmers to switch to less hazardous chemicals, such as, carbamates.

While primary markets (village markets) serves as the major source for fertilizers, the supply source of pesticides are mainly the secondary markets (growth centers) in the rural region (Appendix Table A7.9). Few farmers in Jamalpur reported city market as the primary source. However, an inquiry on the distance of buying places of pesticides revealed that majority of farmers can buy their pesticides within three kms from the villages (Appendix Table A7.10). About 41 percent of them reported that the distance of pesticide buying place is within one km, implying negligible transport costs incurred for pesticide purchases as well.

However, it is a relief (satisfaction) to find that a large majority (66 – 95 percent) of farmers considers that they use sufficient amount of pesticides for their crops (Appendix Table A7.11). The current mean level of pesticide use per ha for all crops is Tk. 240, Tk. 404, and Tk. 633 for Jamalpur, Jessore, and Comilla region, respectively. Once again, the high cost incurred in pesticides as well as fertilizers in Comilla region can be linked to its early adoption and delayed consequences of modern agricultural technology. Few farmers reported any problems regarding the purchase of pesticides and the vast majority (92 – 99 percent) cited no problem, which is very surprising. Among those who cited problems in buying pesticides, reported high price of pesticides as the main problem (Appendix Table A7.12).

7.9.1 Determinants of Pesticide Use: A Multivariate Analysis

It is already evident from Table 5.3 that pesticide use is very high for production of modern varieties of rice and potato irrespective of regions. In order to test

whether there is a significant association between modern variety cultivation and subsequent pesticide use, a multivariate analysis is performed at the crop level. The following equation is fitted to the data:

PEST = f (AMLND, PMVAR, PIRRIG, AGCR, INFRA, SOIL)

where:

PEST	= amount of pesticide used by the household (taka)
AMLND	= amount of land cultivated by the household (ha)
PMVAR	= proportion of cultivated land under modern varieties of rice and wheat (%)
PIRRIG	= proportion of cultivated land under irrigation (%)
AGCR	= amount of agricultural credit borrowed by the household ('000 taka)
INFRA	= index of underdevelopment of infrastructure
SOIL	= index of soil fertility

Since pesticide comes in various forms, granular and/or liquid, and their usage is diversified, a close approximation for pesticide use is to enumerate the cost incurred for its use. Also, price determination is ambiguous. Depending on the rate of concentration of active ingredients and the form of the product, prices vary widely. Moreover, farmer can report only the name and cost of pesticide, not the quantity or the price per unit. Therefore, no attempt is made to determine the unit price of pesticides.

The amount of land cultivated is incorporated in the model to see whether area under crop is associated with increased pest infestation. The modern variety proportion is included to capture the effect of modern agricultural technology. The availability of cash may be a determining factor enabling the farmer to purchase pesticide as required. The agricultural credit variable is incorporated to capture this effect. The argument in favor of infrastructure and soil fertility variable is similar with that cited in examining fertilizer market operations.

The Tobit model is used, as many observations include zero values implying that many farmers did not use pesticides. The analysis is done for rice (all varieties of all seasons), foodgrain (rice and wheat), non-cereal crops, and all crops (rice, wheat, and non-cereal crops). The result of the exercise is presented in Table 7.11 (also see Appendix Table A7.13 for details).

All the regression provides similar results (Table 7.11). Amount of land cultivated is significantly positively ($p<0.01$ and $p<0.05$) related to pesticide use. Irrigation is also a major determinant of pesticide use. The proportion of irrigated area is significantly positively ($p<0.01$) related to pesticide use levels.

Table 7.11 Determinants of pesticide use, 1996.

Variables	Rice crops	Foodgrain crops	Non-cereal crops	All crops
	Tobit estimate	Tobit estimate	Tobit estimate	Tobit estimate
Intercept	-187.680	-292.340	175.860	-126.800
AMLND	134.440[a]	178.69[a]	224.21	237.24[b]
PMVAR	0.074	0.214	na	0.163

PIRRIG	297.52[a]	82.128	199.81[a]	145.77[a]
AGCR	8.9246[a]	7.911[a]	2.636[c]	3.601[a]
INFRA	1.882	3.717[a]	0.106	2.987[a]
SOIL	28.520	31.046	-306.48[b]	-116.87
Log-likelihood	-2176.48	-2297.146	-983.805	-3294.367
Observations	397	497	352	849

Note: [a] = significant at 1 percent level ($p<0.01$); [b] = significant at 5 percent level ($p<0.05$)
[c] = significant at 10 percent level ($p<0.10$).
na means not applicable.
Source: Computed.

Though the technology variable is positively related with pesticide use the coefficient is very small and not significant. Therefore, based on this analysis, one cannot conclude that increase in pesticide use is a direct consequence of modern variety diffusion. The availability of cash approximated by the agricultural credit variable is significantly positively ($p<0.01$ and $p<0.10$) related with pesticide use indicating that greater liquidity increase use rates. The index of underdevelopment of infrastructure is significantly positively ($p<0.01$) related to pesticide use in foodgrain as well as all-crop equations indicating that the pesticide use and/or cost is higher in underdeveloped region. The reason may be the higher prices for the pesticides in underdeveloped regions, which is expected. The soil fertility variable is significantly negatively ($p<0.05$) related to pesticide use in non-cereal crop model and also all crop model (though not significant). The implication is that the lower the soil fertility status the higher is the use of pesticides, which is expected. The positive relationship of this variable in rice and foodgrain crop has very small t-ratio, which might not be the true relation.

7.10 Technological Change and Land Market Operations

As mentioned earlier, land is a primary source of wealth and status in rural regions. The land ownership structure of the study regions is highly skewed in favor of the landed elites as elsewhere across the country (Table 7.12). On an average, while the bottom 50 percent of farmers (landless plus marginal farmers) commands only less than 15 percent of land, the top 7 percent farmers (large landowners) commands about 30 percent of total land. In order to identify the implication of this land ownership structure, Gini-coefficient is computed for each region. The Gini-coefficient is computed by using the following formula (Puapanichya and Panayotou, 1985):

$$G = 1 + 1/n - 2/(n^2\mu)\ [L_1 + 2L_2 + 3L_3 + ...nL_n] \text{ for } L_1 > L_2 > L_3 > .... > L_n \qquad (7.10.1)$$

where, G = gini-coefficient
n = number of cases (farm households)
μ = mean amount of land owned per household
L = amount of land owned by each household

The Gini-concentration ratio (Gini coefficient) is estimated at 0.47, 0.53, and 0.60 for Comilla, Jamalpur, and Jessore region, respectively. This indicates that land ownership structure is highly skewed in Jessore region followed by Jamalpur region and finally by Comilla region. This conforms to the spatio-economic classification of regions computed at the national level where Comilla was designated in 'high level', Jamalpur in 'medium level', and Jessore in 'low level' category of agricultural development (see Table 4.3). The implication of this concentration of land is that if land serves as the main source of income than the income distribution is likely to be skewed in favor of landowners/large farmers. Since the nature of technological change introduced in Bangladesh seeks to raise the income through raising the productivity of land, therefore, the incremental income is distributed unevenly across the land size classes. However, conclusive decision regarding the distributional impact of modern agricultural technology needs further analyses dealt explicitly in Chapter VIII.

Table 7.12 Land ownership structure of the study regions, 1996.

Land Ownership category[1]	Percent of households (%)			
	Jamalpur region	Jessore region	Comilla region	**All region**
Landless	28.6 (3.8)	32.4 (4.2)	33.3 (7.3)	31.0 (4.7)
Marginal	22.3 (9.7)	21.9 (7.7)	22.2 (14.4)	22.2 (10.1)
Small	25.7 (23.7)	16.2 (12.3)	33.3 (45.3)	25.6 (24.8)
Medium	16.6 (34.9)	15.2 (23.6)	11.1 (33.0)	14.5 (30.7)
Large	6.9 (27.9)	14.3 (52.2)	nil	6.7 (29.7)
All land categories (%)	100.0	100.0	100.0	100.0
Total land (ha)	116.8	88.3	59.4	264.5
Gini-coefficient	0.532	0.596	0.468	0.555

Note: Figures in parentheses are proportion of total land owned by respective size classes.
[1] Landless = less than 0.20 ha of owned land, marginal = owned land 0.21 – 0.40 ha, small = owned land 0.41 – 1.00 ha, medium = owned land 1.01 – 2.00 ha, and large = owned land above 2 ha.

Source: Field Survey, 1997.

7.10.1 Land Transactions

Land market in Bangladesh is very thin. In order to observe the dynamics of land exchange, specific questions were asked on the incidence of land purchased and sold during the past five-year period. Questions were also asked on purpose of purchase, sources of finance and reasons for sale.

About 16 percent of the total households purchased land over the last five years (Appendix Table A7.14). The incidence of purchase is highest in Jamalpur (23 percent) followed by Jessore (19 percent) and Comilla region (11 percent), respectively The concentration of purchase is on the agricultural land. About 77 percent of purchasing households bought for agricultural use as compared to only 23 percent for homestead use. It is also interesting to note the similarity of average investment in land purchase per household on agricultural land across region (Tk. 27,477 per household) though per unit cost of land vary across region. On the other hand, the average spending on purchase of homestead land per household is sharply different across regions. The cost is highest in Comilla (Tk. 29,875) followed by Jamalpur (Tk. 27,880) and substantially lower in Jessore region (Tk. 15,367). Farmers' estimate on the present value of their land purchased over the last five years revealed that appreciation in value of the purchased amount of land is higher for agricultural land (42 percent) as compared to homestead land (28 percent) except for Jessore region (Appendix Table A7.14).

About 72 percent of those who purchased land over the last five years reported that the main purpose for land purchase is for cultivation purpose followed by 16 percent reporting home construction as the main purpose (Appendix Table A7.15). The major source of finance is their own source (31 percent of total purchasing households) followed by income generated from agricultural production (30 percent). Income through mortgaged land is the fourth principal source (11 percent) indicating the process of pauperization in the rural region of Bangladesh. The contribution of income from business and services are not high in relation to agriculture. The reason can be explained within the context of net income generated from agriculture and business. Households engaged in business tend to invest in capital building and find it unattractive to invest in agricultural land, which nowadays yield less income. While households engaged in farming still value agricultural land as the prime source of wealth and tend to acquire more agricultural land which is revealed in the source of income for purchase.

A striking similarity in characteristics of purchase and sale was observed in the study region (Appendix Table A7.16). The proportion of farmers who sold their lands in the past five years closely matches with the proportion of farmers who purchased land (16 percent of total households). Also, the concentration of land sale is confined within agricultural land (77 percent of purchasing households). Further, the amount received per household through land sale was found to be similar to the average amount spent on land purchase (Tk. 28,118 per household). However, when question was asked to estimate the level of appreciation in value, striking difference in response pattern was observed. The appreciation in value of agricultural land sold is estimated at only 7 percent of initial value as compared to 43 percent appreciation in value of land purchased (Appendix Table A7.16). This is a reflection of cultural attachment to land in the rural regions where those who sells land find it always cheaper and feel cheated than those who purchase them and feel that they are highly benefited from the transaction. Among the reasons, dowry requirements for marriage, release of land from mortgage and cash investment required to send member of the family for working abroad, particularly, in Mid-east countries, are reported as the main reasons for selling land (Appendix Table A7.17).

7.10.2 Tenancy Market Operations

A major form of transaction of land is through the operation of tenancy market. The most common form of tenurial arrangement in Bangladesh was share tenancy with 50-50 percent crop sharing arrangement with no input cost sharing by landowner. However, with the increased diffusion of modern agricultural technology, the tenurial arrangement underwent changes in terms of shares of input and/or output between the tenants and the landowners. A market for fixed rent tenurial system is also dominant in certain areas of the country. Under the fixed rent tenancy, the tenant pays the owner a fixed amount of money in advance and contract is done usually on a yearly basis. On the other hand, the crop share tenancy is season specific. In the present study, we observed only crop share tenancy with highly varying crop and input sharing system.

There is no sharp difference in the proportion of land cultivated under tenancy of landless and marginal farmers across region (Table 7.13). Also, no substantial difference is observed in share of land under tenancy. However, when tenurial status is considered, the proportion of part-tenant is found to be highest in Comilla region followed by Jamalpur and Jessore region, respectively. The village specific tenurial arrangement in each region is presented in Appendix Table A7.18. From Table A7.18, it is clear that where the landowner shares the input costs, the output sharing is on the 50-50 basis. On the other hand, where no input cost is shared by the landowner, the output sharing is one third for landowner and two-third for the tenant. However, substantial difference exists in type of input cost shared by the landowner in each village. Also, there is a clear regional difference in input cost sharing. This is mainly due to relative scarcity and/or cost of the relevant input that determines the tenurial arrangement. The dominant cost-sharing inputs are irrigation, fertilizers and seedlings. However, for selected villages of Comilla region, ploughing cost is borne paid by the landowner. This is because these villages are within the command area of the Meghna-Dhonagoda Irrigation project where the water is supplied free of cost. Also, the cost of animal power service is estimated to be highest in Comilla as compared to other regions. The scarcity of livestock in Comilla may be due to high population density and relatively smaller homestead land and lack of grazing fields making it difficult to raise livestock.

Table 7.13 Tenurial arrangement by farm size and tenurial status by study regions, 1996.

Farmers	Percent of cultivated land under tenancy				Percent of area under tenancy[1]			
	Jamalpur region	Jessore region	Comilla region	All region	Jamalpur region	Jessore region	Comilla region	All region
Land ownership categories								
Landless	57.3	65.0	58.2	59.4	80.3	77.4	78.2	78.9
Marginal	24.0	20.0	30.9	25.6	48.4	46.2	52.8	49.7
Small	17.3	5.0	10.9	12.9	23.5	22.8	18.6	21.3
Medium	1.3	7.5	nil	1.8	4.0	6.3	nil	4.0
Large	nil	2.5	nil	0.6	nil	1.1	nil	1.1
Tenurial status								
Own-oper.	nil	nil	nil	nil	nil	nil	nil	nil
Part tenant	65.3	57.5	72.7	65.9	56.0	45.9	63.2	55.2
Tenant	34.7	42.5	27.3	34.1	100.0	100.0	100.0	100.0
All	100.0	100.0	100.0	100.0	19.4	13.1	30.6	19.4

Note: [1] Area as percent of gross cropped area.
[2] Landless = less than 0.20 ha of owned land, marginal = owned land 0.21 – 0.40 ha, small = owned land 0.41 – 1.00 ha, medium = owned land 1.01 – 2.00 ha, and large = owned land above 2 ha.

[3] Owner operator = operates owned land; part tenant = operates own land and rent-in additional land, tenant = do not operate owned land but rent-in land for crop production.

Source: Field Survey, 1997.

The estimated land rent for different crops in the study regions is presented in Appendix Table A7.19. There are sharp inter-regional as well as inter-crop variations in land rents. Highest land rents are for potato, spices, vegetables, and modern Boro rice. Among the foodgrain crops, rent is substantially higher for modern rice of all three seasons and is similar across region. This reflects the gain from modern agricultural technology by landowners.

7.10.3 Impact of Technological Change on Land Rent

It is mentioned above that a major form of land transaction is through tenancy. In order to test whether there is a significant association between modern variety cultivation and land rental price, a multivariate analysis is performed at the crop level. The following equation is fitted to the data:

LANDRENT = f (LANDPC, MVAR, IRRIG, TNC, CAPL, INFRA, SOIL)

where:

LANDRENT	= amount of land rent per ha of cultivated land ('000 taka)
LANDPC	= amount of land owned per capita (ha)
MVAR	= amount of cultivated land under modern varieties of rice and wheat (ha)
IRRIG	= amount of cultivated land under irrigation (ha)
TNC	= amount of cultivated land rented-in (ha)
CAPL	= value of farm capital excluding land asset ('000 taka)
INFRA	= index of underdevelopment of infrastructure
SOIL	= index of soil fertility

The supply of land to be rented will depend on the amount of land available in relation to population (Hossain *et al.*, 1990). It was already seen that the large landowners control substantial amount of land in the study regions. The larger the proportion held by large landowners the more land will be supplied for sharecropping. The land per capita variable is therefore represents the supply variable. The area under modern variety and the area under irrigation are included to capture the effect of modern agricultural technology on land rent. Area under share rent reflects the demand for land. Availability of farm capital may induce the farmer to rent-in land and engage in crop production, which would then exert demand for land. The farm capital variable is incorporated to capture its effect on land rent. The argument in favor of infrastructure and soil fertility variable is similar with that cited in examining fertilizer and pesticide market operations. The OLS model is used for the analyses. The analysis is done for rice (all varieties of all seasons), foodgrain (rice and wheat), non-cereal crops, and all crops (rice, wheat, and non-cereal crops). The regression results were corrected for first degree autocorrelated disturbances using the Prais-Winsten method. The result of the exercise is presented in Table 7.14 (also see Appendix Table A7.20 for details).

Table 7.14 Determinants of land rent, 1996.

Variables	Rice crops	Foodgrain crops	Non-cereal crops	All crops
	OLS estimate	OLS estimate	OLS estimate	OLS estimate
Constant	0.019	1.109	2.671[a]	2.564[c]
LANDPC	10.451[a]	6.961[a]	1.517[b]	2.976[a]
MVAR	4.901[a]	6.154[a]	na	10.594[a]
IRRIG	14.319[a]	13.182[a]	6.339[a]	10.057[a]
TNC	4.207[a]	2.296[a]	2.027[a]	2.021[a]
CAPL	0.010[a]	0.083[a]	0.008	0.038[a]
INFRA	0.034[c]	0.038[b]	-0.007	0.017
SOIL	-0.994	-1.690	-1.063[c]	-1.932[b]
Adj.R^2	0.67	0.63	0.28	0.63
F-ratio	118.19[a]	120.81[a]	24.21[a]	206.77[a]
Degrees of freedom	7, 389	7, 489	6, 345	7, 841
D.W. statistic	2.04	2.08	2.03	2.06

Note: [a] = significant at 1 percent level ($p<0.01$); [b] = significant at 5 percent level ($p<0.05$)
[c] = significant at 10 percent level ($p<0.10$).
na means not applicable.
Source: Computed.

Land ownership per capita and the technological variables, the area under modern varieties and irrigation area, are significantly positively ($p<0.01$ and $p<0.05$) related to land rent as expected. Teurial status also significantly ($p<0.01$) influences land rent. The impact of irrigation on land rent is highest followed by the area under modern varieties as indicated by the value of the coefficients. Farm capital also significantly ($p<0.01$) influence land rent. Land rent is higher in underdeveloped area as indicated by positive significant ($p<0.05$ and 0.10) coefficient indicating unfavorable production environment for tenant farmers as they are constrained by lack of opportunity for off-farm income generating activities. The coefficient of tenancy reinforces this finding. Also, as shown in earlier analyses, the intensity of modern technology adoption is higher in underdeveloped areas, thereby, pushing up land rents.

However, lower land rent for higher soil fertility is contradictory. A possible explanation may be higher productivity per unit of land dampens increased pressure on demand for additional land and therefore depresses the land rent. The coefficient is significant ($p<0.10$ and $p<0.05$) for non-cereal crops and all-crop model only, implying that the situation may be true largely for non-cereal crops which is mainly concentrated in kitchen gardens, particularly, vegetables and spices.

7.11 Technological Change and Credit Market Operations

Credit market is an important factor in agricultural development as majority of the farmers lack financial liquidity. The operational procedure of rural credit markets is varied. Basically, there are two major categories of credit market: formal credit market composed of banking institutions largely sponsored by government, and the informal credit market composed of moneylenders, landlords, friends and relatives. However, with the increased infusion of non-governmental organizations (NGOs), a new category commonly termed as quasi-formal credit institutes emerged in the rural regions. The most cited example is the Grameen Bank which runs according to the rules set by the State Bank of Bangladesh but its operational procedure is highly decentralized with provision of other supporting activities which is normally outside the purview of formal credit systems.

Early studies dealing with rural informal credit market designated them as exploitative as well as fragmented with usufructuary interest rates (Ahmed and Hossain, 1990). This view of informal credit market has far reaching implications. If the rural informal credit market is exploitative then the infusion of formal credit markets is expected to lower interest rates of informal credit and/or substitute the moneylenders. However, this will not occur since the excess demand for credit is persistent in rural regions. The large scale diffusion of quasi-formal credit system by NGOs somewhat eased the pressure of excess demand. Though dealing with the impact of credit market in details is beyond the scope of this study, it is however worthwhile to provide a glimpse of the existing rural credit market and deduce some inference from their operations.

The proportion of indebted farm-households is about 40 percent with highest in Jamalpur region (47 percent) followed by similar values for Jessore and Comilla (36 percent), respectively (Appendix Table A7.21). Friends and relatives dominate in Jamalpur region while institutional source dominates in the other two regions (Appendix Table A7.22). This is expected since Jamalpur region is characterized by underdeveloped infrastructure where access to institutional credit sources are relatively scarce as well as scope for non-farm income generating activities are lower (see Chapter V).

The major purpose of credit is for agricultural production in all regions (Appendix Table A7.23). A total of 164 number of loans were taken by the loanee households of which 148 (90 percent) are cash loans while the rest are kind loans. In terms of duration, 157 (96 percent) were taken for upto one year duration while the rest are long-term loans extending upto five years and over. The average loan size per household is similar in Jamalpur and Comilla region, (around Tk. 3,150) while in Jessore region it is almost twice (Tk. 6,700) (Table A7.23). Of these total 164 loans, only 26 (16 percent) had land deeds as collateral while the rest are provided either against a fixed amount of savings (for loans from NGOs) or no collateral. The average value of collateral is estimated at Tk. 6,263, Tk. 14,067, and Tk. 1,393 for Jamalpur, Jessore, and Comilla region, respectively. Though agricultural loans consist of more than 50 percent of total loans taken by the farm households, the use of loan specifically for agricultural purpose is around 20-30 percent only (Table A7.23). This indicates the diversity in use of loans, which is one of the major reasons for lower repayment rates in Bangladesh as most of the loans are used for consumption purposes.

7.11.1 Impact of Technological Change on Agricultural Credit Market

It is mentioned earlier that liquidity is a major factor affecting farmers' decision to cultivate specific crop. Also, requirement of collateral is a major constraint in accessing credit from institutional sources. In most of the analyses done so far in

this study, agricultural credit variable is used as an independent variable. In this section, we are interested in identifying factors determining the availability of agricultural credit that can serve as a vital instrument in solving liquidity crisis of farmers. Therefore, in order to test whether there is a significant association between modern variety cultivation and agricultural credit, a multivariate analysis is performed at the crop level. The following equation is fitted to the data:

AGCR= f (OWNLND, MVAR, IRRIG, TNC, CAPL, WORK, FAMILY, EXPCE, INFRA, SOIL)

where:

AGCR	= amount of agricultural credit borrowed by the household ('000 taka)
OWNLND	= amount of land owned by the household (ha)
MVAR	= amount of cultivated land under modern varieties of rice and wheat (ha)
IRRIG	= amount of cultivated land under irrigation (ha)
TNC	= amount of cultivated land rented-in (ha)
CAPL	= value of farm capital excluding land asset ('000 taka)
WORK	= number of working members in the household (persons)
FAMILY	= number of family members in the household (persons)
EXPCE	= years of experience of farmer in crop cultivation (years)
INFRA	= index of underdevelopment of infrastructure
SOIL	= index of soil fertility

The supply of credit will depend on the amount of land owned by the household as it serves as a major form of collateral. It was already seen that about 40 percent of the sample households are indebted. The area under modern variety and the area under irrigation are included to capture the effect of modern agricultural technology on credit demand. Area under share rent reflects the solvency of the farmer in relation to their demand for land. Availability of farm capital (particularly livestock) may enable the farmer to access credit. Farm capital variable is incorporated to capture its effect on credit demand. The argument in favor of infrastructure and soil fertility variable is similar with that cited in examining other factor market operations.

The OLS model including only the indebted farmers is used for the analyses. The analysis is done for rice (all varieties of all seasons), foodgrain (rice and wheat), non-cereal crops, and all crops (rice, wheat, and non-cereal crops). The result of the exercise is presented in Table 7.15 (also see Appendix Table A7.24 for details).

Table 7.15 Determinants of agricultural credit, 1996.

Variables	Rice crops	Foodgrain crops	Non-cereal crops	All crops
	OLS estimate	OLS estimate	OLS estimate	OLS estimate
Constant	-3.452	-5.798	-35.585	-14.919
OWNLND	-3.333	-2.491	7.565[b]	3.832[b]
MVAR	12.27	12.840[c]	na	2.096
IRRIG	-13.210	-14.190[c]	-3.220	-5.468
TNC	-3.768	-4.297	-8.592	-5.213

CAPL	0.628[a]	0.603[a]	0.518[a]	0.523[a]
WORK	-0.428	-0.593	-8.055[a]	-3.842[a]
FAMILY	0.394	0.190	0.788	0.332
EXPCE	-0.154[b]	-0.136[b]	-0.163	-0.161[b]
INFRA	-0.035	-0.046	-0.212	-0.150[c]
SOIL	4.998	7.396[c]	35.047[a]	18.417[a]
Adj.R^2	0.66	0.62	0.31	0.36
F-ratio	22.19[a]	23.56[a]	6.60[a]	15.14[a]
Degrees of freedom	10, 101	10, 126	9, 106	10, 242
D.W. Statistic	1.96	2.01	2.06	2.07

Note: [a] = significant at 1 percent level (p<0.01); [b] = significant at 5 percent level (p<0.05)
[c] = significant at 10 percent level (p<0.10).
na means not applicable.
Source: Computed.

Land ownership is significantly (p<0.05) positively related with credit demand as evident in non-cereal and all-crop models. The insignificant negative sign of the land coefficient for rice and foodgrain model may not be the true relation. The positive sign is expected because in order to cultivate additional land more capital is required for which credit serves as the proxy (Table 7.15). The area under modern varieties is positively related with credit demand and is significant (p<0.10) in foodgrain model. However, access to modern irrigation has negative influence on credit demand, which is not very convincing. Farm capital is significantly positively (p<0.01) related to agricultural credit, implying that credit requirement is higher for farmers with more farm capital as it complements to undertake intensive farming at the margin.

The significantly negative (p<0.01) coefficient of working members in the family indicates that capital requirement is offset by income from working members or in other words capital constraint is less in farm families with large number of earners which is expected. Longer farming experience also depresses demand for credit indicating that management capacity of experienced farmers help mitigate the capital constraint. The coefficient is significantly negatively (p<0.05) related to credit demand. Demand for agricultural credit is higher in developed regions as indicated by the significant negative (p<0.10) coefficient of infrastructure variable. The higher demand for credit in developed region could be attributed to production of capital intensive non-cereal crops, which was shown to be higher in these regions. Higher level of soil fertility significantly (p<0.01) increase demand for credit largely due to opening up opportunity for intensive cropping, thereby, requiring more capital for farming activities.

7.12 Technological Change and Output Market Operations

Marketing of output is an important factor determining the relative profitability of crop production. In competitive markets, prices are expected to be exogenous. In the rural markets, the price that farmers receive includes the transport cost and traders' margin. State of infrastructural development plays an important role in this respect, by lowering the transport cost for the produce. Also, access to and availability of storage facilities may influence cropping pattern in the region. For example, harvest price of potato is very low in peak season. However, if potato can be stored for a considerable period in cold-storage facilities, it can fetch substantially higher profit for the farmer. Therefore, options for crop diversification as a development strategy need to be considered by keeping all these factors in mind. The farm level prices received by the farmer for specific crop in the study regions is presented in Appendix Table A7.25. Though there are no sharp regional variation in prices of foodgrain crops, the prices for spices and pulses are sharply different. This is mainly due to production of different types of spice and pulse crops in different regions (Appendix Table A7.25).

Primary markets located within 3 kms are the main marketing outlet for the crops produced in the study region (Tables A7.26 and A7.27). About 78 percent of the farmers sell their products at the primary market while 7 percent sell at the farmgate level and remaining sell at secondary markets and/or growth centers also located within 3 kms. Few farmers actually responded on problems with marketing of outputs. Among those who reported of facing problems cited poor communication, low output price and illegal brokerage fees as the major ones (Table A7.28). No single respondent in Jessore region cited problems with marketing. In fact, all the villages in Jessore study area are very well communicated with the thana headquarter (sub-district Centre) where all infrastructural facilities are available.

7.12.1 Impact of Technological Change on Output Market

As mentioned earlier, in the competitive market, prices of inputs and outputs are expected to be exogenous. Also, the prices that farmers pay receive for outputs include transportation cost and traders' margin which is likely to vary across farms and regions, depending on the state of infrastructure development. Higher soil fertility status implies favorable physical condition for agricultural production thereby increases cropping and land use intensity leading to increase in supply of outputs. As soil fertility varies from region to region, farmer's response pattern relating to use of land will vary. In order to analyze the impact of technological change on crop prices, the following price equation is fitted to the plot level data.

OUTP = f (QTY, OWNLND, PMVAR, INFRA, SOIL)

where:

OUTP	= price of crop output at the farm-level (taka/kg)
QTY	= amount of crop produced by the household (kg)
OWNLND	= amount of land owned by the household (ha)
PMVAR	= proportion of cultivated land under modern varieties of rice and wheat (%)
INFRA	= index of underdevelopment of infrastructure
SOIL	= index of soil fertility

OLS model was fitted separately for rice crops (all varieties of rice) foodgrain crops (all varieties of rice and wheat), non-cereal crops, and all crops (foodgrain plus cash/non-cereal crops). The results are corrected for first order autocorrelated disturbances. The result of the exercise is presented in Table 7.16 (also see Appendix Table A7.29 for details).

The price quantity relationship has the expected signs and is significant ($p<0.01$ and $p<0.10$) in three regressions (Table 7.16). The low adjusted R^2 indicates the exogenous nature of prices (Ahmed and Hossain, 1990).). Land ownership status has positive relationship with crop output price indicating that output price is higher in areas with large landowners. The coefficient is significantly ($p<0.01$) positive for foodgrain crops. The negative coefficient in rice crop is insignificant and therefore may not be the true relationship.

Table 7.16 Determinants of crop prices, 1996.

Variables	Rice crops	Foodgrain crops	Non-cereal crops	All crops
	OLS estimate	OLS estimate	OLS estimate	OLS estimate
Constant	5.177[a]	6.144[a]	19.739[a]	13.967[a]
QTY	-0.168	-0.051[a]	-1.071[a]	-0.103[c]
OWNLND	-0.003	0.194[a]	0.055	0.112
PMVAR	-0.001	-0.001	na	0.006[a]
INFRA	-0.004[b]	-0.016[a]	-0.054	-0.041[c]
SOIL	0.346[a]	0.269	-2.737	-2.138
Adj. R^2	0.05	0.16	0.15	0.12
F-ratio	5.02[a]	20.01[a]	16.46[a]	24.63[a]
Degrees of freedom	5, 391	5, 491	4, 347	5, 843
D.W. Statistic	2.10	2.51	2.44	2.50

Note: [a] = significant at 1 percent level ($p<0.01$); [b] = significant at 5 percent level ($p<0.05$);
[c] = significant at 10 percent level ($p<0.10$).
na means not applicable.

Source: Computed.

The impact of technological change is significantly positive ($p<0.01$) in the all crop equation implying that prices are higher in areas with high level of modern technology diffusion. However, this effect is not clear in rice and foodgrain models. The effect of the state of infrastructure on crop output prices is very pronounced. The negative significant ($p<0.01$, $p<0.05$, and $p<0.10$) coefficient for underdevelopment of infrastructure indicates that crop prices are higher in developed areas. The effect of soil fertility status is pronounced in the rice model. The positive significant ($p<0.01$) coefficient of soil fertility variable for rice crop indicates that crop price is higher in areas with higher soil fertility status largely due to better quality of output. The negative sign of soil fertility coefficient in all crop equation is not significant. The regression estimate improves as more crops are added.

7.12.2 Storage Facilities

The seasonal nature of agricultural production exerts sharp downward movement of output prices during peak harvest season. Given the increasing cost of agricultural production, such fall in prices of crop output spell disaster for farm households. Storage is an important infrastructural facility that neutralizes this downward movement of prices. Though substantial amount of cost is involved in storing crop output, particularly perishable products, the gain in prices in lean season offsets the additional costs involved in the process. There are government programs on procuring foodgrain crops in the rural regions. However, the storage capacity is highly inadequate as compared to the demand for storage. Also, the storage facilities for perishable products are largely inadequate and their distribution is skewed.

Table 7.17 reveals that there is sharp inter-regional variation in proportion of farmers using storage facilities and its type. Almost 95 percent of farmers in Comilla use storage as compared to 57 and 35 percent in Jessore and Jamalpur region, respectively. About 22 percent of farmers in Comilla region use government storage facilities. It should be noted that Comilla has the highest facilities of storage infrastructure within close proximity of the study villages. The distance of most storage facilities in Comilla region is within three km (Appendix Table A7.30). Since storage is not a dominant feature in Jamalpur and Jessore regions, the households did not respond to problems related to storage facilities. However, in Comilla region where storage is practiced by a substantial number of farmers, lack of space at home is reported as the major storage problem (Appendix Table A7.31).

Table 7.17. Storage facilities by study regions, 1996.

Storage facilities	Percent of households (%)			
	Jamalpur region	Jessore region	Comilla region	All region
Using storage facilities	**34.8**	**57.1**	**94.4**	**59.1**
Godown	0.6	1.9	22.2	7.6
Own storage	34.2	55.2	72.2	51.5
Not using any storage	65.2	42.9	5.6	40.9
Total number of households	100.0 (175)	100.0 (105)	100.0 (126)	100.0 (406)

Note: Figures in parentheses are percentages of total households.
Source: Field Survey, 1997.

7.13 Technological Change and Demand for Modern Inputs: A Simultaneous Equation Analysis

As shown in Chapter V that cultivation of modern varieties of rice and wheat requires significantly higher amounts of fertilizer and labor. In this section, the following demand functions for modern inputs are postulated:

$$FERT = f(FP, AMLND, MVAR, CAPL, AGCR, INFRA, SOIL) \qquad (7.13.1)$$

$$LABOR = f(WAGE, AMLND, MVAR, AGCR, INFRA, SOIL) \qquad (7.13.2)$$

$$ANIMAL = f(ANIMP, AMLND, MVAR, AGCR, INFRA, SOIL) \qquad (7.13.3)$$

where:
FERT = amount of fertilizer used by the household (kg)
LABOR = number of days of total labor used in crop production (days)
ANIMAL = amount animal power service used by the household (pairday)
FP = fertilizer price at the farm-level (taka/kg)
WAGE = labor wage at the farm-level (taka/day)

ANIMP = animal power price at the farm-level (taka/pairday)
AMLND = amount of land cultivated by the household (ha)
MVAR = amount of cultivated land under modern varieties of rice and wheat (ha)
CAPL = value of farm capital excluding land asset ('000 taka)
AGCR = amount of agricultural credit borrowed by the household ('000 taka)
INFRA = index of underdevelopment of infrastructure
SOIL = index of soil fertility

The amount of input used by the household is assumed to be a function of the price of input, the amount of land under cultivation, and the amount of area devoted to cultivation of modern varieties of rice and wheat. Also, the amount of non-land farm asset owned by the households and the amount of agricultural credit received from both institutional and non-institutional sources may improve the liquidity constraint of the farmers, thereby allowing use of inputs optimally. Further, the adoption of modern agricultural technology may depend on the level of infrastructural development and soil fertility status. It was shown above that infrastructure and soil fertility status influence input and output prices (Tables 7.2 and 7.18). In addition to these factors, the development of irrigation facilities is also a major factor determining modern technology adoption rate (Table 6.12). Therefore, the following equations are presented to explain the variation in the adoption of modern agricultural technology within the sampled farm households:

MVAR = f (IRRIG, AMLND, CAPL, AGCR, INFRA, SOIL) (7.13.4)

IRRIG = f (AMLND, CAPL, AGCR, INFRA, SOIL) (7.13.5)

where IRRIG is the amount of cultivated land under irrigation (ha).

Given the demand structure of modern inputs, it is clear that the IRRIG and MVAR are endogenous variables since MVAR appear on the right hand side of eqs. (7.13.1), (7.13.2), (7.13.3) and IRRIG appear on the right hand side of eq. (7.13.4). This is therefore a case of simultaneous equation model with recursive structure, where irrigation determines modern technology adoption, and modern technology adoption determines the demand for fertilizer, labor and animal power services. Therefore, simultaneous estimation of five equations, (7.13.1), (7.13.2), (7.13.3) and (7.13.4) or (7.13.5) is conducted using Three-Stage Least Squares (3SLS) technique that allows correlation among disturbances in individual equations. The results are presented in Table 7.18 (also see Appendix Table A7.32 for details).

The overall explanatory power of all the five equations are substantially high as indicated by the values of adjusted R-squared and F-ratio. Also, no autocorrelated disturbance is observed as indicated by the Durbin-Watson (D.W.) statistic.

The values of price coefficients have correct signs and are highly significant ($p<0.01$) for labor and animal power demand except for fertilizers. The cultivated area is significantly ($p<0.01$) positively related to demand for inputs as well as irrigation. However the significant ($p<0.05$) negative coefficient for cultivated area in modern variety adoption function indicates that farmers tend to maximize return

from land through cultivation of modern varieties of rice and wheat and is consistent with a priori expectation and in most of the earlier analyses.

Table 7.18 Joint determination of input demand functions, 1996.

Variables	Joint estimates of input demand functions using Three Stage Least Squares				
	Fertilizer demand	Labor demand	Animal power demand	Modern techno-logy adoption	Irrigation demand
Intercept	-82.714[c]	118.030[a]	32.463[a]	0.147	-0.359[c]
FP	-4.578	-	-	-	-
WAGE	-	-1.110[a]	-	-	-
ANIMP	-	-	-0.328[a]	-	-
AMLND	158.350[a]	84.485[a]	13.601[a]	-0.478[b]	1.056[a]
MVAR	119.290[a]	27.436[b]	24.144[a]	-	-
CAPL	1.294[b]	-	-	0.002	0.005[a]
AGCR	-0.659	-0.012	0.056	0.004[c]	-0.005[b]
INFRA	0.957	0.316	-0.115[a]	0.004[b]	0.005[a]
SOIL	23.219	-34.733[a]	-0.229	-0.097	0.101
IRRIG	-	-	-	1.404[a]	-
Adjusted R^2	0.80	0.74	0.86	0.53	0.67
F – ratio	225.56[a]	195.40[a]	427.91[a]	77.81[a]	167.25[a]
Degree of fdm	7, 398	6, 399	6, 399	6, 399	5, 400
D.W. Statistic	1.90	1.95	1.85	1.90	1.79

Note: [a] = significant at 1 percent level ($p<0.01$); [b] = significant at 5 percent level ($p<0.05$);
[c] = significant at 10 percent level ($p<0.10$).
Source: Computed.

The area devoted to modern varieties of rice and wheat is also significantly ($p<0.01$ and $p<0.05$) positively related to input demand, namely, fertilizer, labor as well as animal power demand. Farm capital also significantly ($p<0.05$) positively related with fertilizer and irrigation demand. The coefficient of agricultural credit is weak and provided mixed results. The significant ($p<0.10$) positive relation with modern variety adoption is expected and consistent. However, the significant ($p<0.05$) negative coefficient of this variable in irrigation demand function is disturbing. One reason might be that agricultural credit provided by institutional sources are small and is not sufficient for installing irrigation equipments.

The state of infrastructural development has mixed influence. The positive coefficient of the state of underdevelopment of infrastructure in fertilizer and labor demand functions indicate that demands for these inputs are higher in underdeveloped regions. Also the significant ($p<0.05$ and $p<0.01$) positive coefficient of infrastructure index in modern technology and irrigation demand equation indicates the same. This is expected as in the underdeveloped areas the scope to switch to other non-farm income generating activities are lower and therefore the concentration is on agricultural production particularly modern varieties of rice and wheat which provide significantly higher income. The same results were obtained in a series of analyses explained earlier in this study, thereby, once again validating the findings. The negative significant ($p<0.05$) coefficient of the infrastructure variable in animal power demand function indicates that the demand for animal power services is higher in developed region. This may be due to substitution of demand for animal power services by human labor in the underdeveloped areas, which also resulted in higher demand for human labor. It may also be due to lower incidence of raising livestock in developed regions owing to high population density and relatively smaller size of homestead areas. The influence of soil fertility variable is relatively weak and mixed. The significant ($p<0.01$) negative relation of soil fertility with labor demand indicates that regions with poor soil fertility will have higher demand for labor. For other functions the soil variable is not significant.

7.14 Inferences

Substantially higher amount of total labor as well as hired labor per unit of land is utilized in growing modern rice varieties as compared to local rice varieties. However, the labor employment pattern is not gender-neutral and is skewed in favor of men. Though female labor input ranges between 11 – 18 percent and 6 – 48 percent (highest for vegetables) in foodgrain and non-cereal crop production, respectively, the increased demand for hired labor is met by hiring male labor only or by substituting female family labor. Also, significantly lower wage is paid to female labor, if hired, indicating discrimination against women.

Analysis of determinants of labor demand revealed that modern technology, farm size, and education level of farmers significantly increase demand for hired labor while labor wage, tenurial status, developed infrastructure, soil fertility, subsistence pressure, and working members in the family significantly decrease demand for hired labor. However, demand for total labor is significantly higher in underdeveloped areas.

Analysis of impact on prices revealed that modern technology, soil fertility, land ownership, and underdeveloped infrastructure significantly increase labor wages while soil fertility and developed infrastructure significantly increase fertilizer prices. Demand for pesticide use increase significantly with farm size, irrigation, agricultural credit and underdeveloped infrastructure. Improved soil fertility significantly reduces demand for pesticide use, mainly in case of non-cereal crops. In the output market, modern technology, soil fertility and developed infrastructure significantly increase output prices.

The tenurial arrangements changed substantially from the 50 - 50 output share with no input sharing system to variable output share and input sharing systems unique to each village. The input that is relatively scarce is shared between the landowner and the tenant. Determinants of land rent revealed that per capita land owned, modern technology, irrigation, tenurial status, farm capital and underdeveloped infrastructure significantly increase rent while improved soil fertility significantly decreases land rent.

An analysis of demand for agricultural credit revealed that land ownership, farm capital, soil fertility and developed infrastructure significantly increase credit demand while number of working members in the family and farming experience significantly reduces demand for credit.

A simultaneous analysis of input demand functions revealed that modern technology and farm size significantly increases input demand. Irrigation strongly influences modern technology adoption decisions in addition to agricultural credit and underdeveloped infrastructure while farm size has significant negative influence on adoption. On the other hand, farm size, farm capital, agricultural credit, and underdeveloped infrastructure significantly increases irrigation demand.

CHAPTER VIII

TECNOLOGICAL CHANGE AND ITS IMPACT ON INCOME DISTRIBUTION AND POVERTY

The differential rate of modern variety adoption among farmers, variation in prices, and the impacts of modern technology on production, employment, and expansion of markets for non-farm goods and services will ultimately affect the level and pattern of income distribution in the rural areas (Hossain, 1989). Though it is highly difficult to estimate the exact income of a rural household from a cross-section sample survey, an attempt has been made to estimate total income of households from agricultural activities as well as non-agricultural activities in this study. Based on these estimates of income, the present chapter analyzes the impacts of technological change on income, income distribution and poverty following certain standard assumptions. Details are provided in relevant sections.

8.1 Definition of Household Income

Household or family income is defined as the return to family labor and the assets owned after the current cost of production (excluding family labor and rent for land and assets) is deducted from the gross value of production (Ahmed and Hossain, 1990). Current cost is the cost incurred by individual households in purchasing inputs, hiring labor, hiring animal power services, and renting services. The disaggregation of total family income into a number of following components provides a firsthand picture of sources of income:

1. Income from crop production (CROPI)
2. Income from livestock (LIVEI)
3. Income from fisheries (FISHI)
4. Income from land leased-out/rented-out (LEASEI)
5. Income from wage (WAGEI)
6. Income from business and miscellaneous sources (BUSI)
7. Total agricultural income (AGI) = CROPI + LIVEI + FISHI + LEASEI
8. Total non-agricultural income (NAGI) = WAGEI + NAGI.
9. Total household income (INC) = AGI + NAGI.

8.1.1 Derivation of Various Sources of Household Incomes

Income derived from crop production (CROPI) is straightforward. As the present study covers information on all types of crops produced by the households in one year, so the total income from producing various crops are computed directly from the information detailed in Chapter V.

Income from livestock sources are estimated from direct question to the respondents on various products and by-products produced from livestock resources, such as from milk, meat, egg, sale, value of consumed product, etc. Also, information on weekly expenditure on livestock raising is collected which is then multiplied by 52 to arrive at an annual expenditure and deducted from total gross income to yield net income from livestock.

Incomes from fisheries resources are estimated from direct question on costs and returns of fish production in one year. Costs include excavation, liming, fertilizing, feeding, renting (if multiple owned) and harvesting costs. Incomes include revenue from sale of harvest, imputed value of fish consumed by the family and value of stock in the pond. The total cost is then deducted from gross income to yield net income from fisheries.

Income from all other categories are estimated from direct question on type of activities, in which individual working members of the household is involved for one week preceding the day of survey, number of days worked and income earned from these activities. These weekly income derived from various sources is then multiplied by 52 to arrive at the annual income.

8.2 Description of Household Income from Various Sources

In this section, annual per household income derived from various components for the study regions is described and then final structure is summarized.

8.2.1 Income from Agriculture

Income from agriculture comprises of income from various crops, fisheries, livestock and leased-out land. Crop income is derived from the aggregate of local and modern varieties of rice (all season), wheat, jute, potato, pulses, spices, oilseeds, vegetables and cotton. Table 8.1 presents the disaggregated household level annual income from crops.

Table 8.1 Average annual crop income (Tk.) per household by study regions, 1996.

Source of crop income	Average annual income per household (Tk.)				F-ratio for regional difference in income
	Jamalpur region	Jessore region	Comilla region	All region	
Local rice	1,224^{A}	129^{B}	816^{A}	814	3.58^{b}
Modern rice	14,060^{A}	10,387^{B}	5,725^{C}	10,524	16.90^{a}
Modern wheat	194^{A}	738^{B}	716^{B}	496	5.70^{a}
Jute	241^{A}	1,891^{B}	346^{A}	700	22.20^{a}
Potato	288^{A}	131^{A}	729^{B}	384	6.12^{a}
Pulses	ng	1,531^{A}	50^{B}	412	34.14^{a}
Oilseeds	37^{A}	578^{B}	242^{C}	240	11.03^{a}
Spices	687^{A}	56^{B}	142^{B}	355	4.00^{b}
Vegetables	108^{A}	1,395^{B}	ng	407	19.39^{a}
Cotton	ng	627	ng	162	na
Total crop income	16,839^{A}	17,461^{A}	8,765^{B}	14,494	11.87^{a}

Note: Same block letters in superscript represents similarity in income across region based on LSD at 5 percent level of significance (p<0.05).
^{a} = significant at 1 percent level (p<0.01); ^{b} = significant at 5 percent level (p<0.05)..
ng means not grown; na means not applicable.

Source: Field Survey, 1997.

It is clear from Table 8.1 that the dominant source of crop income is the modern rice varieties that accounts for more than 60 percent of total income from crop production. Other crops including local varieties of rice contribute very little to the total annual income derived from crop production. There are significant ($p<0.01$ and $p<0.05$) inter-regional variations with respect to income per household derived from individual crops (Table 8.1). Income from non-cereal crops such as jute, pulses and vegetables are significantly ($p<0.05$) different between Jessore and other regions. It is worth noting that the more diversified the cropping system the higher is the total crop income per household as evidenced in Jessore region. On the other hand, low crop diversity resulted in low income as evidenced in Comilla region. Also, the concentration of modern variety cultivation does not necessarily translate into higher income from crop production (Table 8.1).

The average annual income derived from agricultural sources is presented in Table 8.2. It is obvious from Table 8.2 that annual income generated from crop production (foodgrain as well as non-cereal crops) is highest of all sources. Livestock and land leasing also serve as major sources of household income. There is significant ($p<0.01$) inter-regional differences in average agricultural income per household as well as per capita (Table 8.2). The average annual household agricultural income is similar in Jessore and Jamalpur region and is significantly ($p<0.05$) lower in Comilla region. The trend is similar for the per capita agricultural income as well. The significantly ($p<0.05$) lower income from all sources in Comilla region is due to lower level of crop diversification, higher input costs, and higher involvement in non-agricultural income earning activities as evident in subsequent analyses. It is clear from Table 8.2 that, the more diversified the cropping system, higher is the income, for example, for both Jamalpur and Jessore as compared to Comilla region.

Table 8.2 Average annual agricultural income (Tk.) by study regions, 1996.

Source of income	Jamalpur region	Jessore region	Comilla region	All region	F-ratio for regional income difference
Income per household					
Crops	$16,839^{A}$	$17,461^{A}$	$8,765^{B}$	14,494	11.87[a]
Livestock	$4,717^{A}$	$6,764^{B}$	$3,400^{C}$	4,838	11.21[a]
Fisheries	$1,746^{A}$	$1,990^{A}$	270^{B}	1,351	5.73[a]
Land leasing	$3,334^{A}$	$2,423^{A}$	265^{B}	2,146	5.74[a]
Total agriculture	$26,637^{A}$	$28,639^{A}$	$12,700^{B}$	22,829	18.41[a]
Income per capita					
Crops	$3,254^{A}$	$2,712^{A}$	$1,417^{B}$	2,542	18.76[a]
Livestock	$1,010^{A}$	$1,158^{A}$	572^{B}	912	7.61[a]
Fisheries	317^{A}	289^{A}	37^{B}	229	5.91[a]
Land leasing	646^{A}	389^{AB}	49^{B}	393	5.18[a]
Total agriculture	$5,228^{A}$	$4,548^{A}$	$2,075^{B}$	4,071	24.83[a]

Note: Same block letters in superscript represents similarity in income across region based on LSD at 5 percent level of significance ($p<0.05$).
[a] = significant at 1 percent level ($p<0.01$).

Source: Field Survey, 1997.

8.2.2 Income from Non-agriculture

The average annual income earned from non-agricultural activities is broadly divided into two categories: (a) income from wage earning (where income as agricultural wage labor is also included); and (b) income from business, small trade, cottage industries, rural transport, carpentry, and other miscellaneous sources. Table 8.3 reveals that though there is no significant difference in wage income across region, income from business and other activities are significantly ($p<0.01$) different. The difference is largely due to significantly ($p<0.05$) lower income in this category for Jamalpur region as compared to Jessore and Comilla region having similar income levels. This is expected as Jamalpur region is characterized by underdeveloped infrastructure and located at a remote distance from district headquarter. On the other hand, business income is highest in Comilla, a developed region, followed by Jessore, also a developed region.

Table 8.3 Average annual non-agricultural income (Tk.) by study regions, 1996.

Source of non-agricultural income	Jamalpur region	Jessore region	Comilla region	All region	F-ratio for regional income difference
Income per household					
Wage income	1,444^{A}	1,446^{A}	2,192^{A}	1,677	0.572
Business and others	3,499^{A}	8,979^{B}	10,422^{B}	7,065	8.581^{a}
Total non-agriculture	4,944^{A}	10,425^{B}	12,614^{B}	8,742	9.358^{a}
Income per capita					
Wage income	316^{A}	291^{A}	378^{A}	329	0.867
Business and others	656^{A}	1,546^{B}	1,751^{B}	1219	7.397^{a}
Total non-agriculture	952^{A}	1,751^{B}	2,129^{B}	1,548	7.050^{a}

Note: Same block letters in superscript represents similarity in income across region based on LSD at 5 percent level of significance ($p<0.05$).
^{a} = significant at 1 percent level ($p<0.01$).
Source: Field Survey, 1997.

8.2.3 Total Family Income

The total family income per household is composed of total agricultural and non-agricultural income. Table 8.4 presents the composition of average family income of the study households. Though there is a sharp difference in income derived from agricultural sources, the inter-regional gap in total family income is narrower. Particularly, the gap in agricultural income of households in Comilla narrowed down substantially when total family income is compared across regions. There are sharp inter-regional differences in share of income derived from various sources. Nevertheless, it appears that agricultural source, particularly, the field crops dominate the rural income scenario. The level of

infrastructural development has high influence on the amount of income derived from non-agricultural sources. For example, non-agricultural source contributed about 50 percent to total family income in Comilla region, which is a developed region in terms of infrastructure. This is followed by Jessore region where non-agricultural source contributed about 27 percent to family income, also a developed region (Table 8.4).

Table 8.4 Structure of annual family income (Tk.) per household by study regions, 1996.

Source of income	Share of component incomes to total family income (%)			
	Jamalpur region	Jessore region	Comilla region	All region
Total agricultural income	84.3	73.3	50.2	72.3
Crops	53.3	44.7	34.6	45.9
Livestock	14.9	17.3	13.4	15.3
Fisheries	5.5	5.1	1.1	4.3
Lease	10.6	6.2	1.1	6.8
Total non-agricultural income	15.7	26.7	49.8	27.7
Wage	4.6	3.7	8.6	5.3
Business and other	11.1	23.0	41.2	22.4
Total family income	100.0 (31,581)	100.0 (39,064)	100.0 (25,314)	100.0 (31,571)

Note: Figures in parentheses represents total family income per household.
Source: Field Survey, 1997.

8.3 Income Distribution by Land Ownership and Tenurial Categories

The striking difference in average household income from crops for Comilla region as compared to other regions as shown in Table 8.4 becomes smaller when the same income is computed per capita and distributed by land categories (Table 8.5).

Table 8.5 Average annual crop income (Tk.) per capita by land ownership categories by study regions, 1996.

Landownership categories[1]	Average annual crop income (Tk/capita)			
	Jamalpur region	Jessore region	Comilla region	All region
Landless	$1,536^{A}$	$1,363^{A}$	961^{A}	$1,305^{A}$
Marginal	$2,412^{A}$	$2,088^{A}$	$1,369^{B}$	$1,957^{B}$
Small	$3,185^{B}$	$1,932^{A}$	$1,543^{B}$	$2,792^{C}$
Medium	$4,293^{C}$	$4,164^{B}$	$2,598^{C}$	$3,856^{D}$
Large	$7,740^{D}$	$6,152^{C}$	na	$6,8590^{E}$
All categories	3,254	2,712	1,417	2,542
F-ratio for income difference by landsize	18.60^{a}	13.10^{a}	6.91^{a}	40.49^{a}
Degree of freedom	4, 170	4, 100	3, 122	4, 401
Correlation coefficient	0.55^{a}	0.64^{a}	0.39^{a}	0.56^{a}

Note: Same block letters in superscript represents similarity in income levels across landownership categories based on LSD at 5 percent level of significance ($p<0.05$).
[a] = significant at 1 percent level ($p<0.01$); na means not available.
[1] Landless = less than 0.20 ha of owned land, marginal = owned land 0.21 – 0.40 ha, small = owned land 0.41 – 1.00 ha, medium = owned land 1.01 – 2.00 ha, and large = owned land above 2 ha.
Correlation coefficient shows relationship between per capita crop income and per capita land owned by the household.

Source: Field Survey, 1997.

It is clear from Table 8.5 that, for landless and marginal farmers, the average crop income per capita is similar across regions. The difference becomes strikingly large for small and medium owner category. No household in Comilla region falls in large category. Therefore, comparison of this category with other regions cannot be made. However, one can notice the very high level of crop income earned by large farmers which pushed up the average income for all categories of households and making the difference between Comilla and other region strikingly large. The sharply rising average household income from crop with increase in the amount of land owned reveals the importance of land as a prime source of wealth in the rural region and the reason for farmers to cling to land for income (Table 8.5). The correlation between crop income and land ownership is significantly ($p<0.01$) positively related and the values are estimated at 0.55, 0.64, and 0.39 for Jamalpur, Jessore, and Comilla region, respectively (Table 8.5).

Striking difference also exists between Comilla and other regions in terms of per capita crop income across tenurial categories (Table 8.6). While there are significant ($p<0.05$) difference between tenants and owner-operators as well as part-tenants in Jamalpur and Jessore region, the difference is insignificant in Comilla region. This is largely due to the fact that, as per capita land size is small in Comilla, most of the farmers rent-in part of the land to increase the farm size to an economic size. Overall, there is significant ($p<0.05$) difference in total crop income across tenurial category (Table 8.6).

Table 8.6 Average annual agricultural income (Tk.) per capita by tenurial categories by study regions, 1996

Tenurial categories	Average annual crop income (Tk/capita)			
	Jamalpur region	Jessore region	Comilla region	All region
Owner-operator	$3,803^{A}$	$3,038^{A}$	$1,497^{A}$	$2,899^{A}$
Part-tenant	$3,261^{A}$	$2,804^{B}$	$1,319^{A}$	$2,464^{A}$
Tenant	$1,130^{B}$	$1,343^{B}$	$1,312^{A}$	$1,241^{B}$
All	3,254	2,712	1,417	2,542
F-ratio for income difference by tenancy	8.52^{a}	2.43^{c}	0.32	9.26^{a}
Degree of freedom	2, 172	2, 102	2, 123	2, 403

Note: Same block letters in superscript represents similarity in income levels across tenurial categories based on LSD at 5 percent level of significance ($p<0.05$).
[a] = significant at 1 percent level ($p<0.01$); [c] = significant at 10 percent level ($p<0.10$).

Source: Field Survey, 1997.

The breakdown of per capita income from agricultural and non-agricultural sources by land ownership categories is presented in Table 8.7. Such breakdown in per capita income by sources depicts certain interesting features. It is interesting to note that while per capita income from agricultural source is significantly ($p<0.01$) positively related with amount of land owned by the households, the per capita non-agricultural income moves in the opposite direction and is significant ($p<0.10$) for Jamalpur region. This finding conforms to a priori expectation that land serves the major source of wealth and income in rural setting. The per capita income from non-agricultural sources is negatively correlated with amount of land owned by the household, a finding reinforcing the a priori expectation. The inter-regional differences in per capita income from agriculture increased sharply at the upper scale of land ownership category while for landless, marginal and small farmers the values are relatively close.

Another interesting feature is that the non-agricultural income per capita is highest in landless categories and has declining trend though not very prominent. This is consistent with the fact that the landless and marginal farmers usually supply their labor in the labor market and thus receives the benefit of increased income from technological change in agriculture through the labor market operations.

Table 8.7 Average per capita income (Tk.) from agricultural and non-agricultural sources by land ownership categories by study regions, 1996.

Land ownership categories	Per capita agricultural income (Tk.)				Per capita non-agricultural income (Tk.)			
	Jamalpur region	Jessore region	Comilla region	All region	Jamalpur region	Jessore region	Comilla region	All region
Landless	2,254^{A}	2,179^{A}	1,441^{A}	1,973^{A}	1,432	2,000	2,414	1,900
Marginal	3,432^{A}	3,978^{B}	2,093^{B}	3,086^{B}	758	2,127	2,832	1,842
Small	6,830^{B}	4,046^{B}	2,110^{B}	4,547^{C}	859	2,179	1,513	1,331
Medium	7,708^{B}	6,352^{C}	3,891^{C}	6,434^{D}	711	717	1,276	847
Large	12,361^{C}	9,683^{D}	na	10,873^{E}	238	1,850	na	1,134
All sizes	5,228	4,548	2,075	4,071	952	1,857	2,129	1,548
F-ratio for catg. diff.	24.69^{a}	16.07^{a}	7.96^{a}	49.27^{a}	1.53	1.02	0.92	1.91
Df	4, 170	4, 100	3, 122	4, 401	4, 170	4, 100	3, 122	4, 401
Correlation	0.55^{a}	0.64^{a}	0.39^{a}	0.56^{a}	-0.13^{c}	-0.04	-0.13	-0.09^{c}

Note: Same block letters in superscript represents similarity in income levels across landownership categories based on LSD at 5 percent level of significance ($p<0.05$).
For per capita income from non-agricultural sources LSD values are not computed as the difference is not significant indicated by F-ratio.
Correlation coefficient shows relationship between per capita income and land owned by the household.
^{a} = significant at 1 percent level ($p<0.01$); ^{c} = significant at 10 percent level ($p<0.10$).
na means not available.
Source: Field Survey, 1997.

The structure of income from various sources by land ownership categories as well as by tenurial categories are presented in Table 8.8. There is a clear increasing trend in income from all sources in ascending levels of land ownership except for the wage income where the trend is reversed. This resulted in similar amount of income from non-agricultural sources for all land categories (Tk.8,600 – 8,900 per household approx.). Similarly, the tenants earn higher income per household from non-agricultural sources, particularly wage income (Table 8.8). This finding further reinforces the expectation explained above. The tendency to move towards non-agricultural income sources increases due to lack of access to land which serves as the primary source of production.

Table 8.8 Structure of annual household income (Tk) by land ownership and tenurial categories (all regions), 1996.

Income categories	Land ownership categories			Tenurial categories			All household
	Landless farmer	Marginal farmers	Farm household	Owner operator	Part tenant	Tenant	
Foodgrain income	27.9	35.4	40.9	37.3	43.9	23.8	37.5
Non-cereal income	6.3	4.7	10.1	9.2	6.7	6.8	8.4
Total crop income	34.2	40.1	51.0	46.5	50.6	30.6	45.9
Wage income	16.2	4.3	2.3	1.8	8.2	23.3	5.3
Miscellaneous inc.	31.3	32.3	17.0	22.6	18.9	28.7	22.4
Agricultural income	52.5	63.4	80.7	75.6	72.9	48.0	72.3
Non-agril. income	47.5	36.6	19.3	24.4	27.1	52.0	27.7
Total household income	100.0 (18,553)	100.0 (24,283)	100.0 (44,773)	100.0 (36,946)	100.0 (25,596)	100.0 (21,235)	100.0 (31,571)
Per capita income	3,873	5,091	7,242	6,363	4,910	4,201	5,236
Family size	5.49	5.39	6.74	6.26	5.88	5.38	6.03
Observations	134	90	182	236	112	58	406

Note: Figures in parentheses are percentages of total income.
Landless = less than 0.20 ha of owned land, marginal = owned land 0.21 – 0.40 ha, small = owned land 0.41 – 1.00 ha, medium = owned land 1.01 – 2.00 ha, and large = owned land above 2 ha.
Farm household refers to the combination of small, medium and large farmers (0.41 – 2.00 + ha).

Source: Field Survey, 1997.

8.4 Determinants of Household Income: A Multivariate Regression Analysis

The previous sections provided an assessment on the structure of household income derived from various sources. The effect of land ownership on the structure of income as well as regional variation in level and structure of income was analyzed. However, income of a household depends on a host of factors, which are not captured in the aforementioned analyses. Therefore, in order to assess the

impact of modern agricultural technology on annual household income, the following equation is fitted to the household level data.

INCM = f (AMLND, WORK, CAPL, AGE, TNC, PMVAR, PIRRIG, EDUCH, INFRA, SOIL)

where,

INCM = total family income of the household ('000 taka)
AMLND = amount of land cultivated by the household (ha)
WORK = number of working members in the household (persons)
CAPL = value of farm capital excluding land asset ('000 taka)
AGE = age of the farmer (years)
PTNC = proportion of cultivated land rented-in (%)
PMVAR = proportion of cultivated land under modern varieties of rice and wheat (%)
PIRRIG = proportion of cultivated land under irrigation (%)
EDUCH = completed years of formal schooling of the head of household (years)
INFRA = index of underdevelopment of infrastructure
SOIL = index of soil fertility

The effect of technological change on household income is captured with the multiplicative term PMVAR*PIRRIG. This is done as these two variables tend to be highly correlated. The regression estimate is specified in log-linear form. Natural logarithm of amount of land cultivated (AMLND), value of non-land fixed assets (CAPL), number of working members (WORK) in the family, and age of the farmer (AGE). The education variable is measured in linear form since many farmers have zero values. The remaining variables are measured in proportions and indices as the case may be. The OLS method is used for estimating the parameters. Various components of household income are regressed independently on the aforementioned set of explanatory variables. The estimated parameters of the income equations for crop income, agricultural income, non-agricultural income and total family income per household are presented in Table 8.9. The explanatory variables explained about 82 percent of the variation in crop income model and 75 percent in agricultural income model respectively (for details see Appendix Table 8A.1). The very low value of adjusted R-squared in the non-agricultural income model reflects the exogeniety of income from non-agricultural sources. The model explains about 46 percent of overall income within the sample households.

Table 8.9. Determinants of rural household income, 1996.

Variables	Crop income (CROPI)	Agricultural income (AGI)	Non-agricultural income (NAGI)	Total family income (INC)
Constant	9.128[a]	9.267[a]	7.260[b]	10.265[a]
lnAMLND	0.962[a]	0.676[a]	-0.741[b]	0.446[a]
lnWORK	-0.001	0.114[b]	0.818[c]	0.110[c]
lnCAPL	0.043[a]	0.142[a]	-0.087	0.113[a]
lnAGE	-0.039	-0.023	-0.206	0.049
PTNC	-0.111	-0.264[a]	0.395	-0.171
PMVAR*PIRRIG	0.238[a]	0.165[b]	-2.471[a]	-0.180
EDUCH	-0.020[a]	-0.005	0.004	0.004
INFRA	-0.001	-0.002	-0.055[a]	-0.007[a]

SOIL	0.287[b]	0.298[b]	-0.193	-0.090
Adj. R-squared	0.83	0.75	0.07	0.46
$F_{(9, 396)}$	213.97[a]	133.81[a]	4.23[a]	38.63[a]
D.W. Statistics	1.74	1.75	1.80	2.02

Note: [a] = significant at 1 percent level (p<0.01); [b] = significant at 5 percent level (p<0.05)
[c] = significant at 10 percent level (p<0.10)
Source: Computed.

Land, value of nonland fixed assets, modern agricultural technology and soil fertility are the major determinants of income from crop and agricultural sources. The coefficient of land is positive and highly significant (p<0.01) in crop, agricultural and family income model. The value of land coefficient in crop model indicates that one percent increase in land area will raise income by about one percent. The negative coefficient of tenancy variable indicates that the sharecropping depresses family income and is consistent with a priori expectation.

The major determinants of non-agricultural income are number of working members in the family. Land, access to modern agricultural technology, and high value of non-land fixed capital negatively influence non-agricultural income indicating that lack of access to modern agricultural technology forces the households to seek income from non-farm sources.

The technology variable is positive and highly significant (p<0.01) in crop and agricultural income model as expected. The education level of the household head has a negative relationship with income from crop and agriculture but positive with non-agricultural income indicating that higher level of education pulls farmers away from agricultural activities. Deb (1995) also reported negative influence of education on agricultural growth.

The number of working members in the family significantly (p<0.05) negatively influence income from agriculture while it is significantly (p<0.10) positively related with non-agricultural income as well as total family income. The implication is that large number of working members in the family lead to high involvement in non-farm activities, as expected.

The influence of the state of infrastructural development is very pronounced in non-agricultural and total family income model and the expected sign is consistent throughout. The significant (p<0.01) negative coefficient of this variable indicates that household income from non-agricultural activities as well as overall income is higher in developed region which reinforces the findings of all the preceding chapters. The significant (p<0.05) positive coefficient of soil fertility variable indicates that the better the soil quality the higher will be the agricultural income also reinforcing the findings of previous analyses.

8.5 Distributional Impact of Technological Change on Farm Households

A major focus of this study is to examine the distributive justice of the highly desired technological change in crop agriculture. The aforementioned analyses already hinted on the fact that though technological change raised income significantly, yet it failed to bring in distributive justice to the rural household economy. In this section, a rigorous analysis of impact of technological change on income distribution is attempted in order to confirm the intuition developed in the foregoing sections.

8.5.1 Impact on Factor Shares

An analysis of the changes in factor shares of crop production will provide a first hand implication on the distributional impact of modern agricultural technology. In absolute value terms, significant (p<0.01) differences exists between modern and local rice varieties in all components of the factor shares (Table 8.10). However, the column of differences in factor shares (modern over local varieties) provides some interesting features. Production of modern varieties is heavier on current inputs with a large purchased component but cheaper on animal power services as well as human labor input per unit of land area though it employs significantly (p<0.01) higher amount of hired labor. Though there is no difference in proportion of family income between alternative rice production technologies, the proportion of net income (farm operator surplus) is almost double for modern variety cultivators. Therefore, those farmers who cannot afford to adopt modern technology lose in terms of net income per unit of land.

Table 8.10 Factor shares of local and modern varieties of rice (all region), 1996.

Factors	Local rice varieties		Modern rice varieties		Share diff. (modern over local)	t-ratio for mean value difference
	Tk/ha	Share of gross value	Tk/ha	Share of gross value		
Current input	1,906	13.66	5,260	21.04	7.38	12.22[a]
Family	567	4.06	994	4.01	-0.05	6.17[a]
Purchased	1,339	9.60	4,266	17.03	7.43	11.37[a]
Animal labor	1,962	14.06	2,170	8.75	-5.31	5.06[a]
Family	769	5.51	1,045	4.21	-1.30	2.54[a]
Hired	1,193	8.55	1,125	4.54	-4.01	-0.61
Human labor	3,479	24.94	4,553	18.35	-6.59	5.66[a]
Family	1,628	11.67	1,806	7.28	-4.39	1.02
Hired	1,351	13.27	2,747	11.07	-2.20	4.92[a]
Land rent	5,494	39.38	9,297	37.47	-2.11	10.15[a]
Operator surplus	1,111	7.96	3,529	14.22	6.26	5.25[a]
Gross output value	13,952	100.00	24,809	100.00	-	13.50[a]
Value added	12,045	86.33	19,549	78.80	-7.53	10.37[a]
Farm-family income	9,002	64.52	15,677	63.19	-1.33	9.04[a]
Observations	117		829			

Note: [a] = significant at 1 percent level (p<0.01).
Source: Field Survey, 1997.

8.5.2 Impact on Income Distribution

To begin with the analysis of distributional impacts of modern agricultural technology, the structure of income of the rural households is analyzed by categorizing the villages according to status of modern technology (variety) adoption as well as status of modern irrigation facilities. Villages with more than 60 percent of land area under modern varieties of rice and wheat are designated as the 'high adopter' villages, between 40 – 60 percent of land area under modern varieties as 'medium adopter' villages, and less than 40 percent land under modern varieties as 'low adopter' villages. The other classification of villages is according to level of modern irrigation facilities. Villages with more than 50 percent of land area under modern irrigation facilities are designated as 'highly irrigated' villages while the remaining are designated as 'poorly irrigated' villages.

Table 8.11 summarizes the intensity of modern technology adoption in the villages thus classified. Though the average size of land owned and area cultivated are lowest with highest incidence of tenancy in 'low adopter' villages, the differences are not as sharp between 'high adopter' villages as compared to 'medium adopter' villages. Similar trend is observed for the villages classified according to level of irrigation facilities. This reinforces the finding that intensity of modern agricultural technology is higher in regions with poor land endowments. But various other factors also determine adoption, which leads to the differentiation between the two extremes, the 'high adopter' and 'low adopter' villages. Two of those factors may be the incidence of tenancy and the level of irrigation facilities.

Table 8.11 Level of modern technology adoption in study villages, 1996.

Variables	Adopter categories			Irrigation level		All
	High	Medium	Low	High	Low	
Average size of land owned (ha)	0.63	0.90	0.51	0.68	0.50	0.65
Average size of land cultivated (ha)	0.95	1.28	0.82	1.01	0.82	0.98
Area under tenancy (%)	19.13	22.74	23.49	20.56	18.30	20.06
Area under modern rice (%)	86.44	57.03	37.26	81.27	55.94	77.59
Area under irrigation (%)	67.02	62.35	17.93	67.42	27.70	61.65
Households in the group (%)	76.35	14.04	9.61	85.47	14.53	100.00

Source: Field Survey, 1997

An analysis of the structure of farmers' income by status of modern technology adoption reveals some interesting features. Though foodgrain income is highest in 'high adopter' villages, the overall crop income is highest in 'medium adopter' villages as presented in Table 8.12. This reinforces the finding in previous sections that the more diversified the agricultural production system, the more is the income. However, a sufficient condition seems that diversification has to be undertaken with medium level of modern technology adoption, implying that one season of modern rice coupled with non-cereal crops in other seasons would bring in highest income per household.

Table 8.12 Structure of annual household income (Tk.) by status of modern agricultural technology adoption (all regions), 1996.

Income categories	Adopter categories of villages			Irrigation level of villages		All household
	High adopter	Medium adopter	Low adopter	High irrigated	Low irrigated	
Foodgrain income	44.7	24.7	13.5	40.5	18.5	37.5
Non-cereal income	4.5	21.9	10.3	8.3	9.0	8.4
Total crop income	49.2	46.6	23.8	48.8	27.5	45.9
Wage income	4.6	3.3	13.4	4.4	11.2	5.3
Miscellaneous income	16.8	26.8	50.4	18.4	48.0	22.4
Agricultural income	78.6	69.9	36.2	77.2	40.8	72.3
Non-agril. income	21.4	30.1	63.8	22.8	59.2	27.7
Total household income	100.0 (28,982)	100.0 (42,534)	100.0 (36,124)	100.0 (31,935)	100.0 (29,427)	100.0 (31,571)
Per capita income	5,352	6,902	6,220	5,763	5,009	5,236
Family size	5.87	6.07	7.21	5.85	7.07	6.03
Observations	310	57	39	347	59	406

Note: Figures in parentheses are total family income per household.
Source: Field Survey, 1997.

Wage income, on the other hand, is highest in 'low adopter' villages, implying that lower income from crop agriculture must be supplemented with either wage income or non-farm income. Interplay of all these diversified factors resulted in lowest household income for 'highest adopter' villages. Consequently, the per capita income is also estimated to be lowest for farmers of 'high adopter' villages. Since, it was already established that modern variety cultivation fetches significantly higher income per unit of land, the associated lowest per capita income is solely to be attributed to high unequal distribution of income across households in these 'high adopter' villages. However, firm conclusion on this finding will be drawn after analyzing the degree of income concentration.

Further, analysis of income structure between villages endowed with 'high' and 'low' level of modern irrigation facilities reveals that crop income as well as total agricultural income is higher in 'highly irrigated' villages while wage and non-farm income is high in 'low irrigated' villages (Table 8.12). However, it is interesting to observe that income per household is not sharply different between these two categories of villages. The difference in per capita income is also not largely different as with the case of villages classified according modern technology adopter categories. The family size dynamics suppressed the household income for villages lying at the bottom of both classes. The family size is more than 7 persons per household in this category as compared to only 6 persons for other categories (Table 8.12).

Conclusion on the existence of income inequality in 'high adopter' villages is reinforced when income structure of only landless and marginal farmers classified by adopter category and irrigation level is analyzed separately (Table 8.13).

Table 8.13 Structure of household income (Tk.) of landless and marginal farmers by status of modern agricultural technology adoption (all regions), 1996.

Income categories	Adopter categories of villages			Irrigation level of villages		All household
	High adopter	Medium adopter	Low adopter	High irrigated	Low irrigated	
Foodgrain income	39.6	21.7	8.8	36.0	12.2	31.4
Non-cereal income	2.8	14.9	7.4	5.3	6.8	5.6
Total crop income	42.4	36.5	16.2	41.2	19.0	37.0
Wage income	9.9	6.7	17.0	9.5	15.3	10.6
Miscellaneous income	24.3	35.3	57.6	26.2	55.4	31.8
Agricultural income	65.8	58.1	25.5	64.3	29.3	57.6
Non-agril. income	34.2	41.9	74.5	35.7	70.7	42.4
Total household income	100.0 (18,031)	100.0 (25,811)	100.0 (36,411)	100.0 (19,670)	100.0 (27,883)	100.0 (20,844)
Per capita income	3,847	5,229	7,271	4,178	5,467	4,362
Family size	5.38	5.24	6.32	5.28	6.50	5.45
Observations	173	22	29	192	32	224

Note: Figures in parentheses are total family income per household.
Source: Field Survey, 1997.

The per capita income in 'high adopter' village is almost half as compared to 'low adopter' villages. The picture is similar, but less sharp, when per capita income between 'highly' and 'poorly' irrigated villages are considered. Therefore, one can intuitively state that expansion of modern irrigation facilities only causes lesser degree of inequality as compared to intensive diffusion of modern varieties of rice and wheat. This is because availability of modern irrigation facilities does not exclusively imply high intensity of modern variety cultivation though it significantly contributes to its diffusion. With access to irrigation and water control, one can increase the cropping intensity and produce a diverse range of non-cereal crops that can fetch higher incomes.

8.5.3 Analysis of Income Concentration

In order to identify the level of income concentration, the proportion of income held by the top 10 percent and bottom 50 percent of households, classified on the basis of per capita income, are analyzed. The result is presented in Table 8.14.

Table 8.14 Pattern of income distribution by status of modern agricultural technology adoption based on per capita income scale (all regions), 1996.

Village category	Proportion of income held by top 10 % and bottom 50 % households					
	Foodgrain income	Agril. income	Non-agril. income	Total family income	Per capita income	Per capita land own
High adopter villages (> 60 percent of land under modern varieties)						
Top 10 % household	22.4	26.4	27.3	26.6	30.0	33.9

Bottom 50 % household	27.6	24.5	13.7	22.1	19.3	28.0
Medium adopter villages (between 40 – 60 percent of land under modern varieties)						
Top 10 % household	31.7	26.5	28.7	27.0	25.1	27.7
Bottom 50 % household	25.9	28.3	21.4	26.2	27.2	31.7
Low adopter villages (upto 40 percent of land under modern varieties)						
Top 10 % household	2.9	5.1	27.6	19.5	23.3	7.3
Bottom 50 % household	48.7	46.5	19.3	29.2	20.2	41.3
Highly irrigated villages (> 50 percent of land under modern irrigation facilities)						
Top 10 % household	22.8	26.2	28.2	26.6	28.7	26.9
Bottom 50 % household	29.0	24.8	16.6	22.9	20.6	27.4
Low irrigated villages (< 50 percent of land under modern irrigation facilities)						
Top 10 % household	4.1	8.1	38.6	26.2	35.6	7.0
Bottom 50 % household	40.5	35.4	10.7	20.8	17.3	38.3
All villages						
Top 10 % household	22.8	25.3	29.5	26.5	29.7	25.1
Bottom 50 % household	29.4	25.4	15.4	22.7	19.9	28.9

Source: Computed.

It is evident from Table 8.14 that the concentration of income into the hands of top 10 percent of the household is low in 'low adopter' villages while it is highest in 'high adopter' villages. About 23 percent of per capita income is held by the top 10 percent households in 'low adopter' villages while for the 'high adopter' villages the proportion is 30 percent. The structure of land ownership also reveals similar pattern across village adopter categories. In 'low adopter' villages the top 10 percent household control only 7 percent of per capita land while in 'high adopter' villages the proportion is 34 percent. The structure of income concentration changes when comparison is made between 'highly' and 'poorly' irrigated villages. The concentration is high in 'poorly irrigated' villages while it is low in 'highly irrigated' villages. In the 'poorly irrigated' villages, the top 10 percent households hold 36 percent of per capita income while for the 'highly irrigated' village the proportion is 29 percent (Table 8.14).

It should be noted that, irrespective of any categorical classification, the concentration of income is high for the top 10 percent of the rural population, which is a general feature of the persistent inequality in the rural economy of Bangladesh. The concern lies in reducing such distributive injustice for which technological change in agriculture was deemed as the solution. However, the present study shows that when the evaluation of the distributional impact of modern agricultural technology is conducted at a matured stage the picture does not seem to be so rosy as expected. The modern technology diffusion though significantly increases income derived from crop production it adds to income inequality as well. The following section reinforces this argument. In other words, the study supports, without controversy, the statement made by Freebairn (1995) that 80 percent of the 307 studies on modern agricultural technologies that he reviewed revealed worsening income distribution.

8.5.4 Measuring Degree of Income Inequality: A Gini-coefficient Analysis

One of the most common measure of inequality in income distribution is the Gini-coefficient, which is based on the Lorenz curve. A number of definition of gini-coefficient is available, such as Rao's (1969), Kendall and Stuart's (1963), Sen's (1973), and Fei and Ranis (1974) and geometric definitions (in Anand, 1983). Anand (1983) proved the equivalence of all these definitions. In this study, the definition of Fei and Ranis (1974) is utilized for the purpose of measuring degree of inequality. The gini-coefficient defined by Fei and Ranis (1974) is as follows (in Anand 1983):

$$G = 2/(n^2\mu)\ [1y_1 + 2y_2 + 3y_3 + ...+ ny_n], \text{ for } \quad y_1 \le y_2 \le y_3 \le ..... \le y_n \qquad (8.5.4.1)$$

where:
G = gini coefficient
μ = mean of per capita income
y_1 .... y_n = individual per capita income.

The degree of inequality measured by Gini-coefficient for the study regions is presented in Table 8.15. Two measures were utilized, one based on 'per capita income scale' and the other based on 'per capita land ownership scale'. The later is used to check the concentration of land ownership status that significantly influence income derived from modern technologies.

Analysis of Gini-coefficient computed on per capita income scale reveals that degree of income inequality is less is 'medium adopter' villages (0.34) and high but similar in 'high adopter' (0.44) as well as 'low adopter' villages (0.45), respectively (Table 8.15). When villages are classified according to the level of modern irrigation facilities, the degree of inequality in per capita income is found to be lower in 'highly irrigated' villages (0.42) than the 'poorly irrigated' villages (0.48). Regional analysis of income inequality reveals that Comilla region has highest degree of inequality (0.47) while the other two regions have similar values (0.40 and 0.41). Figure 8.1 presents the Lorenz curve for each of the regions, which provides a visual effect of this statement.

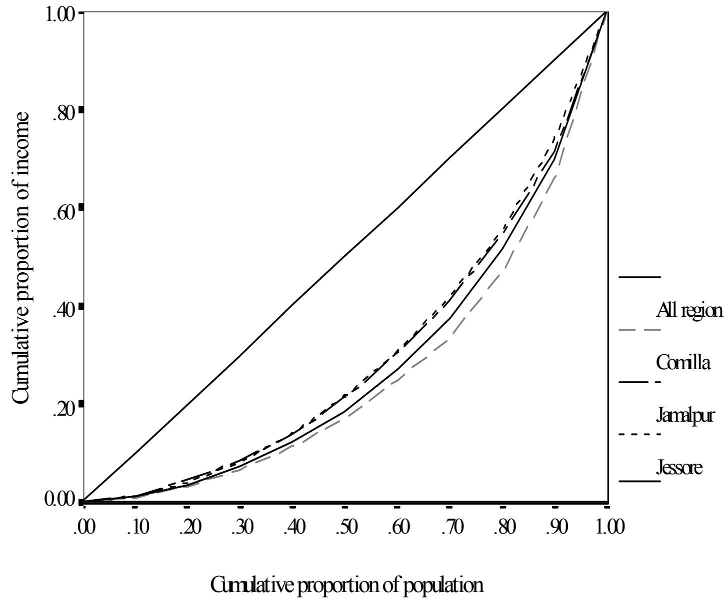
Table 8.15 Inequality of income distribution by status of modern agricultural technology adoption, 1996.

Village category	Gini-coefficient computed on per capita income scale			Gini-coefficient computed on per capita land ownership scale		
	Total income per HH	Per capita income	Per capita landown	Total income per HH	Per capita income	Per capita landown
Villages classified by status of modern technology adoption						
High adopter village	0.40	0.44	0.34	0.39	0.38	0.59
Med. adopter village	0.36	0.34	0.29	0.29	0.25	0.56
Low adopter village	0.32	0.45	0.14	0.02	0.05	0.53
Villages classified by level of modern irrigation facilities						
High irrigated village	0.39	0.42	0.34	0.40	0.38	0.60
Low irrigated village	0.38	0.48	0.17	0.04	0.08	0.51
Villages classified by regions						
Comilla region	0.39	0.47	0.16	0.17	0.18	0.53

Jamalpur region	0.37	0.41	0.37	0.35	0.35	0.56
Jessore region	0.39	0.40	0.33	0.37	0.32	0.59
All category	0.39	0.43	0.32	0.38	0.37	0.60

Source: Computed.

Fig. 8.1 Lorenz curve showing income inequality across study regions based on per capita income scale, 1996.



Analysis of inequality based on per capita land ownership scale provides a different picture (Table 8.15). The level of inequality in terms of land ownership is considerably higher than level of inequality measured in terms of per capita income for all cases (compare the last column with the third column from left). The level of inequality in per capita land owned is lowest for 'low adopter' villages (0.53) and highest in 'high adopter' villages (0.59). Same is the case when comparisons are made between villages based on level of modern irrigation facilities. The inequality in per capita land ownership is lower in 'low irrigated' villages (0.51) and higher in 'high irrigated' villages (0.60). However, when measuring inequality across regions, Comilla reveals the lowest level of inequality (0.53) followed by Jamalpur (0.56) and Jessore (0.59) regions, respectively.

8.5.5 Contribution of Technological Change to Inequality: Gini-decomposition Analysis

Various studies used Gini-coefficient analysis in comparing income inequality with and without technological change as done in the previous section. Thapa *et al.* (1992) noted that such analysis does not capture the impact of modern technology on various income components nor do they control the effects of factors other than modern technology in them. Recognizing this deficiency, a gini-decomposition analysis is attempted in this study. The exact decomposition of Gini-coefficient for total income is given by (Thapa *et al.*, 1992 who in turn adopted from Pyatt, Chen and Fei, 1980):

$G(Y) = \Sigma S_k R(y, x_k) G(x_k)$ (8.5.5.1)

where:
S_k is the share of the kth income source in total income,
$R(y, x_k)$ is the rank correlation ratio,
$G(x_k)$ is the Gini-coefficient for the distribution of individual income source, x_k.

Rank correlation is defined as:

$R(y, x_k) = [Cov(x_k, r(y))] / [Cov(x_k, r(x_k))]$ (8.5.5.2)

where:
$Cov(x_k, r(y))$ is the covariance between income from individual sourc and the rank of household with respect to total income, and
$Cov(x_k, r(x_k))$ is the covariance between income from kth source and the rank of household with respect to total income.

In this formulation, the contribution of each income component to total income inequality depends on the Gini-coefficient as well as the share of component income in total income and the rank correlation ratio (Thapa *et al.*, 1992). The Gini-coefficients, income shares, rank correlation ratios, and contribution of various income components to the overall Gini-coefficient classified by regions is presented in Table 8.16.

It is evident from Table 8.16 that the contribution of modern agricultural technology to income inequality is substantial and is estimated at about one-third (35 percent) of total inequality. Contribution to inequality is lowest in Comilla (27 percent), followed by Jessore (31 percent) and highest in Jamalpur region (45 percent), respectively. This finding makes it clear that higher intensity of modern technology adoption increases inequality (the case of Jamalpur) while medium intensity of technology adoption contributes relatively less to income inequality (the case of Jessore). On the other hand, higher level of non-agricultural income also contributes sharply to income inequality (the case of Comilla).

Table 8.16 Income shares, Gini-coefficients, rank correlation ratios, and contribution of income components to the overall Gini coefficient in study regions, 1996.

Income source	Gini coefficient	Share in total income	Rank correlation ratio	Contribution to overall Gini coefficient	Percentage contribution to overall Gini
Jamalpur Region					
Total household income	0.427	1.00	1.00	0.427	100.0
Modern rice/wheat income	0.492	0.49	0.79	0.190	44.5
Other agricultural income	0.573	0.38	0.82	0.177	41.4
Non-agricultural income	0.828	0.14	0.53	0.060	14.1

Jessore Region					
Total household income	0.452	1.00	1.00	0.452	100.0
Modern rice/wheat income	0.574	0.32	0.76	0.140	31.0
Other agricultural income	0.545	0.42	0.88	0.202	44.7
Non-agricultural income	0.661	0.26	0.64	0.110	24.3
Comilla Region					
Total household income	0.435	1.00	1.00	0.435	100.0
Modern rice/wheat income	0.502	0.39	0.60	0.117	26.9
Other agricultural income	0.495	0.31	0.74	0.115	26.4
Non-agricultural income	0.743	0.30	0.91	0.203	46.7
All Region					
Total household income	0.445	1.00	1.00	0.445	100.0
Modern rice/wheat income	0.541	0.42	0.68	0.154	34.6
Other agricultural income	0.579	0.37	0.80	0.171	38.4
Non-agricultural income	0.758	0.22	0.72	0.120	27.0

Source: Computed.

8.6 Impact of Technological Change on Poverty

Eradication of poverty has been one of the major objectives of the Government of Bangladesh since its emergence as an independent nation in 1971. However, untill today, widespread poverty remains a major problem crippling the country in its pursuit of economic development. As established in the previous sections that modern agricultural technology contributes almost one-third to income inequality and therefore is assumed to affect poverty as well. In order to test this hypothesis rigorously, the present section attempts to analyze the impact of technological change on poverty using various measures of poverty.

Anand (1983) noted that redress of poverty[32] is a most efficient method of redressing inequality. The analysis of poverty, in general, depends on the definition used for poverty, which are many. However, essentially there are two major approaches to define poverty: the absolute approach and the relative approach. In the absolute approach a certain minimum standard is fixed in terms of attaining requisite nutritional level and the cost to attain that level is calculated. The relative approach defines poverty in relation to the standard of living of the community as a whole and, therefore, recognizes the interdependence between the poverty line and the income distribution of the community. In this study, the absolute approach is utilized. This incorporates the empirical estimation of poverty line expenditure necessary to attain a minimum nutritional requirement.

Mian (1978), based on joint FAO/WHO Ad-hoc Expert Committee Report on Energy and Protein Requirement for Bangladeshi nationals (1973), provided an estimate of minimum

[32] Redress of poverty rule can be understood in terms of Anand's (1983) explanation. 'Given an ordered distribution y, if an additional amount of income Δ becomes available for distribution among the population but the existing income of any person cannot be reduced, how should Δ be distributed to maximize social welfare? Give Δ to the poorest person 1 until his or her income reaches that of person 2. Distribute the remainder equally between them until their incomes reach that of person 3. And so on.' (pp. 344-45).

average requirement of energy and proteins adjusted for various losses. His estimate is presented in Table 8.17. He also determined least-cost long-term diet sets with available food items that attain the level of nutrition set out in Table 8.17.

Table 8.17. Minimum nutritional requirement for a person per day.

Minimum average daily requirement	Food energy (Kcal)	Fats (gm)	Thia-mine (mg)	Ribo-flavin (mg)	Niacine (mg)	Vitamin A (I.U.)	Ascorbic acid (mg)	Iron (mg)	Cal-cium (mg)
Per capita/day	2112.00	17.30	0.84	0.92	13.80	2003	24.90	13.90	450.00

Source: Mian (1978), Table 18.

In this study, one of Mian's (1978) long-term diet, named Diet A, is adopted with a minor upward adjustment of food energy from 2,080 to 2,112 kcal and the current cost required to attain the diet is estimated separately for each region using region-specific retail prices of the food products. Expenditure on non-durable goods is estimated at 30 percent of food cost following Hossain *et al.* (1990). The result of the calculation is provided in Table 8.18. The adjustment for additional calorie is to be obtained from increased allocation of wheat from an initial 38.3 to 58.3 gms per capita per day. The calculation of poverty line expenditure provides an estimate of Tk. 5,409 per capita per year (Tk. 5,424, Tk. 5,357, and Tk.5,329 for Jamalpur, Jessore and Comilla, respectively) as shown in Table 8.19. For the purpose of computing poverty indices, the overall expenditure of Tk. 5,409 per capita per year is utilized, as it does not change the composition of poor in each region when computed on the basis of region-specific poverty line expenditures.

Table 8.18. Poverty line income required to fullfil the nutritional and other requirements by study regions, 1996.

Food item	Qty. (gm) of food included in optimal diet	Cost (Tk.) of attaining the optimal diet evaluated at region-specific retail market prices			
		Jamalpur region	Jessore region	Comilla region	All region
Rice	432.6	4.90	4.36	4.46	4.62
Wheat	58.3	0.64	0.58	0.64	0.62
Potato	36.7	0.15	0.14	0.15	0.14
Lentil	25.0	0.53	0.54	0.53	0.53
Fish	38.3	2.11	2.43	2.24	2.24
Meat	1.7	0.11	0.13	0.11	0.12
Milk	31.1	0.48	0.43	0.53	0.50
Dry milk	2.5	0.55	0.55	0.55	0.55
Sugar	27.2	0.70	0.70	0.70	0.70
Oil	12.2	0.70	0.69	0.63	0.68
Onion	8.5	0.09	0.07	0.07	0.08
Non-leafy vege.	86.8	0.38	0.58	0.52	0.53
Leafy vegetable	20.0	0.09	0.09	0.10	0.09
Cost of food per capita per day		11.43	11.29	11.23	11.40
Annual cost of food		4,172.0	4,120.9	4,099.0	4,161.0
Annual cost of non-food items		1,251.6	1,236.3	1,229.7	1,298.3
Poverty line expenditure per year per capita		5,423.6	5,357.2	5,328.7	5,409.3

Source: Computed.

8.6.1 Estimation of Poverty Indices

A number of poverty measures are developed during the 1980s of which the popular indices are Sen's poverty index (1976), Kakwani's poverty index (1980) and FGT's (Foster, Greer, and Thorbecke) poverty measure (1984). In this study, all of these indices are computed to examine the degree of poverty, consistency and stability of results when diverse measurement techniques are utilized. Table 8.19 presents the result of the various poverty indices.

It is clear from Table 8.19 that poverty is highest in areas with high intensity of modern technology diffusion followed by low intensity areas. The lowest incidence of poverty is in the villages with 'medium intensity' of modern technology diffusion. The level of income inequality among the poor is lowest (0.24) in 'medium adopter' villages. The per capita income of the poor is highest in these 'medium adopter' villages (Tk. 3,433) as compared to 'high adopter' and 'low adopter' villages (Tk. 2,570 each). Also, the income gap ratio, poverty gap ratio, and the number of poor people below poverty line (head count ratio) is lowest in 'medium adopter' villages. All measures of poverty, Sen index, Kakwani index and FGT (P2) index consistently indicate poverty is lowest in 'medium adopter' villages. The distributionally sensitive measure of poverty, FGT (P2), reveals that poverty is strikingly low in 'medium adopter' villages with least inequality among the poor, while it is similar and high in 'high adopter' as well as 'low adopter' villages. 'This finding explains to some extent the slow pace of modern agricultural technology diffusion in Bangladesh. The exclusive diffusion of modern varieties sharply increases inequality by inducing sharp income difference between adopters and non-adopters as indicated by head count ratio. On the other hand, total non-adoption of modern variety technology leads to lower income, consequently leading to poverty again as indicated by same value of income gap ratio between 'low adopter' and 'high adopter' villages. The 'medium level of adoption' of modern technology opens up the opportunity to derive higher income from cultivating modern varieties in one season as well as diversifying agriculture in other seasons. The increase in income is accrued through increase in cropping intensity as well as diversified agriculture. The modern irrigation facilities also have a favorable impact on poverty. As explained earlier, modern irrigation opens up opportunities for diversifying the cropping system in addition to facilitate the diffusion of modern variety technology. When regional distribution is considered, Jamalpur and Jessore regions faired similarly with respect to all indices while Comilla region differs distinctly with high level of inequality among the poor as well as higher incidence of poverty.

Table 8.19 Estimation of poverty in the study regions, 1996.

Villages	Inequa-lity among poor	Per capita income of poor	Head count ratio	Income gap ratio	Sen index	Kak-wani index	FGT Poverty gap ratio	FGT Distributionally sensitive
	(G*)	(M*)	(H)	(I)	(P_{Sen})	($P1_K$)	(P1)	(P2)
Villages classified by status of modern technology adoption								
High adopter village	0.301	2,569.4	0.63	0.53	0.42	0.43	0.33	0.21
Medium adopter village	0.243	3,433.4	0.46	0.37	0.24	0.19	0.17	0.09
Low adopter village	0.304	2,569.8	0.54	0.52	0.36	0.31	0.28	0.18
Villages classified by level of modern irrigation facilities								
High irrigated village	0.293	2,731.9	0.58	0.50	0.38	0.35	0.29	0.18
Low irrigated village	0.320	2,304.0	0.66	0.57	0.47	0.51	0.37	0.26
Villages classified by regions								
Comilla region	0.319	2,303.6	0.74	0.57	0.52	0.68	0.42	0.28
Jamalpur region	0.268	2,785.7	0.51	0.49	0.32	0.27	0.25	0.15
Jessore region	0.291	3,047.5	0.55	0.44	0.33	0.28	0.24	0.15
All category	0.300	2,662.7	0.59	0.51	0.39	0.37	0.30	0.19

Note: Head count ratio (H) = q/N where q is the number of poor households having income no greater than poverty line expenditure X (Tk. 5,409) and N is the total number of households.

Income gap ratio (I) = [X-M*]/M*.

Sen index (P_{Sen}) = H [I + (1-I) G*]

Kakwani index (taking into account inequality among poor) ($P1_K$) = (H/M) [X-M*(1-G*)], where M is the per capita income of all households.

FGT Poverty gap ratio (P1) = H * I.

FGT Distributionally sensitive measure (P2) = P_2 (M*; X) = $1/N \Sigma_i^q [(X – M*/M*]^2$.

Source: Computed.

8.7 Inferences

There are significant regional differences in income derived from agricultural as well as non-agricultural sources. Income from crop production is significantly different across land ownership and tenurial classes.

Farm size, working members, farm capital, modern technology, and soil fertility significantly increase crop as well as agricultural income while farmers' education level significantly decreases crop income. Developed infrastructure significantly increases non-agricultural income while farm size and modern technology significantly decreases non-agricultural income. The analysis is similar for landless and marginal farmers.

Analysis of impact of modern technology on factor shares revealed that significant differences exist in absolute values of factor shares between modern and local varieties of rice. Labor wages of about Tk.2,747 (11 percent of gross value of production) per ha of modern rice cultivation goes to landless and marginal farmers through the hired labor market which is double the size of wages estimated at Tk 1,351 (13 percent of gross value of production) for local rice production.

An analysis of distributional impact of modern agricultural technology revealed that income inequality is higher in 'high adopter' villages as well as 'low adopter' villages. Gini-coefficient computed on per capital income scale is estimated at 0.44 and 0.45 for 'high adopter' and 'low adopter' villages while it is 0.34 in 'medium adopter' villages characterized with greater crop diversity. Similarly, with respect to irrigation status, income inequality is higher in low irrigated villages. Gini-coefficient is estimated at 0.42 and 0.48 in 'high' and 'low' irrigated villages. On a regional basis, inequality is higher (0.47) in Comilla region while it is lower and similar 0.41 and 0.40 in Jamalpur and Jessore region, respectively. The differences across categories become less prominent when Gini-coefficient is computed on per capita land ownership scale. The inequality in per capita land ownership remains within 0.50 to 0.60 with minor variations.

Modern technology alone contributes to about 35 percent (minimum 27 percent in Comilla and maximum 45 percent in Jamalpur) to total income inequality. The contribution of non-agricultural income is about 27 percent while other agricultural income contributes the remaining 38 percent to total income inequality.

Analysis of technological change on poverty using a number of measures revealed that poverty is lowest in 'medium adopter' villages. The number of population below poverty line is lowest (46 percent) in 'medium adopter' villages as compared to 63 percent and 54 percent in 'high adopter' and low adopter' villages, respectively. On a regional basis, poverty is similar in Jamalpur and Jessore region while it is sharply higher in Comilla. All measures including the distributionally sensitive measure of poverty confirmed that incidence of poverty is highest in 'high adopter' and lowest in 'medium adopter' villages.

CHAPTER IX

TECHNOLOGICAL CHANGE AND ITS IMPACTS ON THE ENVIRONMENT

Agriculture is characterized by its environmental, behavioral and policy aspects (Clapham, 1980). Though the farmers' behavioral and government's policy dimensions of agriculture has been rigorously analyzed in the past, the environmental dimension is largely neglected and remains unclear despite the fact that ecological integrity of agricultural production system is a pre-requisite for sustainability. The concern of environmental impacts of technological change and sustainability in agriculture has been a recent phenomenon spurred by studies such as Shiva (1991), Wossink *et al.*, (1992), Brown (1988), Wolf (1986), Clapham (1980), and Bowonder (1979 and 1981). The present chapter attempts to provide an insight to this less studied dimension in agriculture. It provides a systematic picture of environmental impacts of modern agricultural technology as perceived by farmers and their relative adverse strengths as ranked by the respondent farmers. Further, material evidence in terms of bio-physico-chemical tests of soil fertility and water quality parameters, and long term trend analysis of indicators believed to be impacted due to this technological change in agriculture is provided in order to substantiate, validate, and authenticate the conclusions drawn from farmers' perceptions and rankings. It should be reiterated that a soil fertility index based on the test results for the study area is already quantified and incorporated as an independent variable extensively in the foregoing analyses (Chapter V through Chapter VIII). Therefore, it is expected that conclusions drawn from the foregoing analyses of socio-economic impacts and the current analyses of environmental impacts of technological change would enable to provide a vivid picture of the present day status and delayed consequences of technological breakthrough in Bangladesh agriculture.

9.1 Direct and Indirect Impacts of Modern Agricultural Technology: An Overview

Bowonder (1979), in the heyday of technological change in agriculture, provided a vivid analysis of present and potential multifaceted impacts of 'Green Revolution' technology in India. Using a multi-criteria network analysis, he outlined impacts of 'Green Revolution' technology on industry, agriculture, economy, society, demography, ecology as well as politics. Clapham (1980) viewed that environmental and social factors comprising agriculture are closely tied together and the environmental problem of agriculture largely stems from the phenomena associated with agricultural development. He finds it pointless to discuss sustainability unless linkages among the three domains, environment, farmers decision making behavior and government policy perspective, are identified, understood and dealt with. He stresses that any practical analysis of agricultural environment must recognize the cultural, economic, policy as well as ecological bases of the problems. The present chapter though cannot deal in its entirety of the domains mentioned above, however, it attempts to provide possible linkages as evidenced from the available information on farm level production systems in the study villages.

The technological breakthrough in Bangladesh agriculture has been primarily in the foodgrain sector, that is the introduction of rice-based 'Green Revolution' technology package followed by a gradual introduction of wheat-based technology package. The overall policy thrust for the past four decades (1960 – till date) has been in provision of technical inputs complementing the expansion and diffusion of these ‘Green Revolution’ technologies. This is the prime reason for all of the past studies on technological change in Bangladesh including the present study to concentrate on evaluating the diffusion of ‘Green Revolution’ technology. The selected indicators of technological change over the past 45 years (1949/50 – 1993/94) are presented in Table 9.1 using triennium averages of four periods.

Table 9.1 Selected indicators of technological change in Bangladesh agriculture, 1949/50 – 1993/94.

	Indicators		Period [a] 1950-52	Period [a] 1968-70	Period [a] 1980-82	Period [a] 1992-94
1	Total cropped area (TCA) (‘000 ha)		10,614	12,871	13,103	13,753
2	Net cropped area (‘000 ha)		8,274	8,787	8,531	7,812
3	Cropping intensity (%)		128.3	146.5	153.6	176.0
4	Total rice area (‘000 ha)		8,071	10,049	10,310	10,135
5	Rice as percent of total cropped area (%)		76.0	78.1	78.7	73.7
6	Modern rice as percent of total rice area (%)		nil	1.5	20.3	49.0
7	Total wheat area (‘000 ha)		39	105	520	609
8	Modern wheat as percent of total wheat (%)		nil	6.1	96.2	98.0
9	Total irrigated area (IA) (‘000 ha)		< 1	1,057[b]	1,865	3,257
10	Irrigated area as percent of TCA (%)		na	8.2 [b]	14.2	23.7
11	Foodgrain irrigated area as percent of IA (%)		na	85.8 [b]	78.4	91.2
12	Irrigation by methods	Modern (%)	na	31.5 [b]	67.2	70.9
		Traditional (%)	na	68.5 [b]	32.8	29.1
13	Total fertilizer used (‘000 mt of nutrients)		< 1	113.1	380.8	664.8
14	Fertilizer use rate per TCA (kg of nutrients/ha)		na	8.8	29.1	48.3
15	Pesticide use (‘000 mt)		na	na	2.2	6.5
16	Rice production (‘000 mt)		7,367	11,504	13,417	18,211
17	Rice yield (kg/gross ha)	Modern variety	nil	3,809	2,297	2,409
		Local variety	913	1,103	1,048	1,208
18	Wheat production (‘000 mt)		22	86	932	1,124
19	Wheat yield (kg/gross ha)		564	819	1,792	1,846

Note: [a] Period 1950-52 refers to average of 1949/50, 1950/51 and 1951/52. Period 1968-70 refers to average of 1967/68, 1968/69, and 1969/70. Period 1980-82 refers to average of 1979/80, 1980/81 and 1981/82. Period 1992-94 refers to average of 1991/92, 1992/93 and 1993/94.
[b] 1968/69 and 1969/70 only.

Source: BBS (Various issues), Alauddin and Tisdell (1991), Hossain (1989), and Hamid (1991).

It is clear from Table 9.1 that agricultural production in Bangladesh is operating at its frontier since the 1980s with declining net-cropped area owing to transfer of land for other uses. The total rice area also reached its frontier and making way for wheat area expansion. It is also interesting to note that though area under modern rice varieties reached only 50 percent of total despite its diffusion as early as 1963, the wheat acreage is totally absorbed by modern varieties which picked up in early 1980s. The stagnancy in the diffusion of modern rice varieties is probably due to slower expansion of modern irrigation facilities, susceptibility to pest and disease attack, and capital intensity. The fertilizer use rates per hectare of gross cropped area, though still low, increased about six folds. Pesticide use, negligible until the 1970s, recorded dramatic increase in recent years. The yield rates of modern rice varieties fell sharply from the 1970 levels while the yield rates of local rice varieties is on the rise probably owing to the use of modern inputs and variety screening. However, it is encouraging to note the rising trend in the yield rates of wheat that is exclusively composed of modern varieties (Table 9.1).

9.2 Farmers' Perception of Environmental Impacts of Modern Agricultural Technology

Farmers' perception on environmental impacts is elicited in two steps. First, a set of 12 specific environmental impacts[33] is read to the respondents and was asked to reveal their opinion on these impacts. Next, they are asked to provide scores on a five-point scale if they agree. And for disagreement of these impacts the score is zero. It is believed that undergoing these two step procedures helped in avoiding leading statements and loaded responses. The results of farmers' opinion on the environmental impacts are presented in Table 9.2.

Table 9.2 Farmers' perception on 12 specific environmental impacts of modern agricultural technology by study regions, 1996.

Sl. No.	Environmental impacts of modern agricultural technology	Farmers responding in the affirmative			
		Jamalpur region	Jessore region	Comilla region	All region
1	Reduce soil fertility	149 (85)	103 (98)	96 (76)	348 (86)
2	Affects human health	129 (74)	92 (87)	88 (70)	309 (76)
3	Reduce fish catch	114 (65)	68 (65)	114 (91)	296 (73)
4	Increase disease in crops	116 (66)	78 (74)	83 (66)	277 (68)
5	Compact/ harden soil	90 (51)	74 (71)	62 (49)	226 (56)
6	Increase insect/ pest attack	93 (53)	71 (68)	26 (21)	190 (47)
7	Increase soil erosion	93 (53)	70 (67)	22 (18)	185 (46)
8	Increase soil salinity	71 (41)	59 (56)	45 (36)	175 (43)
9	Contaminate water source	62 (35)	36 (34)	20 (16)	118 (29)
10	Increase toxicity in soil	39 (22)	21 (20)	27 (21)	87 (21)
11	Creates water logging	38 (22)	23 (22)	7 (6)	68 (17)
12	Increase toxicity in water	30 (17)	11 (10)	25 (20)	66 (16)
	All impacts [a]	1,024 (49)	706 (56)	615 (41)	2,345 (48)

Note: [a] Multiple responses. The total number of responses equal 2,100 (12 impacts x 175 farmers) for Jamalpur, 1,260 (12 impacts x 105 farmers) for Jessore, and 1,512 (12 impacts x 126 farmers) for Comilla regions. Therefore, for all regions, the number of responses equal 4,872 (12 impacts x 406 farmers).

Source: Field Survey, 1997.

[33] This set of 12 specific environmental impacts were identified in a focus group discussion (FGD) with the farmers conducted during the pre-testing of structured questionnaire in another sub-district of Jessore region.

Among the 12 specific environmental impacts of modern agricultural technology, majority of the farmers cited 'decline in soil fertility', 'effect on human health', 'reduction of fish catch', 'compaction of soil', and 'increased incidence of crop disease' and 'insect/pest attacks' as the major impacts (Table 9.2). The proportion of affirmative responses declines sharply when one moves down to more intangible and indirect impacts, such as 'contamination of water bodies and soils'.

Since there are multiple responses on these impacts which is consistent with the diversity of impacts of technological change, an attempt has been made to identify the relative strength of these environmental impacts in terms of farmers' own perception. To accomplish this, farmers were asked to rank specific environmental impacts on a five-point scale. The result of this ranking exercise is presented in Table 9.3.

Table 9.3 Ranking of farmers' perception on 12 specific environmental impacts of modern agricultural technology by study regions, 1996.

Sl. no.	Environmental impacts of modern agricultural technology	Index weighted by rank of responses [a]							
		Jamalpur region		Jessore region		Comilla region		All region	
		Index	Rank	Index	Rank	Index	Rank	Index	Rank
1	Reduce soil fertility	0.82	1	0.94	1	0.63	1	0.79	1
2	Affects human health	0.60	2	0.79	2	0.45	4	0.60	2
3	Reduce fish catch	0.55	3	0.59	4	0.57	2	0.56	3
4	Increase disease in crops	0.51	4	0.61	3	0.45	3	0.52	4
5	Compact/ harden soil	0.36	7	0.57	6	0.37	5	0.42	5
6	Increase insect/ pest attack	0.43	5	0.58	5	0.12	9	0.37	6
7	Increase soil erosion	0.39	6	0.49	7	0.11	10	0.33	7
8	Increase soil salinity	0.28	8	0.43	8	0.24	6	0.30	8
9	Contaminate water source	0.26	9	0.24	9	0.08	11	0.20	9
10	Increase toxicity in soil	0.14	11	0.16	11	0.13	7	0.15	10
11	Creates water logging	0.14	10	0.18	10	0.05	12	0.13	11
12	Increase toxicity in water	0.12	12	0.07	12	0.13	8	0.11	12
	All impacts	0.38[b]	2	0.47[b]	1	0.28[b]	3	0.37	

Note: The higher the index the stronger the perception.
[a] Ranking done by weighting individual responses by their ranks.
Index = $\{R_{VH}(1.0) + R_H(0.8) + R_M(0.6) + R_L(0.4) + R_{VL}(0.2) + R_0(0.0)\} / N$
where R_{VH} = very high rank, R_H = high rank, R_M = medium rank, R_L = low rank, R_{VL} = very low rank, and R_0 = farmers responding in the negative, respectively. N = sample size.
[b] = Ranking done across 3 regions.
Source: Field Survey, 1997.

'Decline in soil fertility' features top of the list of adverse environmental impacts of technological change followed by 'health effects', 'decline in fish catch', 'increase in crop disease', 'soil compaction', 'increase in insect/pest attack' and 'soil erosion and soil salinity'. It is interesting to note that the perception on adverse impact of modern technology on water resources is very weak as evident from sharp decline in index values. This leads to the conclusion that, though farmers' are aware of the adverse environmental impacts of modern agricultural technology, their awareness level remains confined to the visible impacts most closely related to their farm field and sources of livelihood (crops and fish). The awareness on indirect and wider impacts such as 'contamination of water bodies' is not very strong. The consistency of these response patterns across region is evidenced from the analyses of rank correlation. All relative rankings of impacts are significantly ($p<0.01$) positively related across regions thereby providing confidence in the results (Table 9.4).

Table 9.4 Rank correlation of environmental impact ranking among regions, 1996.

	Jamalpur region	Jessore region	Comilla region	All region
Jamalpur region	1.00			
Jessore region	0.99[a]	1.00		
Comilla region	0.70[a]	0.73[a]	1.00	
All region	0.97[a]	0.98[a]	0.80[a]	1.00

Note: [a] = significant at 1 percent level ($p<0.01$).
Source: Field Survey, 1997.

9.3 Soil Fertility Evaluation of the Study Areas

Land is the single most important natural resource that provides livelihood for the vast majority of rural poor in an agrarian economy like Bangladesh. The productivity of land depends largely on biophysical factors such as soil fertility and water quality. It was largely perceived that soil fertility status of Bangladesh is on the decline resulting in declining productivity, particularly for the modern varieties of rice (BASR, 1989). Evidence from the present study also suggests that the soil fertility status is rather poor and is declining. As evident from the farmers' ranking of major environmental impacts, 'declining soil fertility' was identified as the major adverse environmental impact that the modern agricultural technology exerted in the study areas. To further authenticate this version of farmers, a detailed bio-physico-chemical analysis of soil fertility status of the study area, which was already an integral part of the research design of this study, is provided below. The present section provides a brief on the importance of soil properties that are tested and their comparative fertility status. Later, the general relation between the soil fertility status and crop productivity is analyzed with the application of multivariate analyses.

A total of 10 properties – *soil reaction* (pH)*; available nitrogen* (N)*, phosphorus* (P)*, potassium* (K)*, sulfur* (S)*,* and *zinc* (Zn)*; organic matter content* (OM)*, cation exchange capacity* (CEC)*; electrical conductivity* (EC); and *textural class* were analyzed to evaluate the general fertility levels of the soil in the study areas.

9.3.1 Soil Fertility Parameters and Nutrient Availability

(a) Soil pH: Soil reaction, a measure of the degree of acidity or alkalinity of a soil usually expressed on a pH scale, is one of the most important indicator of crop response to soil nutrients. Generally, the pH range of 6.5 to 7.3 is suitable for most of the nutrient becoming available for plants (Thompson and Troeh, 1973). It is evident from Appendix Table A9.1 that Jamalpur soils are slightly acidic as compared to Jessore which is slightly alkaline, and Comilla soils are neutral in reaction. As a whole, the soil reaction of the study area is in the neutral range (6.6 – 7.3 pH) and are relatively favorable to standard requirements provided that there are sufficient nutrients in the soil to be supplied to plants, which are investigated subsequently.

(b) Organic Matter Content: Though organic matter constitutes only a small fraction (3-5 % in weight) of soils, it has a profound influence in fertility management particularly by influencing the physical, chemical and biological properties of the soil. The organic matter is mainly composed of decomposed plant and animal residues. The average organic matter content of Jamalpur and Comilla region is low while Jessore is very high (Appendix Table A9.2). Low organic matter in general can be attributed to massive removal of crop straws, plant residues, and grasses from the soils, lack of litters from shrubs and bushes and increased use of farmyard manure as fuel instead of applying as source of nutrients and organic matter to the soil.

(c) Nitrogen Levels: Nitrogen is one of the most important nutrient elements required for plant growth. In fact, nitrogen is the dominant external fertilizer applied for cereal production by farmer, as nitrogen deficiency in soils is a common phenomenon in Bangladesh. Since most nitrogen is associated with organic matter, the rate at which this element is liberated from the soil organic matter varies with temperature, moisture, and microbial decomposition. Nitrogen serves as the regulator that governs to a considerable degree the utilization of potassium, phosphorus, and other nutrients. With cereals, nitrogen increases the plumpness of the grain and their protein percentage. Plants with deficient nitrogen are stunted in growth and possess limited root system. On the other hand, oversupply may delay crop maturation by encouraging excessive vegetative growth as well as reduce resistance to certain crop diseases (Brady, 1974). Appendix Table A9.3 clearly establishes the fact that there is widespread deficiency in available nitrogen in the soils in the study regions. The reason for low levels of available nitrogen in soils is obvious. As all these areas grow at least two rice crops a year and burning of organic matter as fuel is widespread in these regions, the nutrient uptake is greater than the intake and the consequence is nitrogen deficient soils. This interpretation is further authenticated by nutrient (N, P) pathway analysis conducted later in this chapter.

(d) Phosphorus Levels: The second major nutrient element critical for plant growth is the quantity of phosphorous. The major source of phosphorus is mineral appetite, which is also a principle source of non-cereal fertilizers. Native phosphorus is usually fixed in highly acidic soils and in soils rich in oxides of iron and aluminum. Though organic matter contains phosphorus but the amount is very low. Lack of phosphorus prevents acquiring of other nutrients by the plants. Adequate phosphorus levels promote seed formation, crop maturation, root development, and resistance to certain diseases (Brady, 1974). Appendix Table A9.4 reveals that the available phosphorus is not as deficient as the case of available nitrogen. Jamalpur soils have high levels of available phosphorus and Comilla and Jessore have medium levels of available phosphorus. The reason for high phosphorus content may be due to external application of phosphate fertilizers rather than the native fertility of the soils.

(e) Potassium Levels: The third most important nutrient element in soil is the potassium content. Under natural condition, it is the most abundant of all soil nutrients. However, since minerals such as feldspars or mica are very resistant to weathering, about 90 percent of the potassium are termed as unavailable potassium. In fact readily available potassium which is only 1-2 percent of all potassium element is the major available source for plant growth (Dahal, 1996). Potassium is essential for photosynthesis and for starch formation (Brady, 1974). It is clear from Appendix Table A9.5 that, as with the case of available nitrogen, the available potassium content is low in all study areas. The availability is far from the upper bound of the 'low' range in all the regions. However, in relative terms, Jessore is in a better position. In general, potassium deficiency occurs in heavily leached soils, particularly on the light and sandy soils, and leaching loss may be intensified if the soils become acidic. Moreover, potassium is a mobile element and its losses are common under poor farm management practices. As such, frequent low doses of potassium fertilizers is preferable than occasional heavy dose which are consequently absorbed by the plants but not transferred into increased yield (Dahal, 1996).

(f) Sulfur Levels: Sulfur is another important nutrient required for plant growth. Sulfur deficiency in soil retards plant growth as well as yield. Plants that are sulfur deficient are characteristically small and spindly. The maturity of seeds and fruits is delayed in the absence of adequate sulfur (Brady, 1974). Appendix Table A9.6 reveals that, as with case of nitrogen and potassium, sulfur availability is also low. Only in relative terms, Jessore seems to be in better position. Major reason for sulfur deficiency in soils is due to greater removal of this element in harvested crops through increased yields (Brady, 1974).

(g) Zinc Levels: A total of 17 nutrient elements are essential for plant growth. Of these, eight are required in such small quantities that they are termed as micronutrients or trace elements. Zinc is one such important micronutrient. Zinc is essential for formulation of growth hormones, promotion of protein synthesis, seed and grain maturation and production (Brady, 1974). In recent times, zinc deficiency became a major concern in some regions of Bangladesh. Appendix Table A9.7 reveals that available zinc in soil is high in Jamalpur and Jessore region and medium in Comilla region. It should be noted that, since the early 1990s, widespread publicity of zinc deficiency in many areas aroused interest in the farmers to add gypsum fertilizers in their farming lands. This might have been one reason for higher availability of zinc in the study areas. However, it should be noted that excess availability of this micronutrient element is also harmful (Brady, 1974).

(h) Cation Exchange Capacity: Cation exchange capacity (CEC) is an important soil property. It affects the capacity of soil to hold nutrients such as ions of calcium (Ca), magnesium (Mg), potassium (K) and ammonium (NH_4). It also affects the quantity of nutrient required to change its relative level in soils. For example, high CEC soils require more potassium ions to raise soil potassium from a low to high level than do low CEC soils (Jones, 1982). The amount of CEC of soils is determined by the amount of clay, the kind of clay, and the amount of humified organic matter. The amount of CEC possessed by a soil is partly pH dependent. The CEC is lower under acid conditions and rises as the pH rises (Thompson and Troeh, 1973). In fact, CEC is a very important indicator of soil fertility, or at least of potential soil fertility. Appendix Table A9.8 reveals that the CEC levels are low in Jamalpur and Comilla regions where soils are relatively acidic, as compared to Jessore region which is relatively alkaline. This indicates that the soil fertility status in the study region is poor.

(i) Electrical Conductivity: Electrical conductivity (EC) or the specific conductance is defined as the inverse of resistivity and is often used for comparing resistance of any materials. The reciprocal of resistance is known as the mho or Siemen (S) (Gupta, 1992). The conductivity of any matter is a measure of its ability to convey an electrical current. Different ions vary in their ability to conduct electricity, but in general, the greater the concentration of ions in soil, the larger the conductivity (Boyd, 1990). The optimal conductivity for agricultural soils is 200 μS/cm (CCME, 1991). Appendix Table A9.9 reveals that EC is highly variable across regions. Jessore soils have relatively high EC compared to other areas. However, as a whole the EC of soils in the study regions are below the optimal conductivity.

(j) Soil Texture: Soil fertility management is not only dependent on bio-chemical properties of soil, but also on physical properties of the soil. Each type of particle present in the soil makes its contribution to the nature of the soil as a whole. Physical properties determine nutrient, water holding and supplying capacity of soils, drainage, extent of water run-off and erosion, soil aeration, temperature and other processes of the soil ecosystem vital for plant growth. Loamy soils are highly desirable for most uses. A loamy soil is formed with a combination of 10-25 percent clay, approximately equal amount of silt and sand combined with several percentage of organic matter (Thompson and Troeh, 1973). The textural analysis results reveal that most of the soils are silt loam and some are silty clay (Appendix Table A9.10). This implies that soil texture is fine and the soil in the study regions is moderate with respect to physical characteristics.

9.3.2 Overall Soil Fertility Evaluation

The previous sections evaluated each of the soil fertility parameters individually. This section provides an estimate of the overall soil fertility status of the study areas by comparing all indices together as one. In deriving the mean index, eight soil test variables are considered for which same procedure for index construction were applied. It is obvious from the Table 9.5 that the overall soil fertility status of Jamalpur and Comilla is 'low' and Jessore is 'medium'. As a whole, all three regions combined, the overall soil fertility status is in the 'low' range.

Table 9.5 Overall soil fertility evaluation of the study regions, 1997.

Region	**Soil fertility index interpretation**								Mean index	Soil *pH*	Tex-ture
	OM	N	P	K	S	Zn	CEC	EC			
Jamalpur region	1.55	1.00	2.60	1.00	1.00	2.40	1.00	1.00	1.44 (low)	6.0	*Silt loam*
Jessore region	2.60	1.00	2.20	1.00	1.40	2.80	1.80	1.2	1.75 (med)	7.9	*Silty clay*
Comilla region	1.20	1.00	2.00	1.00	1.00	2.20	1.20	1.00	1.33 (low)	7.1	*Silt loam*
All region	1.73	1.00	2.27	1.00	1.13	2.47	1.33	1.07	1.50 (low)	6.7	*Silty clay*

											loam

Note: The index value rated as **< 1.67 = low, 1.67 – 2.33 = medium,** and **> 2.33 = high**.
Source: Field survey, 1997.

9.3.3 Relationship between Soil Fertility and Crop Productivity: A Regression Analysis

Broadly speaking, biological production is the product of crop genotype and physical environment. In this study, an attempt has been made to examine the relationship among soil parameters and crop productivity with mean farm-level yield[34] of various crop groups[35] as the dependent variable and the soil variables as the explanatory variables. Stepwise forward regression procedure, which selects the significant explanatory variables from among the given set of independent variables, is employed. The full model is provided below:

Model: $lnY_i = \beta_0 + \beta_1 \, ln\,K + \beta_2 \, ln\,N + \beta_3 \, ln\,P + \beta_4 \, ln\,S + \beta_5 \, ln\,Zn + \beta_6 \, ln\,CEC + \beta_7 \, OM + \beta_8 \, EC + \beta_9 \, pH$ .....(6.1)

where: ln Y_i = natural log of crop output i measured in kg/ha.
ln K, ln N, ln P, ln S, ln Zn, and ln CEC = are natural log of *available potassium*, *nitrogen*, *phosphorus*, *sulfur*, *zinc*, and *cation exchange capacity* measured in kg/ha.
OM = *organic matter* content measured as % of total.
EC = *electrical conductivity* measured in μS/cm.
pH = soil reaction which is measured in log scale
β_0 ... β_9 = are parameters to be estimated.

Table 9.6 presents the results of the selected regression estimates (for details, also see Appendix Table A9.10). A total of 17 regressions representing each of the 14 crop types and 3 for all local rice varieties, all modern rice varieties, and foodgrain (all varieties of rice and wheat), were tried. However, results of the 8 regressions, namely, local Aman rice, modern Aman rice, modern wheat, all foodgrain, jute, pulses, spices, and vegetables, were reported as the remaining regressions provided weak results. As the variables are measured in natural logarithms the coefficients can be interpreted as the output elasticities with respect to relevant soil variables except OM (*organic matter*) and EC (*electrical conductivity*). The order in which coefficients are written (except constant) corresponds to the order in which the relevant variables

[34] The yield levels are the averages for observations on crop production in each of the 21 villages. The soil variables are collected from 15 locations (i.e., 15 villages). Therefore, for the remaining 6 villages the soil variables are replicated by careful judgement. In fact, adjacent villages having the same soil series is replicated.

[35] A total of six crop groups are formed. These are: (a) Foodgrain = includes local and HYV rice of three seasons (Aus, Aman, and Boro), and local and HYV wheat (n = 1,049); (b) Oilseeds = include rapeseed, mustard and groundnut (n = 71); (c) Pulses = include lentil, chola, and kalai (n = 70); (d) Spices = include onion, garlic, turmeric, and chilly (n = 47); (e) Vegetables = include potato, sweet potato, brinjal, cauliflower, seem, radish, yam, and leafy vegetables (n = 103).

enter in subsequent iterations in the stepwise forward regression procedure (Appendix Table A9.10).

As a whole, all the regression results have consistent signs. The explanatory power, reflected by the adjusted R^2 is highly satisfactory for vegetables, spices, pulses, and jute crops, moderately satisfactory for local Aman rice and all foodgrain crops, and comparatively weaker for modern Aman rice and modern wheat crops. It should be noted that the dependent variable used in this regression is the weighted averages of all individual sample observations from each of the 21 villages under study. Therefore, the relationship can be interpreted with confidence on its representativeness though the overall degree of freedom of the regression is rather small.

Table 9.6 Soil fertility and crop productivity relations in the study regions, 1996.

Soil variable	Stepwise forward regression of soil fertility and crop production relations							
	Local Aman rice	Modern Aman rice	Modern wheat	All foodgrain	Jute	Pulses	Spices	Vege-tables
Intercept	5.968^a	7.523^a	7.154^a	7.749^a	16.716^a	22.517^a	9.380^a	5.754^a
ln K	0.323	-	-	0.144^a	0.349^a	0.457^a	1.200^a	-1.246^a
ln N	-	0.169^b	-	-	-	-	-	-0.547^a
ln S	-	-	-	-	-	-	-	1.829^a
ln Zn	-	-	0.217^b	-	-	-	-	-
ln CEC	0.557^c	-	-	-	-	-	-	-
pH	-0.401^a	-	-	-0.048^c	-	-2.352^a	-0.935^a	1.004^a
EC	-	-	-	-	-	-	-	-0.011^a
Adj. R^2	0.42	0.20	0.24	0.31	0.56	0.79	0.78	0.95
F-ratio	5.52^a	5.36^b	4.78^b	5.57^b	17.25^a	13.88^a	20.59^a	51.58^a
Df	3, 16	1, 17	1, 11	2, 18	1, 12	2, 5	2, 9	5, 8

Note: [a] = significant at 0.01 level ($p<0.01$); [b] = significant at 0.05 level ($p<0.05$).
[c] = significant at 0.10 level ($p<0.10$).
Source: Field survey, 1997.

From Table 9.6, one can readily observe the significance ($p<0.01$) of *available potassium* in the soil for increased crop production, except vegetables. This is consistent with observed very low levels of *available potassium* in all regions (Table A9.5 in the appendix). *Available nitrogen* in the soil is significant ($p<0.05$ and $p<0.10$) for modern Aman rice. This is consistent with the observation of very low levels of *available nitrogen* in all the study areas (Appendix Table A9.2). For MV wheat yield, *available zinc* in the soil is the significant ($p<0.05$) one. Another general observation is the significant ($p<0.01$ and 0.10) negative influence of soil pH to crop production, except vegetables, which is also consistent.

9.4 Analysis of Decline in Soil Fertility

Analysis of soil fertility status revealed that soil in the study regions is of poor quality (Table 9.5). A number of factors may be responsible for soil fertility decline. In general, lack of knowledge on appropriate dosage of fertilizers to supplement the nutrient uptake by the crop may be one of the crucial factors in soil fertility decline. Farmers using high doses of fertilizers tend to avoid application of organic manure. Deficiency of organic matter content in soil cannot be supplemented by application of chemical fertilizers.

Analysis of nutrient uptake revealed that modern varieties of rice alone contributes to 71 percent (highest is Jamalpur 84 percent) of total nutrient (N, P) uptake. The contribution is lower in areas with diversified cropping system, i.e., Jessore (60 percent of total uptake). Baanante *et al.* (1993) noted that the current production of food crops take up an estimated 0.92 million tons of nutrients (NPK and S) from the soil.

In order to validate the claim of 'declining soil fertility' and to check whether the farmers' perception is reflected in their practice of fertilizer application, the village level data were analyzed. The a priori expectation is that there will be a negative association between soil nutrient availability and fertilizer application rate. Also, a negative association between fertilizer use and organic manure application is expected. The result of the exercise is presented in Tables 9.7 and 9.8, respectively.

Table 9.7 Average levels of available soil nutrients, fertilizer and pesticide use levels in the study regions, 1996.

Adopter catogory/region	Available NPK in soil (kg/ha)	Fertilizer use (kg/ha)	Manure use (ton/ha)	Pesticide use (Tk/ha)
Villages classified by adopter categories				
High adopter	168.5^{A}	223.6^{A}	1.13^{A}	399.2^{A}
Medium adopter	212.3^{B}	206.4^{AB}	1.47^{A}	476.3^{A}
Low Adopter	137.5^{A}	164.0^{B}	0.18^{B}	341.8^{A}
F-ratio for adopter difference	3.23^{c}	3.24^{c}	1.13	2.00
Villages classified by regions				
Comilla region	146.0^{A}	227.3^{A}	0.13^{A}	663.8^{B}
Jamalpur region	169.3^{A}	213.4^{A}	1.71^{B}	214.2^{A}
Jessore region	205.4^{B}	204.5^{A}	1.46^{B}	356.6^{A}
F-ratio for regional difference	6.21^{a}	0.68	49.7^{a}	7.36^{a}
All category/region	171.8	215.5	1.09	404.7

Note: Same block letters in superscript represent similarity in yield levels across regions for individual crop based on LSD at 5 percent level of significance ($p<0.05$).
[a] = significant at 1 percent level ($p<0.01$); [c] = significant at 10 percent level ($p<0.10$)
Source: Field Survey, 1997.

Table 9.8 Correlation between available soil nutrients and levels of fertilizer and pesticide use in the study regions, 1996.

	Available NPK in soil (kg/ha)	Fertilizer use (kg/ha)	Manure use (ton/ha)	Pesticide use (Tk/ha)
Available NPK in soil (kg/ha)	1.00			
Fertilizer use (kg/ha)	-0.22	1.00		

Manure use (ton/ha)	0.40[c]	-0.23	1.00	
Pesticide use (Tk/ha)	-0.23	0.52[b]	-0.59[a]	1.00

Note: [a] = significant at 1 percent level ($p<0.01$); [b] = significant at 5 percent level ($p<0.05$); [c] = significant at 10 percent level ($p<0.10$)

Source: Field Survey, 1997.

It is clear from Table 9.7 that available major soil nutrient (NPK) is significantly ($p<0.05$) higher in 'medium adopter' villages and the fertilizer application rate is relatively lower while the manure use rate is highest. There is no significant difference in pesticide use rate across modern technology adopter categories of villages. It is observed that though higher doses of fertilizer is applied in areas with low soil nutrient status, the application rate is not significantly different across villages, while the soil nutrient availability is significantly ($p<0.05$) different (Table 9.7). This implies that, though farmers are aware of declining soil fertility, their knowledge on optimum dose required to make up the deficiency is not clear resulting in depletion of soil fertility over time.

Table 9.8 clearly reveals that negative association ($r = –0.22$) exists between available major soil nutrients and fertilizer application rate per ha of cropped land consistent with the a priori expectation. Negative association ($r = –0.23$) between available major soil nutrients and pesticide use rate per ha of cropped land is also observed. The negative association ($r = –0.23$) between fertilizer application rate and organic manure use rate is observed consistent with the priori expectation. This finding reveals that farmers' knowledge on soil fertility management is limited which may have led to soil mining through intensive cropping without proper replenishment. Also, a contrasting relationship between pesticide use with fertilizer and organic manure use is observed. While significant ($p<0.05$) positive relation ($r = 0.52$) exists between pesticide and fertilizer use, the association is significantly ($p<0.01$) negative between pesticide and organic manure use ($r = –0.59$). This implies that pesticide usage increases with fertilizers while it declines with organic manure.

The phenomenon of 'declining soil fertility' is no doubt a direct threat to sustainability unless it can be restored through proper management. Also, conclusion on declining soil fertility must be made with caution, as it would affect strongly on policy formulation. Therefore, time trend analyses of fertilizer use rates as well as overall fertilizer productivity for the study regions for a period of 29 years is attempted to confirm the notion of 'declining soil fertility'. The result is presented in Table 9.9.

The annual increase in fertilizer use rate per ha of gross cropped area for the period 1961 – 1992 is estimated at above 10 percent for all regions and is highly significant ($p<0.01$). However, it is interesting to note that the fertilizer productivity (output per kg of fertilizer application) is significantly ($p<0.01$) declining at an annual rate of about 10 percent. The rate of decline in fertilizer productivity is almost equivalent to the growth rate of fertilizer use rate per ha of land. This finding clearly demonstrates the decline in soil fertility which is confirmed by soil test results as well as from farmers' perception ranking. It was also shown in Table 4.8 that the productivity of modern varieties of rice per ha of gross cropped area is declining significantly ($p<0.05$) at an annual rate of 1.2 percent over the period 1968 – 1994.

Therefore, considering the various analyses of the issue of soil fertility, it can now be safely concluded that one of the major adverse environmental impacts of modern agricultural technology is the 'declining soil fertility' in the rural regions. It should be noted that the reason for 'soil fertility decline' is not due to fertilizer application, rather it is the lack of proper replenishment of the nutrient uptaken by crops, particularly modern varieties of foodgrain, by soil fertility management practices, such as, application of organic manure.

Table 9.9 Growth trends in fertilizer use and fertilizer productivity in the study regions, 1960/61 – 1991/92.

Region	Growth rate (%)	t – ratio	Adjusted R-squared	F – ratio	Degree of freedom
Fertilizer use per ha					
Comilla region	10.28	12.17[a]	0.84	148.10[a]	1, 27
Jamalpur region[1]	12.48	22.14[a]	0.95	489.99[a]	1, 27
Jessore region	13.07	20.67[a]	0.94	427.23[a]	1, 27
Bangladesh	11.60	22.27[a]	0.95	496.06[a]	1, 27
Output per unit of Fertilizer					
Comilla region	-9.50	-11.73[a]	0.83	137.69[a]	1, 27
Jamalpur region[1]	-11.01	-17.40[a]	0.92	302.88[a]	1, 27
Jessore region	-11.17	-14.30[a]	0.88	204.39[a]	1, 27
Bangladesh	-10.40	-19.23[a]	0.93	369.60[a]	1, 27

Note: Growth rates are estimate using semi-log trend function $\ln Y = \alpha + \beta t$ where t is time.
[a] = significant at 1 percent level ($p<0.01$).
The figures are actually for Mymensingh region as a whole, which includes Jamalpur region.
Source: Computed on data of Deb (1995).

9.5 Analysis of Health Effects

Though 'adverse effect on human health' has been reported as the second most important environmental impact of technological change, the validation of this statement with material support is beyond the scope of this study. However, an inference is attempted by analyzing categories of pesticides used by the farmers of the study regions and their perception on this input. It is needless to mention that health effect of modern agricultural technology directly stems from the use, inhalation, and handling of the hazardous pesticides/insecticides, which became a vital input in crop production in recent times. Pingali (1995) noted that indiscriminate use of pesticide use can result in one or more of the following: (1) health impairment due to exposure to hazardous chemicals; (2) contamination of ground and surface waters through pesticide runoff and seepage; (3) the transmittance of pesticide residues in the food chain ultimately reaching human consumers; (4) an increase in the resistance of pest populations to pesticides thereby causing outbreaks and poor control; (5) the reduction of beneficial insects and predators; and (6) the reduction in the populations of micro-organisms in the soil and water that assists in sustaining soil fertility.

An investigation on pesticide uses in the study area revealed that about 77 percent of farmers (highest 94 percent in Comilla) apply pesticides at least once (Table 9.10). Though about half of the farmers in Jamalpur and Jessore applies pesticides only once in a crop season, 63 percent of Comilla farmers applies twice in a season. Further, 22 percent of farmers in Comilla region applies as much as 3 - 5 times in a crop season indicating relatively higher incidence of pest and insect attack as compared to Jamalpur and Jessore region. About 23 percent of farmers in Jamalpur and Jessore regions are considering to either reduce or stop the use of pesticides while 81 percent of Comilla farmers considers their present use rate as appropriate (Appendix Table A9.11).

Table 9.10 Number of applications of pesticides by study regions, 1996.

Number of applications of pesticides	Number and percent of households (%)			
	Jamalpur region	Jessore region	Comilla region	All region
Farmers applying pesticides	**118 (67.4)**	**77 (73.3)**	**119 (94.4)**	**314 (77.3)**
One time	81 (46.3)	57 (54.3)	13 (10.3)	151 (37.2)
Two times	31 (17.7)	17 (16.2)	79 (62.7)	127 (31.3)
Three times	5 (2.8)	3 (2.8)	18 (14.3)	26 (6.4)
Four times	1 (0.6)	-	5 (4.0)	6 (1.5)
Five times	-	-	4 (3.1)	4 (0.9)
Farmers not applying pesticides	57 (32.6)	28 (26.7)	7 (5.6)	92 (22.7)
Total households	175 (100.0)	105 (100.0)	126 (100.0)	406 (100.0)

Note: Figures in parentheses are percentages of total households.
Source: Field Survey, 1997.

The major beneficial effect of pesticide/insecticide use as perceived by farmers is destruction of insects and consequent increase in production (Table 9.11). Few (4 percent) link it to requiring less fertilizer. A large majority in Jessore (63 percent), who uses less pesticides, considers that harmful effects of pesticides is not critical as compared to only 19 percent of Comilla farmers who uses high levels of pesticides. About 7 percent of farmers in Jamalpur link the use of pesticides to result in bitter test for rice. The awareness on health effect of pesticide use is profound in Comilla (17 percent) while it is negligible and nil in Jamalpur and Jessore, respectively. Similar is the case with awareness on causes of fish death. The awareness on the effect on animal health is evident in Comilla and Jamalpur regions. It is evident from Table 9.11 that the perception on harmful impacts of pesticides use is stronger and widespread in Comilla region who happen to use more of these pesticides.

An analysis of the types of pesticides used by these farmers raise alarming concern. Table 9.12 reveals that a large majority of farmers in Jamalpur (86 percent) and Jessore (77 percent) followed by Comilla (53 percent) use organophosphate pesticides which is rated as extremely to highly hazardous according to World Health Organization (WHO) standard. Few of the selected pesticides in this group is milder, i.e., between moderately and slightly hazardous for human health. It is encouraging to note that the Comilla farmers, whose perception on adverse effects of pesticides is relatively stronger, uses carbamates (37 percent) which is classified between highly to moderately hazardous by WHO. The use of extremely hazardous pesticides, the organochlorine group, is relatively less in all the regions. Nevertheless, the combination remains alarmingly dangerous if proper application and handling regulations (which are largely non-existent) are not maintained. Therefore, considering the combined perception of farmers' responses on harmful effects of pesticides, frequency of use, and types of pesticides used by them, it can be safely inferred that their ranking of 'effect on human health' as the second major environmental impact of technological change remains valid.

Table 9.11 Farmers' perception on beneficial and harmful effects of pesticide use by study regions, 1996.

Farmers' perception on beneficial and harmful effects of pesticides	Number and percent of households (%)			
	Jamalpur region	Jessore region	Comilla region	All region
Farmers' perception on beneficial effects				
Destroy insects	55 (31.4)	38 (36.2)	66 (52.4)	159 (39.2)
Production increase	40 (22.9)	12 (11.4)	47 (37.3)	99 (24.4)
No disease infestation	40 (22.9)	27 (25.7)	1 (0.8)	68 (16.7)
Good plant growth	7 (4.0)	1 (0.9)	8 (6.3)	16 (3.9)
Require less fertilizer	6 (3.4)	7 (6.7)	1 (0.8)	14 (3.4)
Non-responding farmers	27 (15.4)	20 (19.0)	3 (2.4)	50 (12.3)
Farmers' perception on harmful effects				
Do not affect much	82 (46.9)	66 (62.9)	24 (19.0)	172 (42.4)
Plant damage if used in excess	7 (4.0)	6 (5.7)	26 (20.6)	39 (9.6)
Affects human health	4 (2.3)	-	21 (16.7)	25 (6.2)
Cause fish destruction	1 (0.6)	-	21 (16.7)	22 (5.4)
Cause livestock/poultry death	8 (4.6)	1 (0.9)	10 (7.9)	19 (4.7)
Tasteless/bitter test of rice	12 (6.9)	1 (0.9)	-	13 (3.2)
Production reduce if use excess	-	1 (0.9)	11 (8.7)	12 (2.9)
Destroys soil fertility	2 (1.1)	1 (0.9)	2 (1.6)	5 (1.2)
Pollutes water	-	-	3 (2.4)	3 (0.7)
Non-responding farmers	59 (33.7)	29 (27.6)	8 (6.3)	96 (23.6)
Total households	175 (100.0)	105 (100.0)	126 (100.0)	406 (100.0)

Note: Figures in parentheses are percentages of total households.
Source: Field Survey, 1997.

Table 9.12 Type of pesticides used by farmers by study regions, 1996.

Pesticide group	WHO chemical hazard category	Number and percent of households			
		Jamalpur region	Jessore region	Comilla region	All region
Organophosphate	IA, IB, II	142 (86.1)	117 (76.5)	128 (53.3)	387 (69.4)
Carbamate	IA, IB, II, III	3 (1.8)	16 (10.5)	88 (36.7)	107 (19.2)
Organochlorine	IB, II	9 (5.5)	14 (9.1)	15 (6.2)	38 (6.8)

Pyrithroid	II	11 (6.6)	6 (3.9)	9 (3.8)	26 (4.6)
Total households		175 (100.0)	105 (100.0)	126 (100.0)	406 (100.0)

Note: Figures in parentheses are percentage of total households.
IA = extremely hazardous, likelihood to hospitalize or long term illness.
IB = highly hazardous, likelihood to hospitalize or long term illness.
II = moderately hazardous, likelihood for more than two days of sickness, need to see physicians
III = slightly hazardous, likelihood for dizziness or vomiting or blurred vision or skin rash.

Source: Paraquat and Disquat, Environmental Health Criteria 38. Geneva: WHO (1984); Field Survey (1997).

9.6 Analysis of Decline in Fish Catch

'Reduction in fish catch' was ranked as the third major environmental impact of technological change by farmers. Fish serves as a major source of animal protein in Bangladeshi diet. Traditionally, a number of fishes, particularly the miscellaneous wildfish, were available in the rice fields, which served as a major source of protein for the poor people. There has been increasing concern about the contamination of fisheries resources by use of agrochemicals (pesticides) on agricultural lands. Pesticide use became a common feature in modern rice cultivation (Rola and Pingali, 1993). With the introduction of the modern varieties of rice, the stock of such fishes declined sharply and practically became non-existent in recent years. The use of pesticides has been seen as the major cause for decline in fish production (Cagauan, 1995). The seasonally flooded areas in the floodplains in Bangladesh, which are recaptured during the off-flooding season for rice production, are affected by chemical and toxic materials (fertilizers and pesticides), thereby, consequently damaging fish habitat and spawning of freshwater fish in rice fields (Aguero, 1989). For example, increased pesticide use is attributed for 67 percent decline in paddy-fish production in Malaysia (Spiller, 1985). The Focussed Group Discussion (FGD) conducted with the farmers as a part of the survey also confirmed this notion of sharp decline of freshwater fish species from and around the rice fields. Cagauan (1995) claims that '*the impact on fish of pesticides presently recommended for rice is direct toxicity resulting in massive mortality rather than bioaccumulation in the harvestable fish*' (p.240).

It has now been widely accepted that the construction of Flood Control Drainage and Irrigation Project (FCD/I) to support diffusion of modern agricultural technology in crop production also became a major cause of fish habitat destruction in open water bodies (Ali, 1989 and WRI, 1990). Ali (1989) noted that the FCD/I systems by modifying the timing of flooding reduce fish productivity and species diversity. For example, 18 fish species used to be available in the south Dakatia River capture fishery became non-existent due to embankments constructed under Chandpur FCD/I[36] Proejct (MPO, 1987). The overall fish production in this

[36] The Chandpur FCD/I project is located within 20 km of the Meghna-Dhonagoda FCD/I Project area, one of the sample region of this study. Both these projects fall within Chandpur district of the Comilla region.

project area declined by 35 percent over the first two years of implementation and the major Indian carp fishery (*Labeo ruhita*, *Catla catla*, *Cirrhina mrigala*, and *Labeo Calbasu*) disappeared in open waters inside the embankment (Ali, 1990). Vaughan (1996), in his study located within the Meghna-Dhonagoda FCD/I Project area (one of the sample region of this study), noted that there had been a major change in the fisheries as a result of the embankment and this had affected profoundly on the livelihood of the rural households. '*Poor people had been particularly adversely affected as they now had little opportunity of catching or cultivating fish. The respondents attributed this directly to the reduction of wild fish stocks due to the lack of annual flooding*' (Vaughan, 1996:p.39) due to the construction of the embankment.

Trend analyses of fish catch in rivers and open water bodies (beels) in regions encompassing the study areas for the period 1984 – 1994 confirmed the widespread claim of fish reduction in open water bodies (Table 9.13). The average annual compound rate of decline is about 6 percent for Bangladesh and as high as 14 percent for Jamalpur region which is very alarming. The catch rate is also negative for the beels (all weather depressed water bodies) of Jessore region (4 percent). It should be noted that, since the early 1990s, a program of fish-stocking in floodland was undertaken by the government. This stocking might have reduced the rate of decline in fish catch to some extend. Otherwise, the declining trend would have been observed in the floodlands as well. Therefore, considering all the evidences, it can be concluded that the farmers' claim of 'reduction in fish catch' in open water bodies within the study regions remains valid.

Table 9.13 Average annual compound growth rate of fish-catch in the study regions for the period, 1983/84 - 1993/94.

Source of catch	Annual growth rate (%)	t-ratio	Adjusted R^2
Jamalpur region			
Catch from rivers/estuaries	-14.42	-2.65[b]	0.47
Catch from beels (depressions)	1.80	3.25[b]	0.57
Jessore region			
Catch from rivers/estuaries	-6.71	-6.48[a]	0.09
Catch from beels (depressions)	-4.15	-1.64	0.25
Comilla region			
Catch from rivers/estuaries	-0.24	-0.10	0.01
Catch from beels (depressions)	4.23	1.91[c]	0.31
Bangladesh			
Catch from rivers/estuaries	-5.87	-6.85[a]	0.85
Catch from beels (depressions)	0.84	1.18	0.15

Note: Growth rates are estimate using semi-log trend function $\ln Y = \alpha + \beta t$ where t is time.
[a] = significant at 1 percent level ($p<0.01$); [b] = significant at 5 percent level ($p<0.05$);
[c] = significant at 10 percent level ($p<0.10$).

Source: Computed from Hamid (1993) and DoF (1993, 1992, 1991, 1990, 1989, 1988, and 1986).

9.7 Analysis of Insect, Pest and Disease Infestations in Crop Production

There is widespread acceptance that the modern agricultural technologies are much more prone to insect, pest and disease infestations. Therefore, with the increased diffusion of modern varieties of rice and wheat, pesticides became and will continue to be a major component of modern technology. The 'increase in crop disease' and 'insect and pest attack' has been ranked 4th and 6th by farmers of the study areas. Though direct analysis of increase in insect, pest and disease infestations in crop production requires time-series information and is beyond the scope of the present study, an indirect analysis of these statements is attempted using time-trend analysis[37] of pesticides use in the study regions. Table 9.15 provides the estimated annual compound growth rate of pesticides for the period 1976/77 to 1992/93. Annual growth rate of pesticide use is highest in Jessore (10 percent) closely followed by Jamalpur region (9 percent). The use rate of pesticides in Comilla region is highly fluctuating and therefore recorded very low growth rate. The annual growth rate of pesticide use for the country is also very high (8.6 percent). Therefore, it can be safely stated that the farmers' claim of 'increased infestation of pests, insects and diseases' as a result of the introduction of modern agricultural technology remains valid.

Table 9.14. Average annual compound growth rates of pesticides in the study regions for the period, 1976/77 - 1993/94.

Region	Period	Average annual compound growth rate of pesticides		
		Growth rate (%)	t-ratio	Adjusted R^2
Jamalpur region	1976/77 – 1988/89	9.30	4.01[a]	0.60
Jessore region	1976/77 – 1988/89	10.40	3.88[a]	0.58
Comilla region	1976/77 – 1988/89	4.60	1.51[a]	0.17
Bangladesh	1976/77 – 1992/93	8.60	7.26[a]	0.78

Note: Growth rates are estimate using semi-log trend function $\ln Y = \alpha + \beta t$ where t is time. From crop year 1989/90, pesticide market was liberated and therefore regionwise data became unavailable. Also, pesticide use data for Jamalpur is not available separately. Therefore, pesticide use data of Mymensingh region is computed and presented which includes Jamalpur region.
[a] = significant at 1 percent level ($p<0.01$).
Source: Computed from Hamid (1991) and BBS (various issues).

9.8 Analysis of Water Quality

Water also plays an important role in crop production. The 'Green Revolution' technology popularly known as 'seed-fertilizer-water' technology relies on water control. In Bangladesh, both surface water and ground water are used for irrigation depending on the ease of utilization. Much emphasis is on ground water exploitation for both drinking as well as irrigation. Previously, there was no concern to test ground water quality to judge its suitability

[37] It should be noted that regionwise pesticide use data is not reported systematically. For example, data for 1980/81 and 1981/82 was missing which were interpolated with preceding three-year average use rates. Also, the data for 1985/86 was missing and was interpolated with preceding three-year average use rate.

for drinking as well as for irrigation. Only recently, during the 1990s, when **arsenic** was found in groundwater extracted by Deep Tube Wells (DTWs) that lifts water from a depth of more than 100 meters in many areas, the concern over water quality, particularly for drinking purpose, became a major issue. Further, 'contamination of water source' was ranked 9th by the responding farmers. In this study, 6 surface water samples (2 from each region) and 7 groundwater samples (2-3 from each region) were taken from sources that are used to irrigate the land from where the soil samples were also collected. This was done mainly to check whether the irrigation sources add nutrients to the soil or not. For the surface water sample, mainly the river and beels, water pH, *electrical conductivity*, *available nitrogen* (μl/l), and *available phosphorus* (μl/l) were tested. For the *ground*water samples, water pH, *electrical conductivity* (μS/cm), *available chlorine* (μl/l), and *available iron* (μl/l) were tested.

Table 9.15 presents the summary of water quality test results. Within the region, with respect to *surface* water quality, significant difference exists in water pH and *electrical conductivity* (EC_w) while no significant difference were observed for *available nitrogen* (N_w) and *available phosphorus* (P_w). In case of *ground*water, significant difference exists in water pH only. However, it is worth mentioning that Comilla region do not show traces of iron in the *ground*water samples. A test of differences between the water sources, the groundwater and the surface water, reveals that both water pH and *electrical conductivity* are significantly different (last column of Table 9.15).

Table 9.15 Summary of water quality test results (6 *surface* water and 7 *ground*water samples) by study regions, 1997.

Water variables	Jamalpur region	Jessore region	Comilla region	All region	F – ratio for regional difference	F- ratio for water source difference
<u>**Surface water**</u>						
pH	6.8	7.8	7.3	7.3	54.20^a	47.77^a
EC_w (μS/cm)	96	342	229	222	19.88^a	3.37^c
Available N_w (μg/l)	3.31	2.94	2.02	2.75	1.87	
Available P_w (μg/l)	0.13	0.14	0.15	0.14	0.06	
<u>Groundwater</u>						
pH	7.0	7.6	7.4	7.4	55.31^a	
EC_w (μS/cm)	188	472	471	390	2.16	
Available Cl (μg/l)	3.90	19.50	22.20	15.80	0.41	
Available Fe (μg/l)	Trace	Trace	nil	Trace		

Note: a = significant at 0.01 level (p<0.01); b = significant at 0.05 level (p<0.05).
c = significant at 0.10 level (p<0.10).
Source: Field survey, 1997.

As a whole, it seems that water quality parameters are somewhat insignificant in their role in adding nutrients to the soil. The conductivity of surface water is much lower than the conductivity of groundwater. Water pH is around *neutral* levels and very little *nitrogen*, *phosphorus* and *chlorine* is *available* for supporting the nutrient deficiency in the soils.

However, it should be noted that, the number of samples drawn were rather small and few parameters (though important) were tested to derive any rigorous conclusion with regard to water quality status of the study areas.

9.9 Arsenic Pollution in Water and Soil

Presence of arsenic in groundwater in most part of the Bangladesh is believed to be due to geological reason, particularly, in the region of alluvial land (Siddique *et al.*, 1998). These alluvial lands contain high amount of pyrites rich in arsenic. Sample drilling showed that arsenic rich layers are in the strata closer to the surface down to about 40 m (Siddique *et al.*, 1998). An estimated 40 million people are believed to be affected by arsenic contamination in groundwater in all over Bangladesh (Bhattacharya, *et al.*, 1998). The problem is more acute in the rural areas where groundwater is used for drinking as well as irrigation purposes.

BRAC, one of the largest non-governmental organizations (NGOs) in the Asia-Pacific region, carried out a program of testing arsenic contamination in groundwater at its 802 field offices spread in 61 districts out of a total of 64 districts of Bangladesh during November, 1997. The program also undertook a complete coverage of all 11,954 tubewells of Hajiganj Thana, situated within 30 km of the study area of Comilla region of this study. Test result shows that, out of 802 tubewells of field offices, 94 (12 percent) are contaminated with arsenic. For the Hajiganj area, only 859 tubewells out of 11,954 tubewells were found to be within the limit set by World Health Organization (WHO) while 11,093 (93 percent of the total) is contaminated with arsenic concentration greater than the acceptable limit (Chowdhury, *et al.*, 1998).

Test result of arsenic pollution in groundwater falling within the study regions conducted by BRAC is provided in Table 9.16. It is evident from Table 9.16 that level of arsenic concentration in water is very high in study villages of Comilla and Jessore region. It is also evident that arsenic concentration tends to be high in tubewells that are recently installed, during the 1990s. Chowdhury *et al.* (1998) noted that there is strong relationship between the depth of the tubewell and the arsenic contamination. Very deep tubewells (> 40 m) and shallow tubewells (< 25 m) are less likely to be contaminated. This finding matches with the claim of Siddique *et al.*, (1998) that arsenic rich layers are closer at a level of 40 m depth.

Table 9.16 Arsenic pollution in groundwater in study regions, 1997.

Test locations	Depth of Tube Well	Date of installation	Level of arsenic concentration in water (mg/litre)			
			Nil	0.01 – 0.05	0.06 – 0.10	0.11 +
Jamalpur region						
Rupshi	80 – 85 ft.	1986 – 1990	2	-	-	-
Other areas	50 – 85 ft.	1986 – 1996	19	3	2	-
Jessore region						
Chandipur	90 ft.	1990	1	1	-	-
Taherpur	90 – 110 ft.	1988	-	1	-	1
Other areas	105 – 150 ft.	1988 – 1995	6	-	-	4
Comilla region						
Dhakirgaon	90 – 100 ft.	1990 – 1994	-	-	-	3

Uddamdi	80 ft.	1974	-	-	-	1
Other areas	75 – 200 ft.	1990 – 1997	2	-	-	4
<u>All region</u>						
Study villages	80 – 100 ft.	1974 – 1994	3	2	-	5
Other areas	50 – 200 ft.	1986 – 1997	27	3	2	8
			Arsenic level < 0.05		Arsenic level > 0.05	
All Bangladesh (748 locations in 24 districts)			657		91	

Note: Test date is November, 1997.
Named villages are the study villages. Other areas refer to villages within the study regions but not the study villages.

Source: Adapted from BRAC-RED/HPP/RDP Joint Study Project, 1997 (unpublished).

According to Comittee of CCME (Canadian Council of Ministers of the Environment) on Environmental Quality Criteria for Contaminated Sites (1991), the safe level of arsenic concentration is 25 μg/litre (0.025 mg/litre) for drinking purpose and 100 μg/litre (0.100 mg/litre) for irrigation purpose. Taking safe level set by CCME (1991), it is clear that rural Bangladeshis are at high risk of arsenic pollution, particularly, in the southwest region, such as, Jessore.

In addition to the widespread contamination of arsenic in groundwater, surface soil irrigated with these waters is also found contaminated. An estimated 42 districts covering an area of 87,400 sq km contains arsenic in toxic levels (Ullah, 1998). Irrigation with groundwater contaminated with arsenic levels above 10 mg As/litre resulted in increasing the levels of arsenic concentration in soils upto 83 mg As/kg soil in Comilla while the allowable limit is 20 mg As/kg soil (Ullah, 1998). Though arsenic contamination in groundwater is geogenic, the agricultural soil contamination is anthropogenic. The diffusion of modern varieties of rice increased the demand for irrigation (as shown explicitly in Chapters VI and VII). The major source of irrigation water in Bangladesh is groundwater lifted through either Shallow Tubewell (for lifting water from a depth of < 40 m) or the Deep Tubewell (for lifting water from a depth of > 40 m). As a result, excessive groundwater is used, with millions of tubewells installed for both agricultural as well as safe (?) drinking water purposes leading to fluctuation of water table from pre-monsoon to post-monsoon season and aeration of groundwater aquifers. The result is the decomposition of pyrites and acids containing arsenic from the sediments, which is later uptaken through lifting groundwater (Siddique *et al.*, 1998). The concentration of arsenic in soil is high at the surface level (0 – 15 cm) and decreases with depth (Ullah, 1998). Another, anthropogenic source of arsenic in surface soils is the chemical quoted wooden electric poles installed nationwide under the rural electrification program. It was found that normal irrigated soils of Bangladesh contain 4 – 8 mg As/kg soil, while areas with installed wooden electric poles contained upto 87 mg As/kg soil (Ullah, 1998).

Arsenic from these contaminated soils enters the foodchain through crop uptake. Analyses on the effect of arsenic in plant growth revealed that arsenic antagonized the uptake of most of the plant nutrients. The antagonization is strongest in uptake of micronutrients (Ullah, 1998).

It should be noted that role of technological change in arsenic pollution is indirect. The widespread diffusion of modern varieties of rice resulted in an increased demand for irrigation. This caused the excessive withdrawal of groundwater for irrigation, thereby, bringing the arsenic from minerals to surface. However, the excessive use of pesticides in causing arsenic pollution is not tested and established for Bangladesh case, though pesticide is generally cited as a potential source of arsenic contamination.

9.9.1 Water Use Pattern in the Study Areas

Since high level of arsenic is detected in the groundwater in the study regions as well as nationwide, an attempt is made to provide some detail on the pattern of water use in the study regions that will be indicative of the degree of risk for human health hazard. It was already established that though arsenic contamination in groundwater is geogenic, the contamination in surface soil is anthropogenic spurred by excessive withdrawals for irrigation and drinking purposes as well as expansion of rural electrification with wooden electric poles.

All of the sample households reported tubewell as their main source of drinking water while for washing and cleaning purposes pond and tubewells are equally important (Appendix Table A9.12). Therefore, presence of arsenic in ground water and the exclusive use of this source for drinking purpose indicate the magnitude of the potential human health hazard. Chowdhury *et al.*, (1998) noted that 53 percent of villages of Hajiganj Thana have all their tubewells contaminated with arsenic. About 40 percent of all households consider water from hand-pumps is of poor quality while 98 percent perceives that rain water is good (Appendix Table A9.13). However, about 38 percent of households believe that the ground water drawn through shallow and/or deep tube well is clean and contains less iron (Appendix Table A9.14). Also, 15 percent of the households consider pond water clean and good for cooking and bathing purposes while 7 percent linked it to the cause of diarrhea and rheumatic pain (Appendix Table A9.14).

About 14 percent of the farmers, who reported insufficiency of water supply for irrigation, cited lack of electricity supply and coverage of irrigation scheme as the major reasons (Table A9.15). Finally on the question of water logging, drainage and flooding problem, about 48 percent of farmers reported to have drainage and flooding problems sometimes and 20 percent reported that these problems occur every season (Table 9.17). 'Water logging' and 'increased toxicity' in water has been ranked 11th and 12th, respectively by the farmers in their response of environmental impacts of modern agricultural technology which seems to be consistent.

Table 9.17 Drainage and flooding problem by study regions, 1996.

Drainage or flooding problem	Number and percent of households (%)			
	Jamalpur region	Jessore region	Comilla region	All region
No drainage or flooding problem	**68 (38.9)**	**82 (78.1)**	**63 (50.0)**	**213 (52.5)**
Have drainage and flooding problem				
Sometimes	107 (61.1)	23 (21.9)	63 (50.0)	193 (47.5)
Every season	53 (30.3)	19 (18.1)	9 (7.1)	81 (20.0)

Total households	175 (100.0)	105 (100.0)	126 (100.0)	406 (100.0)

Note: Figures in parentheses are percentages of total households.
Multiple responses.
Source: Field Survey, 1997.

9.10 Inferences

'Decline in soil fertility' is identified as the top major adverse environmental impacts of modern agricultural technology according to farmers' perception rankings. Results on the soil fertility analyses and time trend analyses of fertilizer use rate and fertilizer productivity validated the claim of 'declining soil fertility'. The second most important impact is the 'effect on human health' which was inferred through the analyses of types of pesticides used, frequency of use as well as farmers' perception on the harmful impacts of pesticide use. The third major impact is the 'reduction in fish catch in open water bodies'. Results from Focussed Group Discussion, other sources as well as time trend analyses of fish catch in open water bodies revealed declining trend in fish catch, thereby, validating the claim.

Apart from these three major impacts, 'increase disease in crops', 'compaction of soil', 'increased insect/pest attack', 'contamination of water bodies', etc. are also reported by the farmers with subsequently lower ranks. The strength of ranking sharply declines as one moves from visible and direct impacts to intangible and indirect impacts of technological change in agriculture implying that farmers' perception is stronger only in case of visible impacts and that directly effects their livelihood (soil fertility and fish catch).

Widespread arsenic contamination in groundwater and surface soil was found including groundwater samples of the study villages. Though arsenic contamination in groundwater is geogenic, the contamination of arsenic in surface soil is largely anthropogenic. The role of technological change in arsenic contamination is indirect. It is the increased demand for irrigation resulting in bringing the arsenic from minerals to surface through lifting groundwater. However, the excessive use of pesticides in causing arsenic pollution is not tested and established for Bangladesh case, though pesticide is also cited as a potential source of pollution.

CHAPTER X

SUMMARY OF FINDINGS, SYNTHESIS OF IMPACTS OF TECHNOLOGICAL CHANGE AND POLICY OPTIONS

Technological change is an important factor in economic growth and development. Technology, by raising productivity of factors, plays an important role in development. Though the developed countries benefited most from technological progress, particularly in the industrial sector, the developing countries also benefited from technological innovations in the agricultural sector.

Agriculture constitutes the major source of livelihood in Bangladesh accounting for more than 50 percent of national income and employs two-third of the labor force. 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 percent of total. Being one of the most densely populated nations of the world, the land-man ratio is highly unfavorable resulting in lack of food security and widespread hunger. As such, continued agricultural growth is deemed pivotal in alleviating poverty and raising standard of living of the population. Consequently, over the past four decades, the major thrust of national policies were directed towards transforming agriculture through rapid technological progress to keep up with the increasing population. Accordingly, development programs were undertaken to diffuse modern varieties of rice and wheat with corresponding support in the provision of modern inputs, e.g., chemical fertilizers, pesticides, irrigation equipments, institutional credit, product procurement, storage and marketing facilities.

The overwhelming belief in the pursuit of this 'high-input payoff' model of agricultural development is due to its potential in increasing foodgrain productivity, employment as well as income (seen in many countries during 1960 – 1970s), thereby, alleviating poverty and hunger. However, impacts of this 'Green Revolution' technology among the adopting nations have been mixed and are filled with controversies largely due to the approach utilized in the evaluation process and the extent of issues covered in the analyses. Particularly, knowledge on the delayed consequences of this technological change on other spheres of the economy is nascent and has not been felt until recently. Given this backdrop, the present study employed a holistic approach to evaluate the impacts of technological change in agriculture in Bangladesh. Specifically, the study is set to evaluate the impacts of technological change on productivity, employment, gender equity, income distribution, poverty and the environment at the local level and on regional development, aggregate crop production and foodgrain sustainability at the national level. The study is accomplished by specifying eleven objectives: four at the national level and seven at the local level, respectively.

The overall hypothesis of the study is that though the diffusion of modern agricultural technology has contributed to increased production, employment and income, its distributional consequences have been mixed. Also, this technological change in agriculture has exerted adverse impacts on the environment and its diffusion has not been uniform across regions resulting in regional disparities. Moreover, the long run crop production scenario is believed to reach a saturation level thereby posing threat to sustainability of food production vis-a-vis agricultural and economic development. As such, the research is designed with a blend of economic (crop input-output), biophysical (soil fertility) and behavioral (farmers' perception) analyses to capture the diverse issues. The study is based on time-series data for 47 years (1948 – 1994) and farm-level cross-section data of cropyear 1996 collected from three agro-ecological regions including soil samples from representative locations and information on infrastructural facilities. Economic principles and concepts are used as the basic tools of analysis. A total of eleven composite hypotheses were postulated to fulfill the eleven objectives and are tested using a combination of quantitative and qualitative techniques.

The present chapter provides the major findings of the study drawn from Chapters IV – IX blended with results of hypothesis tests. Also, a synthesis of the multifaceted impacts of technological change in agriculture is presented. Finally, an integrated agricultural development model is proposed that will complement towards achieving sustainable agricultural vis-a-vis economic development.

10.1 Summary of Findings and Results of the Hypothesis Tests

The major findings together with results of the hypothesis tests are presented under four broad categories: (a) impacts of technological change at the national level; (b) farmers' decision making process under changing production environment; (c) factors influencing adoption of modern agricultural technology; and (d) impacts of technological change at the local level.

10.1.1 Impacts of Technological Change at the National Level on Regional Variation, Aggregate Crop Production and Foodgrain Sustainability

Analysis of regional variation in agricultural development process is important for spatial as well as development policy perspectives. Regional variations arise largely due to diverse agro-ecological factors as well as disparate access to technological and infrastructural facilities among various regions. As a result, the capacity for utilization of these factors varies across regions. The present study attempted to analyze the impact of technological change on regional agricultural development as well as regional equity in Bangladesh for the 1972 – 1993 period that covers the take-off stage of modern agricultural technology diffusion in the country.

Results revealed the *significant role of technological factors in explaining regional variations in agricultural development levels*. Also, *foodgrain productivity, infrastructural and population factors play important role in explaining inter-regional variations as well as in bridging the gap among regions over time*. From a total of 20 regions, Chittagong region was ranked top followed by Comilla. Indicators such as the gross output value, local rice variety yield, area under modern varieties of rice and wheat, fertilizer use and area under irrigation of Chittagong region was highest in these three periods which altogether placed Chittagong at the 'very high' level of agricultural development. The reasons for Chittagong to top the list are largely due to low population density, high land fertility, and relatively better socio-economic condition of the rural population. Comilla region consistently held the second rank in all the three periods and was placed in 'high' level. Comilla also possesses similar characteristics as of Chittagong. It should be mentioned that, though Comilla has high population density, it is considered as the birthplace of all technological innovations in agriculture since the early

1960s. The Comilla model of Integrated Rural Development Program earned widespread recognition during the 1970s and 1980s. Further, the literacy level is relatively high in this region for many years. All these factors contributed this region to hold the 'high' level for the two decades under consideration.

Seven regions, Bogra through Jamalpur with ranks 3 through 9, were categorized into 'medium' level. The inter-period standing of each of these regions has been variable. However, as a whole, these seven regions are grouped in a single category with Bogra reaching the upper limit and Jamalpur the lower limit. Next nine regions, Barisal through Patuakhali with ranks 10 to 18, were grouped into 'low' level of agricultural development. The least developed regions were Khulna and Faridpur. The phenomenon behind the stagnation of regions classified under 'low' or 'very low' levels are due to their agro-ecological and physical constraints. For instance, Rajshahi is the hardest hit region following the drying of main river Padma (Ganges) and onset of the desertification process largely owing to building of Farakka barrage at the upstream of Padma river. Patuakhali is a low-lying riverine region with numerous *char* (delta) lands and produces one rice crop only. Faridpur lies at the confluence of Jamuna and Meghna rivers and often faces severe river erosion and flooding. Khulna is a saline area wherein most of the prime agricultural lands are converted into shrimp culture area thereby destroying the productive capacity of the lands for crops.

The analysis of impact of technological change on regional variation highlighted the significance of non-conventional factors in influencing regional agricultural growth patterns. Results of the Analysis of Variance (ANOVA) confirmed that *significant differences exist among regions grouped into five different levels of development* which therefore nullify the first hypothesis (# H1) that agricultural development levels across regions are uniform in Bangladesh (Table 10.1). Rather, it indicated that *significant differences exist in development levels that are explained to a large extent by the level of technology diffusion, irrigation development, rainfall, local rice variety yield, level of infrastructure and population density*.

The major thrust of the agricultural development policies for the past four decades was in achieving self sufficiency in food production, particularly, foodgrain (rice and wheat) production, which grew at an estimated annual rate of about 3.25 percent during the 47-year period (1947/48 – 1993/94). Further, it is increasingly felt that, in the later years, the productivity from new technology is tapering off towards a saturation value which is a threat to sustainability of economic development in Bangladesh (Alauddin and Tisdell, 1991). The present study attempted to examine the impact of technological change on total crop production by estimating an aggregate production function with regionwise disaggregated data for 29 years (1961/62 – 1991/92). Also, it attempted to provide an indication whether the food production is likely to be sustained by applying logistic function and comparing it with the linear trend function of foodgrain yield per net hectare for 47 years (1947/48 – 1993/94). Also, long term compound annual growth rates of major food crops were estimated for the entire period as well as by breaking the data into two segments, the pre-technological change period (1947/48 – 1967/68) and post-technological change period (1969/70 – 1993/94).

Results from the *aggregate production function estimation revealed that in addition to conventional factor inputs, technological and infrastructural factors significantly influences crop production.* The role of human capital is mixed (significantly positive in only one model). This finding therefore nullifies the second hypothesis (# H2) and establishes the *significant role of technological as well as infrastructural factors in influencing aggregate crop production in addition to the conventional factor inputs* (Table 10.1).

Computation of returns to scale in crop production revealed that *'constant returns to scale (1.08 ≈ 1.00)' prevails in long-run crop production when only conventional inputs are considered. This estimate match with the 'constant returns to scale (1.04 ≈ 1.00)' computed indirectly from the farm-level profit function estimation* (Section 10.1.2). This finding, therefore, maintains the third null hypothesis (# H3) that *crop production in Bangladesh exhibits 'constant returns to scale'. Inclusion of technological, infrastructural and human capital factors in returns to scale computation decisively revealed that 'increasing returns to scale (1.17 > 1.00)' prevails in crop production, thus, reinforcing the notion that crop production can be sustained in the future by manipulating the non-conventional inputs in addition to the conventional inputs.* However, it should be noted that the environmental impact of the modern agricultural technology is not taken into account in this computation.

Results of the sustainability analysis of foodgrain production suggest that, though productivity of food crop is increasing at an annual rate of 2.3 percent, the *productivity of modern rice varieties is declining at the rate of 1.25 percent*, thereby, *casting doubt on sustaining food production through technological change alone*. Moreover, logistic function analysis suggests that the yield level of foodgrain seems to be tapering off towards a saturation value of 2,200 kg/ha. This finding therefore nullifies the fourth hypothesis (# H4) and establishes that, *although crop productivity growth is increasing, but it is likely to reach an upper limit in future* (Table 10.1). The implication is that, once foodgrain productivity reaches the upper limit, capacity of the production level will be unable to support the growing food demand by the increasing population.

10.1.2 Farmers' Decision Making Process under Changing Production Environment

Several studies on farm-level input demand estimations were conducted in the past two decades in Bangladesh. Demand relationships in these studies were typically estimated from a sample of farms in which a common variety of seed was planted. Such studies ignored the possibility that cultivators can *respond to price changes not only by adjusting their use of variable inputs but also by switching to different seed varieties*. In this study, details of production technologies of foodgrain, jute, potato, oilseeds, pulses, vegetables and cotton is analyzed including their implications for cost of production, capital requirements, profitability of cultivation, and returns to factor shares. The input demand and output supply elasticities for foodgrain is estimated utilizing the 'meta-production function' framework that allows for switching between seed varieties while responding to price changes. For the non-cereal crops, input demand and output supply elasticities are estimated using an aggregate production function.

Results from the input-output analysis of crop production revealed that *yields, profit (gross margin) and net return per unit of land area for modern rice varieties is significantly higher than the local rice varieties in all crop seasons*. The yield level for modern rice varieties is estimated at 4.2 ton/ha while the yield level of local rice varieties is 2.3 ton/ha, respectively. No significant regional differences in yield levels of modern rice varieties are observed while significant differences are observed for local rice yield across regions. *The fertilizer use rates per ha of land is also significantly higher for modern rice varieties (246 kg/ha) as compared to local rice varieties (94 kg/ha).* Profit per ha of land area is estimated to be significantly higher for modern rice varieties (Tk. 12, 826) than the local rice varieties (Tk. 6,515). Highest modern rice variety profit per ha is estimated at Tk.14,157 for Boro season followed by Tk.12,273 and Tk. 11,310 for Aus and Aman season, respectively. Among the non-cereal crops, highest profit per ha is estimated at Tk. 29,767 for vegetables followed by spices (Tk. 29,220) and potato (Tk. 26, 990). The net return (farm operator surplus) for modern rice varieties is estimated at 14 percent of the gross value of output (Tk. 3, 529) while it is 8 percent (Tk. 1,111) for local rice varieties. The highest net return is estimated at Tk. 12,608 (29 percent of gross output value) for vegetables followed by Tk. 8, 938 (19 percent of gross output value) for spices, respectively.

Farm-level *decision analysis of alternative technologies utilizing the 'meta-production function' framework revealed that farmers are profit maximizers and their response to variation in input prices and to changing environment is high*. Probit analysis of the seed selection function revealed that *farmers' probability of switching from local to modern foodgrain varieties increases with increase in output price and/or decrease in input prices*. Among the fixed inputs, availability of land and farm capital, and improved soil fertility increases the probability of planting modern varieties while infrastructural development and education decreases the probability. This finding therefore nullifies the fifth hypotheses (# H5) and *establishes the profit maximizing behavior of Bangladeshi farmers* (Table 10.1).

Estimation of *price elasticities for foodgrain crops revealed inelastic response to price changes. Allowance for seed switching improved the input and output price elasticity estimates to a large extent*. The price elasticities of demand for foodgrain crops after allowing for seed switching are estimated at –0.53, -0.60, and –0.98 for labor, fertilizer, and animal power, respectively. The foodgrain output supply elasticity is estimated at 0.65. On the contrary, highly elastic response to changes in soil fertility status and infrastructural development and inelastic response to education level of farmers for foodgrain crop is observed. The sign of these elasticity estimates revealed that *input demand and output supply increases with improvement in soil fertility status and decreases with infrastructural development and education level*.

In contrast to the estimates for foodgrain crops, *the elasticity estimates for non-cereal crops revealed elastic response to factor utilization, except for fertilizers*. The price elasticities of demand for non-cereal crops are estimated at –1.55, -0.72, and –1.22 for labor, fertilizer, and animal power, respectively. The non-cereal output supply elasticity is estimated at 1.34. Also, response to infrastructure and farmer's education level is in contrast. The sign of these elasticity estimates revealed that *input demand and output supply increases with infrastructural development and education level of farmers. Soil fertility also increases input demand and output supply*.

Indirect estimation of production elasticities from price elasticity information revealed the dominant role of variable inputs to crop production growth as compared to the fixed inputs of land and farm capital for all crops. Computation of *returns to scale revealed that* '*constant returns to scale* (1.04 ≈ 1.00*)' prevails in foodgrain production while* '*decreasing returns to* *scale* (0.82<1.00)' *is observed in non-cereal crop production*. This finding though provides hope for sustaining foodgrain production in future but limits the scope to expand non-cereal crops without proper planning and management to increase its scale efficiency.

10.1.3 Factors Affecting Adoption of Modern Agricultural Technology

Major criticism of the modern agricultural technology relates to its equity implications and one of the crucial factors determining this equity implication is the extent and intensity of modern technology adoption by all groups of farmers (Hossain, 1989). Adoption decision may be influenced by a number of factors, such as, irrigation, infrastructural, soil fertility, and socio-economic factors. The present study attempted to provide a detailed understanding of the diverse factors influencing adoption of modern agricultural technology utilizing both qualitative and quantitative analytical techniques.

Analysis of farmers' motives revealed that it is the higher yield (ranked one), ready marketability (ranked two) and short maturity period (ranked three) of the modern varieties of rice and wheat that induces them to grow the crop while its profitability is ranked lowest (rank six). On the other hand, low yield (ranked one), poor quality of grains (ranked two) and low output price (ranked three) are the major reasons cited for not growing local varieties of rice and wheat. Land ownership and tenurial status do not seem to adversely affect modern technology adoption decisions. The landless and marginal farmers are observed to be the higher adopters who in turn mainly operate as sharecroppers or tenants.

Analysis of *determinants of modern technology adoption revealed that irrigation is the major determining factor in influencing adoption decisions*. Farm size, number of female family labor, non-agricultural income, and infrastructural development significantly negatively influence adoption decisions. Soil fertility has significant positive influence in adoption decisions. This finding therefore nullifies the sixth and seventh hypotheses (# H6 and # H7) of the study and *establishes the crucial role of socio-economic as well as irrigation, infrastructural and soil fertility factors in influencing modern technology adoption decisions.*

An investigation into the support services for agricultural extension revealed *lack of interaction among agricultural extension officials and farmers. Lack of training in agricultural production technologies is also observed*. Farmers' knowledge of modern agricultural technology are mainly confined to fertilizer and pesticide application techniques only while knowledge on crop diversification, variety screening, health hazards of pesticide uses, and adverse impacts of technological change is relatively weak.

10.1.4 Multifaceted Impacts of Technological Change on Employment, Income Distribution, Poverty and the Environment

Past evaluations of modern agricultural technology mostly emphasized on the direct effects on income distribution and on geographical regions based on the argument that the technology is not scale neutral and benefited most in areas endowed with favorable agro-ecological conditions (Lipton and Longhurst, 1989). However, Hossain *et al.* (1990) argue that modern agricultural technology may also have indirect effect, which operates through the factor markets and enable transfer of income across socio-economic groups as well as regions.

The present study analyzed the direct and/or indirect effects of modern technology diffusion on employment, rural labor market and other factor markets. The employment effect of the modern agricultural technology is analyzed with particular reference to its effect on gender distribution of labor, which is a major source of controversy. The other factor markets on which the impact of technological change is analyzed include fertilizer, pesticide, land, credit, and output markets.

Analysis of *labor utilization in crop production revealed that substantially higher amount of total labor as well as hired labor per unit of land area is utilized in growing modern rice varieties as compared to local rice varieties*. However, *the labor employment pattern is not gender-neutral and is highly skewed in favor of men*. The female labor input ranges between 11 – 18 percent in foodgrain production and 6 – 48 percent (highest for vegetables) in non-cereal crop production. The increased demand for labor owing to rapid technological progress in foodgrain production was absorbed in two ways, first by an increased supply of women members from farm families, and second by hiring-in male labor alone. Therefore, women are affected in two ways from this technological change in agriculture. First, by an increased workload of intensive agriculture if they belong to a farm family, and second by being displaced from the hired labor market on two counts, from the post-harvest sector as well as the crop production sector. Also, significantly lower wage is paid to female labor, if hired, indicating discrimination against women. Analysis of the *employment effect of technological change revealed that modern technology, farm size, and the education level of farmers significantly increase demand for hired labor while labor wage, tenurial status, developed infrastructure, soil fertility, subsistence pressure, and working members in the family significantly decrease demand for hired labor*. However, demand for total labor is significantly higher in underdeveloped areas due to high intensity of modern technology adoption.

Analysis of the impact of technological change on prices revealed that *modern technology, soil fertility, land ownership, and underdeveloped infrastructure significantly increase labor wages while soil fertility and developed infrastructure significantly increase fertilizer prices*. Demand for pesticide use increase significantly with farm size, irrigation, agricultural credit and underdeveloped infrastructure. Improved soil fertility significantly reduces demand for pesticide use, mainly in case of non-cereal crops. *In the output market, modern technology, soil fertility and rural infrastructure significantly increase output prices*.

Analysis of the impact of technological change on land market operations revealed that the tenurial arrangements changed substantially from the traditional 50 - 50 output share with no input sharing system to a variable output share and input sharing system unique to each village. It is found *that relatively scarce input is usually shared between the landowner and the tenant*. Analysis of determinants of land rent revealed that *per capita owned land, modern technology, irrigation, tenurial status, farm capital and underdeveloped infrastructure significantly increase rent while improved soil fertility significantly decreases rent*. Analysis of the impact of technological change on agricultural credit market operation revealed that *modern technology, land ownership, farm capital, soil fertility and developed infrastructure significantly increase credit demand while number of working members in the family and farming experience significantly decreases demand for credit*.

A simultaneous estimation of input demand functions revealed that *modern technology and farm size significantly increases input demand. Irrigation strongly influences modern technology adoption decisions in addition to agricultural credit and underdeveloped infrastructure while farm size has significant negative influence on adoption*. On the other hand, *farm size, farm capital, agricultural credit, and underdeveloped infrastructure significantly increases irrigation demand*.

All these aforementioned results individually, and in combination, nullifies the eighth composite hypothesis (# H8) and establishes the notion of *significant influence of modern agricultural technology on employment, operation of the rural labor market and various factor markets* (Table 10.1).

The most widely debated criticism of the modern agricultural technology relates to its *distributional implications*. The impact of differential adoption rate of modern varieties by farmers, variation in input and output prices, and the impact of technology on production, employment, and expansion of markets for non-farm goods and services will eventually affect the level and pattern of income distribution in the rural areas (Hossain, 1989). The present study analyzed the impact of technological change on income, distribution of income and poverty using a wide variety of measures.

Results revealed that there are significant regional differences in income derived from agricultural as well as non-agricultural sources. *Income from crop production is significantly different across land ownership and tenurial classes*. Analysis of the determinants of various income sources revealed that *farm size, working members, farm capital, modern technology, and soil fertility significantly increase crop as well as agricultural income while farmers' education level significantly decreases crop income*. Developed infrastructure significantly increases non-agricultural income while farm size and modern technology significantly decreases non-agricultural income. This finding therefore nullify the ninth hypothesis (# H9) of the study and *establishes the crucial role of modern technology in influencing crop as well as agricultural income* (Table 10.1).

Analysis of the impact of modern agricultural technology on factor shares revealed that *significant differences exist in absolute values of factor shares between modern and local varieties of rice*. About 11 percent of the gross value of output (Tk.2,747) per ha of modern rice cultivation goes to landless and marginal farmers as labor wages through the hired labor market which is double the size of wages for local rice production and is estimated at Tk 1,351 (13 percent of gross value of production).

Analysis of the distributional impact of technological change revealed that *income inequality is higher in high adopter villages as well as low adopter villages*. Gini-coefficient computed on per capita income scale is estimated at 0.44 and 0.45 for high adopter and low adopter villages while it is 0.34 in medium adopter villages. With respect to irrigation status, income inequality is higher in low irrigated villages. Gini-coefficient is estimated at 0.42 and 0.48 in high and low irrigated villages. When analyzed across regions, inequality is found to be higher (0.47) in Comilla region while it is lower and similar in Jamalpur (0.41) and Jessore (0.40) region. The differences across adopter categories and/or regional categories become less prominent when Gini-coefficient is computed on per capita land ownership scale. The inequality in per capita land ownership remains within 0.50 to 0.60 with minor variations among categories. *Modern variety cultivation alone contributes to about 35 percent* (minimum 27 percent in Comilla and maximum 45 percent in Jamalpur) *to total income inequality*. The contribution of non-agricultural income is about 27 percent while other agricultural income contributes the remaining 38 percent to total income inequality.

Analysis of the impact of technological change on poverty using a number of measures revealed that *poverty is lowest in medium adopter villages showing consistency with results from income distribution analysis*. When analyzed across regions, poverty is observed to be similar and low in Jamalpur and Jessore region while it is sharply higher in Comilla. The distributionally sensitive measure of poverty indicates that 'high adopter' villages contribute to 84 percent to total poverty. Villages with 'high level of irrigation' also contribute to about 80 percent to total poverty. Among the regions, Comilla region contributes to 46 percent of total poverty followed by Jamalpur (34 percent) and Jessore (20 percent), respectively.

All these aforementioned results, therefore, nullifies the tenth hypothesis (# H10) of the study and establishes the fact that *technological change in agriculture significantly contribute to income inequality and poverty* (Table 10.1).

Agriculture is characterized by its environmental, behavioral and policy aspects (Clapham, 1980). Though the farmers' behavioral and government's policy dimensions of agriculture has been rigorously analyzed in the past, the environmental dimension is largely neglected and remains unclear despite the fact that ecological integrity of agricultural production system is a pre-requisite for sustainability. *The concern of environmental impacts of technological change and sustainability in agriculture has been a recent phenomenon*. The present study attempted to provide an insight to this less studied dimension in agriculture by providing a systematic picture of environmental impacts of modern agricultural technology as perceived by farmers and the relative strengths of adverse impacts as ranked by them. Further, material evidence in terms of bio-physico-chemical tests of soil fertility and water quality parameters, and long term trend analysis of indicators believed to be impacted due to this technological change in agriculture is provided in order to substantiate, validate, and authenticate the conclusions drawn from farmers' perceptions and rankings.

'Decline in soil fertility' is identified as the first major adverse environmental impact of modern agricultural technology according to farmers' perception ranking. The second important impact is the 'effect on human health' followed by 'reduction in fish catch', 'increased disease in crops', 'compaction of soil', 'increased insect/pest attack', etc. The strength of ranking sharply declines as one moves from visible and direct impacts to intangible and indirect impacts of technological change in agriculture. Results from the soil tests indicated the poor quality of soil in the study regions. *Modern rice varieties alone contribute to an estimated 71 percent of total nutrient uptake from the annual cropping system. The inverse relation between fertilizer use and available nutrient in the soil, inverse relation between fertilizer and organic manure use, as well as time-trend analyses of increasing fertilizer use rates and declining fertilizer productivity validated the claim of 'declining soil fertility' impact*. Time-trend analysis of relevant variables also validated the perception rankings of other adverse environmental impacts of modern agricultural technology. For

example, the negative growth rates of open water fish catch in the respective regions validated the 'reduction in fish production' impact. The positive growth rate of pesticide use in the respective regions validated the notion of 'increase disease, insect and pest attack'. In addition, arsenic pollution in water is identified in Jessore and Comilla region. In fact, arsenic pollution is estimated to affect 40 million people in about 42 districts of the country. *Though arsenic contamination in groundwater is geogenic, the surface soil contamination is anthropogenic spurred by the demand for irrigation using groundwater and installation of chemical quoted wooden electric poles for rural electrification nationwide*. The excessive withdrawal of groundwater for irrigation and drinking purpose resulted in fluctuation of water table causing aeration of groundwater aeration resulting in decomposition of pyrite and other arsenic compounds, which reaches the human and animal body. These findings therefore nullifies the eleventh hypothesis (# H11) and provide evidence that *technological change in agriculture has exerted adverse impacts on selective environmental components, such as soil fertility, human health, fish production, disease, pest and insect attacks in crops, and contamination of water*.

10.2 Synthesis of the Approaches Used and Their Implication on the Study Results

Since the nature and direction of the impacts of technological change in agriculture is multifaceted, the present study utilized a blend of economic, biophysical and behavioral analyses to capture the diverse issues. Particularly, in economic analyses, the modeling structure included a combination of single equation as well as simultaneous equation framework. The choice of the modeling structure, single equation and/or simultaneous equation, is mainly guided by the objectives to be fulfilled as well as *a priori* knowledge on the nature and dimension of the relationships among variables. The synthesis of the quantitative approaches used and their implication on the results of the study is presented in Table 10.2.

Table 10.2. Synthesis of approaches used and their implication on the results of the study.

Obj.1	To examine the impact of technological change on regional variation in agricultural development levels and to identify relatively homogenous agricultural regions with respect to a set of technological, demographic, infrastructural, and crop production efficiency parameters.	
	Model	Single equation model for analyzing determinants of regional variation with regionwise disaggregated data for three time periods.
	Technique	Stepwise Forward Regression procedure.
	Output	Parameter estimates of significant factor influencing regional foodgrain production that is then used for constructing index of agricultural development levels.
	Implication on result	No simultaneity is expected to occurr in this single equation modeling structure. Therefore, the estimates obtained are unbiased and consistent.
Obj.2 and 3.	To examine the impact of technological change on long-run aggregate crop production, and to estimate the output elasticities and returns to scale from the aggregate crop production function in order to determine the prospect of sustaining food production in future.	

	Model	Single equation aggregate production function model of the Cobb-Douglas form with regionwise disaggregated data for 29-year period.
	Technique	Ordinary Least Squares (OLS) procedure.
	Output	Parameter estimates of output/production elasticities and measures of returns to scale.
	Implication on result	No simultaneity is expected to occurr in this single equation modeling structure. Therefore, the estimates obtained are unbiased and consistent.
Obj. 4	To examine the long-run growth path of crop productivity using logistic and linear functions in order to determine the prospect of food production sustainability	
	Model	Single equation linear time trend and logistic regression models using national-level foodgrain productivity data for 47-year period.
	Technique	OLS procedure.
	Output	Parameter estimates of annual compound growth rates of foodgrain productivity.
	Implication on result	No simultaneity is expected to occurr in this single equation modeling structure. Therefore, the estimates obtained are unbiased and consistent.
Obj.5	To assess the soil fertility status of the farmers' field in terms of availability of major plant nutrients influencing crop productivity	
	Model	Single equation model of available major plant nutrients influencing crop productivity based on the actual soil test results from representative locations.
	Technique	Stepwise Forward Regression procedure.
	Output	Parameter estimates of production elasticities of major plant nutrients for foodgrain and non-foodgrain crops.
	Implication on result	No simultaneity is expected to occurr in this single equation modeling structure. Therefore, the estimates obtained are unbiased and consistent.
Obj.6	To analyze the farmers' decision making process in foodgrain production with respect to changes in variable input prices at the same time allowing for making a choice between local and modern varieties of rice and wheat using 'meta-production function' approach.	
	Model	Simultaneous equation profit function models of the translog form of traditional and modern foodgrain varieties jointly estimated along with the variable factor demand functions.
	Technique	Two Stage Switching Regression procedure. First stage utilizes Probit Maximum Likelihood Estimator (MLE) procedure for the 'reduced-form seed selection function'. The second stage utilizes the Seemingly Unrelated Regression Estimator (SURE) procedure for the joint estimation of the variable profit function and factor demand functions of traditional and modern foodgrain varieties, respectively.
	Output	Direct estimates of price elasticities of variable factors and production elasticities of fixed factors. Also, indirect estimates of production elasticities of variable and fixed factors and measures of returns to scale are obtained. In addition, estimates of probability of switching from traditional varieties to modern varieties are obtained and presence of any sample selection bias is eliminated.

	Implication on result	This estimation procedure is considered superior to single equation model for analyzing farm-level decision making process. Hence, parameter estimates obtained from this modeling structure is exclusively used for 'price policy analyses' focussing on producers' welfare.
Obj.7 and 8	To identify determinants of modern agricultural technology adoption at the farm-level, and to identify the role of technological, infrastructural and soil fertility factors in influencing crop production decisions.	
	Model	Single equation model for analyzing determinants of modern technology adoption.
	Technique	OLS and Tobit (Two-limit Probabilistic) procedures.
	Output	Parameter estimates of factors influencing modern technology adoption.
	Implication on result	Simultaneity bias is expected to occurr in this specification. As such, adoption behavior is again analyzed within a simultaneous equation framework discussed below. Decision on the impact is made based only on the nature and direction of the parameter estimates. The actual value of the estimated coefficient is not used.
Obj. 9	To examine the impact of modern agricultural technology on employment and gender equity in employment in the rural labor market as well as on factor markets, such as, fertilizers, pesticides, crop output, agricultural credit, and tenancy markets.	
	Model	A combination of single equation models of price functions and input demand functions and a simultaneous equation model of input demand functions along with modern technology adoption and irrigation demand function.
	Technique	OLS procedure for all single equation price functions (fertilizer prices, labor wages, output prices, and land rents). OLS and Tobit procedures for single equation model of hired labor demand function, Tobit procedure for single equation model of pesticide demand function, and only OLS procedures for single equation models of total labor demand and agricultural credit demand functions. Three Stage Least Squares (3SLS) Regression procedures for simultaneous equation model for total labor, fertilizer, animal power, modern variety adoption and irrigation demand functions.
	Output	Parameter estimates of factors influencing prices and input demand functions as well as modern technology adoption decision.

	Implication on result	Since, the prime objective of this study is to analyze the impact of modern agricultural technology on various components of the factors market, it must appear as explanatory variable in all functions in one hand, and also as a dependent variable in the analysis of adoption behavior on the other. Therefore, simultaneity bias is expected. However, extent of simultaneity bias is checked by analyzing estimates of same input demand functions estimated within a single equation framework as well as simultaneous equation framework. Price functions are, however, tested for their exogeneity from the farm-level influence and hence not incorporated in simultaneous equation model. Also, it should be noted that decision on the impact of technological change is based only on the nature and direction of the parameter estimates. The actual value of the coefficient is not used and, therefore, the existence of simultaneity in equations does not pose any major problem. However, if exact measure of influence is a primary concern, then the estimates obtained from the simultaneous equation model should be preferred.
Obj.10	To examine the impact of modern agricultural technology on income, distribution of income and poverty.	
	Model	Single equation model of determinants of income components.
	Technique	OLS procedure.
	Output	Parameter estimates of factors infuencing incomes.
	Implication on result	No simultaneity is expected to occurr in this single equation modeling structure. Therefore, the estimates obtained are unbiased and consistent.
Obj.11	To examine the impact of modern agricultural technology on selected aspects of environment, such as, soil fertility, water quality, human health and fisheries resources.	
	Model	Combination of behavioral model and linear single-equation time-trend models.
	Technique	Perception ranking, soil and water quality parameter analyses, and OLS procedure for time-trend analyses.
	Output	Rank of adverse environmental impacts of technological change in agriculture, and trends (annual compound growth rate) of relevant variables over time.
	Implication on result	No simultaneity is expected to occurr in this single equation modeling structure. Therefore, the estimates obtained are unbiased and consistent.

10.3 Synthesis of Impacts of Technological Change

The aforementioned summary of major findings provided a comprehensive picture on the multifaceted impacts of technological change in agriculture. However, synthesizing the nature of these multifaceted impacts of technological change on key economic variables and the environment would provide the basis for strategic agricultural development planning for the future. Also, the crucial role of two factors, infrastructure and soil fertility, are of special concern since the scope for managing the agricultural production environment depends largely on the nature of their impacts on the same set of key areas. The key impact areas at the national level are regional equity, aggregate crop production and foodgrain sustainability, and at the local level, these are input and output prices, input demand, employment, income, distribution of income and the environment. A synthesis of the multifaceted impacts of modern agricultural technology as well as infrastructure and soil fertility factors on these areas are presented in Figures 10.1, 10.2, and 10.3, respectively (the details are provided in Appendix Tables A10.1, A10.2, A10.3, A10.4 and A10.5, respectively).

At the national level, the nature of impact of technological change is complex and multidimensional (Figure 10.1). Though modern agricultural technology increases regional crop production, it also *exacerbates regional disparity*. On one hand, increase in aggregate crop production confirms the *positive impact of technological change in raising productivity*, implying that food production can be sustained in future. On the other hand, the *declining yield rate of modern rice varieties over time is raising doubt on sustaining food production trhough technological change alone*. However, the observed increase in modern wheat yield over time will somewhat offset the depressing effect of modern rice yield, thereby, providing hope for food production sustainability in future. Current increase in foodgrain production is largely due to switching from local to modern varieties of rice and wheat, which still provides higher yields.

At the local level, *it is clear that the modern technology diffusion in agricultural sector exerted a distinct upward pressure on input and output prices as well as input demands* (Figure 10.1). The upward pressure on output price will raise income of the farm producers and the increase on labor wages will smooth income inequality through an indirect transfer of income from rich farmers to the poor landless laborers. However, the increase on land rent raises equity concern since landownership in rural Bangladesh is highly skewed with more than 50 percent of farming population being landless and tenants. Higher land rent implies that the technological change opened up opportunities for the landed elites to raise their income through the tenancy market.

Though technological change significantly raised employment, it remained highly skewed in favor of men since only male labor are hired to meet the increased demand. Women constituting half of total population failed to get benefit from this technological progress. However, it should be noted that failure to generate women's employment opportunities is not solely due to the nature of the technology, rather it is the social and cultural barriers that restricts them to participate and accrue the benefit from this technological change in agriculture. The simultaneous operation of higher labor wages and demand for hired labor owing to technological progress may further redistribute income but the level of redistribution will not be substantial to bridge the gap between the rich and the poor farmers.

Technological change significantly contributed to increase in income from crop as well as agricultural production. However, *it also contributed to worsening income inequality. The concentration of income was estimated to be highest in 'high adopter' villages*. *Modern technology diffusion has also exacerbated poverty*. All the measures of poverty indices revealed that *poverty is high in 'high adopter' as well as 'low adopter' villages. It is the 'medium adopter' villages characterized by diversified cropping system that the incidence of poverty and income inequality is estimated to be lowest.*

On account of environmental impacts of modern agricultural technology, the picture is gloomy. The *detrimental effect on soil fertility is more than obvious* in the present study. Associated with this are the *adverse effects on human health as well as decline in open water fisheries* that served as a major source of animal protein for the rural poor in Bangladesh. Decline in fisheries resources may also be attributed in part to over-fishing, increased popoulation pressure and poor management. Increase in crop disease, pest and insect attack is also clear from the results of this study. In addition to this, contamination of water bodies through chemical run-off and eutrophication, though cannot be distinctly proved, remains a major environmental concern in future. *Arsenic pollution in groundwater though caused by geogenic processes, it was brought to surface through anthropogenic processes spurred by increased demand for irrigation for the modern variety cultivation in one hand and demand for safe drinking water on the other. The surface soils in intensively irrigated region now contain high level of arsenic*. Therefore, a complex mix of strengths and weaknesses are intertwined with this highly proclaimed technological breakthrough in agriculture that need to be carefully screened in order to pave the way for future agricultural development plans.

The influence of soil fertility factor on prices is positive (Figure 10.2). Higher soil fertility depresses demand for labor, animal power and pesticides. However, the decrease in demand for labor can be offset by an increase in cropping intensity through crop diversification in fertile soils. The reduction in pesticide use with improvement in soil fertility strengthens the case for soil fertility management. The positive impact of soil fertility on crop as well as agricultural income reinforces the argument.

The influence of infrastructural factor on prices, employment, input demands, technology adoption and income are mixed (Figure 10.3). Output and fertilizer prices are higher in infrastructurally developed region implying increase in farm income as well as promoting optimal use of inputs. Demand for irrigation and modern technology adoption declines with infrastructure development that would consequently promote crop as well as economic diversification, thereby, exerting less detrimental effect to the environment. In addition, influence of infrastructure in increasing income, particularly non-agricultural income, make a strong case for investment in rural infrastructure. At the national- level, the positive impact of infrastructure in raising crop production further reinforces the need to invest in infrastructure, particularly, road, transportation, storage and marketing facilities.

10.3.1 'Balanced Adoption is Equitable': Salient Features of 'Medium Adopter' Villages

As mentioned earlier that a complex mix of strengths and weaknesses are intertwined with this highly proclaimed technological change in crop production in Bangladesh agriculture. Analyses of the distributive justice of modern technology diffusion clearly revealed that it is the 'medium adopter' villages that consistently revealed least income inequality and incidence of poverty. This finding, therefore, challenges the conventional notion that high level of modern technology diffusion is the key to agricultural development and economic growth. In order to identify the conditions determining the superiority of this category of villages, selected socio-economic characteristics of villages by adopter categories is examined (Table 10.3).

It is clear from Table 10.3 that a number of features distinguishes ‘medium adopter’ villages from the other two categories. The striking difference is in the proportion of large farmers (16 percent) in the ‘medium adopter’ villages as compared to only 6 percent in ‘high adopter’ and none in ‘low adopter’ villages. Also, the proportion of medium farmers are highest (18 percent) in these villages. The higher proportion of large farmers resulted in large farm size (0.96 ha/farm) in ‘medium adopter’ villages, which is more or less an economic size of farm within the context of Bangladesh. The level of irrigation development is strikingly similar between the ‘high adopter’ and ‘medium adopter’ villages, 62 percent and 60 percent, while the difference in the level of modern variety adoption is very large, 75 percent and 47 percent, respectively. This implies that the medium level of adoption of modern variety is not due to limitation posed by the lack of irrigation, which is a feature for the ‘low adopter’ villages.

The cropping intensity is very high in ‘medium adopter’ villages (190 percent) and cropping system is highly diversified. Despite highest level of cropping intensity, the level of fertilizer use per ha of cropped land is much lower in ‘medium adopter’ villages (209 kg/ha) as compared to ‘high adopter’ villages (225 kg/ha), while level of organic manure application rate is highest (1.5 ton/ha). Also, the soil fertility level is relatively better in ‘medium adopter’ villages as compared to other two categories of villages. Further, these villages are located in areas with most developed rural infrastructure. This has opened up the opportunity to produce high-valued non-cereal crops in addition to modern varieties of rice and wheat since marketing risk associated with cash crop production is reduced to a large extent due to developed rural infrastructure.

All these features combined together resulted in better performance of these ‘medium adopter’ villages in terms of income inequality and poverty. The per capita income is highest (Tk. 6,902/person) in the ‘medium adopter’ villages with least income inequality (Gini = 0.34). The number of population below poverty line is also lowest (46 percent) and all types of poverty measures consistently revealed lowest incidence of poverty.

Therefore, one of the strategies for sustainable agricultural development planning will be to internalize the salient features of the ‘medium adopter’ villages and to replicate and/or create such conditions in ‘high adopter’ as well as ‘low adopter’ villages. In short, following Schultz’s (1964) terminology of ‘small is beautiful’ (used for small farmers), it can be said in the context of sustainable agricultural development that, ‘balanced adoption is equitable’.

10.4 Strategies for Agricultural Development Planning and Policy Options

The previous two sections provide a comprehensive summary of the major findings together with the results of hypothesis tests and a synthesis of multifaceted impacts of technological change on key economic variables and the environment, respectively. In this section, an integrated agricultural development plan is outlined. The choice of the program components is made by applying the SWOT (Strength-Weakness-Opportunity-Threat) analysis based on the results of multifaceted impacts of technological change discussed so far. The proposed strategic development planning is viewed as an integrated model involving (1) balanced modern technology diffusion, (2) crop diversification, (3) soil fertility management, (4) rural infrastructure development, (5) pricing policy and (6) economic diversification. The first three components are interlinked with each other and need to be implemented simultaneously. The remaining three components will smoothen the process by: (a) enhancing effective input delivery and output marketing systems through developed infrastructure, (b) responding to price signals through appropriate pricing policies, and (c) engaging in non-agricultural income generating activities through economic diversification. The result of SWOT analysis of the aforementioned program components is presented in Table 10.4, which formed the basis of devising various policies for sustainable agricultural development in Bangladesh.

Policy #1: Balancing Modern Technology Diffusion

Results of the SWOT analysis (Table 10.4) clearly revealed that though a number of strengths and opportunities are associated with this highly proclaimed modern agricultural technology, the corressponding weaknesses and threats reduce its merit to a large extent. Particular concern is the adverse effect of modern agricultural technology on income distribution and poverty and its threat to environmental health. On the other hand, findings from this study clearly reveals that a balanced level of modern technology adoption along with crop diversification provides highest per capita income and is associated with least income inequality and poverty (Table 10.3). Therefore, keeping the level of modern technology adoption at an optimum level with a right mix of improved varieties and crop diversification, as opposed to exclusive diffusion suggested in earlier evaluations of 'Green Revolution', seems to be the best option in improving income distribution and bridging the poverty gap between rich and poor.

It should be noted that, limited adoption of modern technology might not be able to meet the income needed for year round expenses on family maintenance even in the rural regions. Therefore, two alternative options are forwarded, crop diversification (an option allowing the farming households to remain within agriculture) or economic diversification (an option paving the way for the farming households to move out of agriculture). As there are two major cropping seasons, *rabi* (dry winter) and *kharif* (monsoon), with an overlapping season for modern Boro rice, one principal strategy would be to allocate land for modern varieties of rice during the *kharif* season and diversify the cropping system during *rabi* season. Modern transplanted Aman rice played a dominant role in meeting the foodgrain demand in Bangladesh. The advantage with modern Aman rice is that it is grown in the monsoon season and, therefore, requires less irrigation as early rain can supplement the water requirment. Therefore, research must be geared to introduce Aman varieties that are flood and disease resistant and provides higher yields.

Table 10.4 SWOT analysis of the integrated agricultural development planning components.

Component	Strength	Weakness	Opportunity	Threat
1.Modern technology diffusion	• Increase employment • Increase crop income • Increase price • Increase labor wage • Increase land rent	• Increase income inequality • Increase regional disparity • Increase gender inequality • Increase pesticides and fertilizer use • Ignore indigenous technical knowledge	• Increase food self-sufficiency • Reduce food import • Save foreign exchange	• Increase poverty • Decline soil fertility • Affect human health • Reduce fish production • Increase disease, pest and insect attack in crops • Contaminate water body • Reduce biodiversity • Degrade environment
2.Crop diver-sification	• Increase crop income • Increase employment • Increase price • Increase labor wage • Increase land rent	• Increase fertilizer use • Require skilled labor • Poor infrastructure • Capital intensive	• Improve soil fertility • Improve income equality • Improve regional equality • Improve gender equity • Promote export earning • Substitute import • Reduce pest attack • Preserve biodiversity • Reduce production risk	• Maximum production may not be achieved • Increase commerciali-zation • Increase dependency on external markets
3.Soil fertility management	• Increase crop productivity • Increase crop income	• Increase management cost • Require skilled personnel	• Improve soil properties • Preserve soil fertility • Stabilize crop productivity • Sustain food production	• Intensive agricultural practice may lead to environmental degrada-tion in the long run • Risk of pollution
4.Infrastruc-tural deve-lopment	• Promote diversification • Increase non-agricultural income • Increase	• Require high implementation cost • Require skilled personnel • Increase maintenance cost	• Promote access to inputs and delivery of outputs • Promote extension network and facilities • Increase access to information • Facilitate export	• Irreversible development threatening environment in the long run • Increase capital out-flow from rural to urban areas

Component	Strength	Weakness	Opportunity	Threat
	non-farm employ-ment • Increase price		• Promote economic growth • Raise standard of living	• Increase commerciali-zation
5.Price policy manageme nt	• Promote crop diversificati on • Increase crop income	• Require subsidies • Poor information • Poor infrastructure	• Promote optimum input utilization • Promote long run crop production stability • Increase farm investment • Promote economic growth	• Increase risk due to price fluctuation • Increase dependency on external markets • Increase inequality if implemented poorly
6.Economic diversi-fication	• Increase non-agricultural income • Increase non-farm employment	• Investment intensive • Require skilled personnel • Poor infrastructure	• Develop agro-industries • Develop enterprise • Mobilize investment • Promote economic growth • Raise standard of living	• Increase commerciali-zation • Increase congestion • Increase in-migration • Risk of Pollution • Environmental degrada-tion in the long run

Source: Based on multifaceted impact analysis of technological change in agriculture in previous chapters, namely, Chapters IV, V, VI, VII, VIII and IX.

Policy #2: Crop Diversification

Crop diversification possesses similar strength as that of modern rice and wheat technology. In addition, it possesses considerable opportunities for environmental improvement and is accompanied with least threat if managed properly (Table 10.4). The present study clearly demonstrates that vegetable, spices (chilly, onion, garlic and turmeric), potato and cotton provide higher return than the modern varieties of rice and wheat. Mahmud *et al.* (1994) also reported the superiority of these crops in terms of returns over modern varieties of foodgrains. Promotion of these crops with appropriate management and pricing policies would exert favorable impact on income distribution as well as balance in nutritional intake. Alauddin and Tisdell (1991) noted that Bangladeshi diet has become highly skewed in favor of starch intake only, which is detrimental to health in the long run. It should be noted that a general model of crop diversification could not be implemented in every region due to different micro-climatic requirements for specific non-cereal crops.

A burning question remains that if non-cereal crops perform so well in terms of returns, then why their acreage are declining over time? One of the most convincing answers for this question is the price and yield risks associated with growing these crops. Thus far, little or no research has been done in the area of risk analyses of non-cereal crops in Bangladesh. Shahabuddin (1991) using a farm level analysis of farmer behavior under uncertainty indicates that areas where farm households are unable to meet consumption needs reveal risk-taking behavior in making crop choices while those who can meet consumption needs tend to be risk-averter[38]. Therefore, one of the principal strategies to promote crop diversification should be through controlling the price risks (details of price policy analyses is presented in the subsequent section). Strengthening of crop insurance policies through public and private insurance agencies could be an additional support to promote crop diversification. In Bangladesh, the concept of crop insurance to hedge against risk is non-existent. In an uncertain production environment characterized by frequent occurrence of natural hazards and calamities, crop insurance policies can play a major role in hedging yield risks.

In addition to price and yield risk, marketing risk for perishables, such as vegetables, is another major factor hindering crop diversification. Development of market facilities coupled with improved transport facilities would be an effective strategy. Such development would also reduce the price risk to a large extent. The positive influence of infrastructural development on prices, input demand and non-agricultural income has been established in this study (Figure 10.2).

Lack of technical skills in growing these crops optimally may be another factor, hindering the expansion of non-cereal crops. The 'decreasing returns to scale (0.82 < 1.00)' computed for non-cereal crops in Chapter V hints on either overutilization or inefficient

[38] However, it should be mentioned that data for his study dates back to crop year 1979/80 when the diffusion of modern agricultural technology was in its mid-stage and the extent of income inequality and poverty were not as adverse as of now. As such, studies in analyzing risk behavior of farmers need to be emphasized.

utilization of resources in non-cereal crop production. It is also shown that the existing interaction among the agricultural extension system and farmers are weak (Chapter VI). Therefore, the existing agricultural extension needs to be strengthened (detail is discussed in subsequent section).

Suggested Crops for Jamalpur Region

Based on the existing land use, yield rates, and profitability (output-input ratio) criterion, it is suggested that crop diversification policy in Jamalpur region should focus on oilseeds (mainly mustard), spices (mainly chilly, onion and garlic), vegetables, modern Aman rice, and potato cultivation. The profitability for these crops are estimated at 1.27, 1.25, 1.23, 1.19 and 1.15, respectively with corressponding rank order from 1 to 5 (Appendix Table A10.6). Cultivation of modern Boro rice provides a profitability of 1.13 and is lower than modern Aman rice crop while the investment is substantially higher. Since rice is still the major staple food in Bangladeshi diet, cultivation of at least one crop of rice is a pre-requisite. Moreover, modern Aman rice is grown in monsoon season, therefore, require fewer cost for irrigation. The dry winter season can be devoted to growing oilseeds, spices, vegetables, as well as potato that would bring higher annual farm family income.

Suggested Crops for Jessore Region

Using the same set of criterion as of Jamalpur region, the crop diversification policy in Jessore region should focus on vegetables, jute, modern Aman rice, cotton, pulses and oilseeds. The profitability for these crops are estimated at 1.47, 1.38, 1.36, 1.33, 1.27, and 1.22 respectively with corressponding rank order from 1 to 6 (Appendix Table A10.6). Cultivation of modern Boro rice provides a profitability of 1.19 and is lower than modern Aman rice crop while the investment is substantially higher. Similar argument in favor of modern Aman rice also holds for Jessore region. The yield rate of jute is highest in Jessore, thereby, providing substantially high net return. Cotton is a specialized crop grown in Jessore region only largely due to the micro-climatic requirement for this crop. The relatively better soil fertility status of this region provides high potential for promoting vegetables, jute, cotton and pulses.

Suggested Crops for Comilla Region

For the Comilla region, the crop diversification policy should focus on spices (mainly chilly, onion, and garlic), jute, modern Boro rice, potato, and pulse crops. The profitability for these crops are estimated at 1.25, 1.18, 1.13, 1.10 and 1.08, respectively with corressponding rank order from 1 to 5 (Appendix Table A10.6). The profitability of modern Boro rice is higher in Comilla region due to the existence of Meghna-Dohanagoda Flood Control, Drainage and Irrigation Project (M-D FCD/I) resulting in substantially lower cost for irrigation. The profitability of modern Aman rice is lower due to higher cost of other inputs, particularly animal power price and wage of labor in this region. The profitability of potato is

also high in Comilla region due to exclusive use of modern varieties and high doses of fertilizers. Rate of return from spices is highest. The potential for diversification is relatively higher in areas outside the embankments of M-D FCD/I, since a tendency to move out of rice is observed among many farmers owing to high cost of irrigation as well as land preparation.

Production of modern varieties of wheat is not suggested for any of these three regions largely due to its low and similar profitability (1.04) across regions (Appendix Table A10.6). This may be a major reason for slow growth of wheat acreage in the country. From the aforementioned analysis, it is clear that the choice of crops in promoting the policy of crop diversification should be region specific. Though the entire country is characterized with a rice-based cropping system, dominated by Aman rice crop, the annual crop cycle underwent vast changes by developing pockets suitable for particular crops, e.g., cotton and pulses, that has to be taken into account while planning for sustainable agricultural development.

Policy #3: Strengthening Bottom-up Planning and Agricultural Extension Services

It was observed that lack of technical skills is one of the factors hindering expansion of non-cereal crop production in Bangladesh. The strategy to improve technical know-how of the farmers can be undertaken in two ways with effective inter-links: (a) by intensifying the existing agricultural extension network utilizing a bottom-up planning approach, and (b) by collaborating with the national and regional level NGOs working at grassroots.

High potential lies with the existing agricultural extension network spread all over the country. The major need is to transform the existing top-down approach to rural development to a bottom-up approach where the basic need specific to individual areas is assessed at the grassroots. Then these needs are converted into action plans and later delegated up in the hierarchy ultimately reaching the center for approval and fund allocation. Starting from 1995, the DoAE initiated bottom-up planning approach to agricultural extension at a pilot scale that require sub-district and district level extension officials to prepare 'bottom-up extension plans'. The department also organized training programs on planning skills for staff at all levels and published 'modified agricultural extension manual' that emphasizes 'little or no cost extension system' (DoAE, 1995 and 1996). Though the success of this modified extension system is yet to be evaluated, this change of attitude from the conventional top-down planning approach to bottom-up planning approach already paved the way to successfully implement the strategies suggested in this study. The NGOs can be involved to impart training on planning skills and preparation of individual bottom-up extension plans by working closely with the sub-district level agricultural extension officials. Involvement of NGOs from the beginning of the process will enable the government to undertake joint implementation programs for the proposed individual plans. Also, this will bring in consistency of development programs undertaken separately by the NGOs and the governments thereby avoiding duplications of programs. Moreover, it could

overcome the constraints faced by government related to budget deficiency as well as the lack of trained officials and the stiff bureaucratic time killing.

Presently, NGOs in Bangladesh operate in more than 50 percent of the total villages of the country involving over 3.5 million families as beneficiaries mainly composing of the most disadvantaged section of the society (Rahman, 1994). Over the past two decades, NGOs had significant contributions in the areas of health, family planning and sanitation, education (adult and non-formal primary education), social forestry, livestock and sericulture. Therefore, the expertise of NGOs in providing extension services at the grassroots can be tapped through devising appropriate collaborative mechanisms with the government agencies. Leading national NGOs, such as BRAC, Proshika, and ASA, initiated programs in collaboration with the government since the early 1980s in other areas of development. Starting from the 1990s, BRAC expanded its 'vegetables production program' involving the landless rural women. These women lease-in land or use their homesteads for growing vegetables. BRAC provides them with training, technical services, inputs and credits required for the operation. Currently, an estimated 51,565 women are involved in 'vegetables programs' (BRAC, 1996). Therefore, a formal collaborative arrangement between the Department of Agricultural Extension (DoAE) and NGOs, such as BRAC, Proshika and ASA, could promote the scope of crop diversification to a large extent.

Policy #4: Soil Fertility Management

In this study, 'declining soil fertility' has been identified as the major adverse environmental impact of modern agricultural technology diffusion (Chapter IX). The decline in productivity trend of modern rice in most of the regions has been detected as early as 1987 (BASR, 1989). Therefore, improving soil fertility is a major concern in the pursuit for sustainable development in Bangladesh. The direct approach to improve the soil fertility status would be to test the physico-chemical parameters of the soil and recommend suitable crop rotation and soil conservation measures suited to individual soil series. Also, promotion of biotechnology and use of biofertilizers would restore soil fertility status. Promotion of crop diversification policy will in turn contribute positively to soil fertility restoration measures.

In this context, it should be mentioned that the Soil Resources Development Institute (SRDI) in collaboration with five other institutes[39] initiated a project to prepare 'Land and Soil Resource Use Guide' (in Bangla) for each of the 460 sub-districts of the country in the early 1980s. The manual consists of physical and chemical test results of soil for each of the soil series found in specific sub-district and a soil map drawn on 1:50,000 scale for each sub-district indicating the soil collection locations. It also contains fertilizer recommendation guide for optimum

[39] The collaborating institutes are Bangladesh Agricultural Research Institute (BARI), Bangladesh Rice Research Institute (BRRI), Bangladesh Institute of Nuclear Agriculture (BINA), Bangladesh Agricultural Research Council (BARC) and DoAE, respectively.

production for all major and minor crops. Thus far, manual for about two-thirds of the sub-districts are published and are distributed to the Block Supervisors, the lowest unit of agricultural extension officials, residing in the rural areas. The considerable delay (about 15 years since the project started to collect soil samples) in publishing the manual reduced its effectiveness for planning. For example, the soil test results collected under this project somewhere between 1980 – 1985 for two of the regions, Manirampur sub-district of Jessore region and Jamalpur Sadar sub-district of Jamalpur region is published in 1990 and 1991, respectively. But manual for the Matlab sub-district of Comilla region is yet to be published. A comparison of the presently collected soil test results with those reported in the manual for the same soil series revealed sharply different results. Nevertheless, these manuals will serve the basic purpose for identification of suitable crops suited to each individual soil series along with recommended fertilizer doses for individual crops.

Therefore, an inter-agency coordination is needed to ensure that these soil resource use manuals as well as training on bottom-up planning skills are provided together to the root level agricultural extension officials. The joint implementation of both these programs will lead to the preparation of effective agricultural development plans at the sub-district level that are conducive to the suggested policies of crop diversification as well as soil fertility management. Involvement of NGOs will speed up the process of imparting knowledge on environmental awareness as well as training on soil conservation measures.

Uncertainty in land tenurial arrangement depresses incentives of farmers to undertake soil conservation measures. Since, no long-term security is ensured in existing tenurial arrangements in Bangladesh, tenants find it un-economic to invest in soil conservation measures. Though no specific analysis on this aspect is conducted in this study, it is widely accepted that secure tenure indirectly promotes soil conservation. Therefore, effective implementation of the already existing policies on security to tenure (currently only on paper) will indirectly influence soil conservation measures.

Policy #5: Price Policy Prescription

One of the most effective ways to influence individual decision making process is by exerting an effect on the prices of inputs as well as outputs. Effective price policies have the unique advantage of minimum control and monitoring requirements and can be implemented at a national level. But it carries a disadvantage of market distortion and huge investment in subsidies. However, if the target is to improve the lives of the disadvantaged farming population, then such investment seems worthwhile if properly implemented. In order to specify the price policy instruments to be implemented, a rigorous analyses on several policy alternatives and their welfare implications based on the response of farmers' to changing production environment (Chapter V) is presented in the following section. The impact of any policy instrument would have to work through the actions of the farmers and the agronomic characteristics of the crops. Therefore, in order to predict the impact of alternative policy instruments, knowledge of farmers' quantitative response to economic incentives introduced by these instruments as well as the response of the crops to changes in input use as consequence of their response to policy instruments is required. Information required for such analyses is detailed in Chapter V.

Fifteen policy alternatives are considered: four single instrument policies (fertilizer price, labor price, animal power price and output price); six two-instrument combinations; four three-instrument combinations; and, one four-instrument combination. For analysis, we consider the effect of a 10 percent reduction in input prices (i.e., fertilizer, labor and animal power subsidies) and a 10 percent increase in output prices (output subsidy) both individually and in combination. The computations were done separately for foodgrain crops and non-cereal crops since the response pattern is different for these two broad crop groups (see Chapter V). The procedure used to calculate the cost-effectiveness of the policy alternatives is detailed in Appendix D.

It should be noted that, in this study, the measure of overall welfare conducted through the price policy analyses focussed only on estimating the operators' or producers' surplus. The detail treatment of consumers' surplus in this overall welfare analysis has not been attempted, since the focus is on analyzing the distribution of gains of technological change on farmers' income.

When only cost-effectiveness rather than distributional implication is concerned, Table 10.6 reveals that the most cost-effective policy for increasing foodgrain production is a reduction in labor wages (ranked 1) and for non-cereal production a subsidy on fertilizer prices (ranked 1). The rate of return is 95 percent return on the labor wage subsidy for foodgrain production and the rate of return is 254 percent on fertilizer price subsidy for non-cereal crop production (Appendix Tables D3, D4 and D5).

However, it is not desirable to choose policies based on only a single criterion of cost-effectiveness but also must satisfy distribution considerations. The latter criterion often complicates the policy prescriptions. If the government's distributional objective is targeted to raise the income of farmers, then the most-effective policy appears to be output price subsidy that would yield substantially higher income to farmers as well as the society, though they rank very low in terms of cost-effectiveness.

The option for labor wage subsidy is ruled out on the ground that it will adversely affect the landless and marginal farmers whose major source of income is wage labor. Also, rise in real wage of labor is desired as a policy in order to bridge the gap between rich and poor. The fertilizer subsidy policy, though ranks very high in terms of cost-effectiveness, it is ruled out due to serious controversies in the past as well as its adverse effect on the environment. Fertilizers were heavily subsidized since the introduction of modern agricultural technology in the early 1960s. The average rate of subsidy was about 58 – 67 percent in 1968/69 and was lowered to about 25 percent in 1983/84 (Hossain, 1989). Subsidy on fertilizer was finally removed on December 1992 (Baanante *et al.*, 1993). The International Fertilizer Development Center (IFDC) study on the impact of fertilizer subsidy removal in Bangladesh showed that the rise in fertilizer/paddy price ratio due to the removal of subsidy would exert negligible impact on crop yield and farmers' income. Moreover, it will save cost of the government and allow efficient resource allocation (Baanante *et al.*, 1993). Though large fluctuation in fertilizer prices is observed in the present study, an effective marketing policy and retail price control would optimise the use of fertilizers for agricultural production.

Since both labor wage and fertilizer price subsidies are ruled out, the focal point of the policy lies in subsidizing animal power services that would be cost-effective, relatively less expensive to the government, and provide reasonable benefit to the farmers as well as the society (Appendix Table D5). The subsidy on animal power services can be operated using two approaches: (a) developing the much desired livestock sector, and/or (b) developing farm mechanization, particularly, tillage equipments. Farm mechanization in Bangladesh has not been successful largely due to the biophysical constraints imposed by the maze of canals and waterbodies separating the scattered fragmented farm plots of individual farmers in almost every region of the country coupled with poor and inadequate service delivery systems. Also, the labor displacing potential of farm mechanization is another concern. Studies carried out during the early 1980s showed that power tillers do not have significant positive effect on land productivity; cause net labor displacement and benefit the better-off who can afford to buy it (Jabbar and Green, 1983). Therefore, the best option lies in developing the livestock sector that would serve the dual purpose of draft power requirements as well as nutritional requirements of the malnourished population. The current policy thrust in the livestock development is far from adequate. The plan allocation for livestock sector remained within 2.7 – 6.8 percent of total budget in successive Five-Year Plans covering the 1973 – 1995 period while its contribution to national GDP ranges between 7.8 – 13.9 percent, respectively (Rahman and Bhuiyan, 1991). The sector is consistently under-funded with poor research, training and extension facilities given the magnitude of the problem. For example, budget allocation for veterinery services and genetic improvements declined steadily since 1980 – 1995 despite the policy thrust on improving the livestock sector (Rahman and Bhuiyan, 1991). Therefore, existing financial, technological and institutional constraints of the livestock sector need to be removed as it serves as one of the most important supporting activity in the crop production sector of Bangladesh providing 98 percent of the draft power requirement.

As providing a complete set of policies is beyond the scope of this study, it seems that price policies for raising farm incomes in three regions of Bangladesh should focus on animal power and output price subsidies.

Policy #6: Rural Infrastructure Development

The need to develop rural infrastructure has been indicated a number of times in the aforementioned strategies. Infrastructural development is emphasized mainly to pave the way for both crop diversification as well as economic diversification policies. The present study clearly demonstrates the favorable impact of infrastructural development on prices, input demand and income (Figure 10.2). Also, infrastructural development open up opportunities for increased interaction between urban and rural regions. The major types of infrastructures need to be developed are: agricultural extension network, markets and marketing facilities, storage facilities, milling and processing facilities, road and transportation facilities, financial institutions, educational institutions, and information and communication networking. The rotated factor matrix analysis of infrastructural facilities in the study regions revealed that the first five elements of infrastructure,

the agricultural extension office, bank, bus stop, storage and growth centers alone explain more than 85 percent of the variations in the infrastructure index (Appendix Table A5.1).

The major role has to be taken up by the government to build these facilities, as there are little scope to engage NGOs in these public sector investments. Though road communication is quite satisfactory in the study regions, the concomitant development of market, storage and other infrastructural facilities are far from adequate, particularly, in the Jamalpur region. Therefore, a balanced development of rural infrastructure is needed to promote sustainable agricultural development.

10.5 Potential for Economic Diversification in the Study Regions

A major advantage of economic diversification is that it enables to earn income from non-agricultural sources (Table 10.4), thereby, exerting less pressure on land that are already intensively utilized with improper soil conservation measures. It was shown in Figure 10.2 that non-agricultural income is higher in developed infrastructure regions. Therefore, planning for economic activity for the study regions should not be confined to crop diversification alone. In general, economic diversification strategy should focus on developing rural enterprises and cottage industries that are small and labor intensive and possess a strong marketing potential.

Based on the observation during the farm-survey and results of the Focussed Grouped Discussion (FGD) conducted as a part of the survey, considerable potential for diversification to non-agricultural as well as non-crop agricultural activities are identified. For example, Comilla study region possesses vast potential to develop fishing industry, as it is located at the confluence of the Meghna and Dhonagoda rivers. Since there exists a good river as well as road communication between the Comilla study region and the capital Dhaka, tapping the huge potential for developing fishing industry through commercial fishing and establishing fish processing facilities will raise income in the locality. Jessore study region, on the other hand, possesses huge potential for agro- processing and tile-processing industries. The region is famous for gur (raw sugar) made from datepalm and the clay available in the region form good roofing material. An advantage of both these processing industries is that they are labor intensive and would generate non-farm employment. Therefore, economic diversification strategy for this region should focus on promoting these industries. For Jamalpur region, enterprise development, particularly, small-scale cottage industries and handicrafts, may be a desirable strategy for economic diversification in this region.

Apart from the development of infrastructural facilities to spur economic diversification, a major strategy would be to implement joint programs promoting rural small-scale labor-intensive industries by actively involving NGOs in the process. The active involvement of NGOs in economic diversification programs will release the burden of providing skills training, supervision and monitoring requirements on the part of the government agencies thereby leaving only the task of effective promotion of marketing and input delivery systems for the government. The success in the development of silk production with joint collaboration between

Bangladesh Sericulture Board and BRAC is a case in point (Rahman, 1996).

10.6 Conclusions

Widespread controversies exist on the delayed consequences of technological change or 'Green Revolution' technology in agriculture. The reasons can be largely attributed to the approach utilized in analyzing the impact of technological change as well as the extent of issues covered in the evaluation processes. The present study employed a holistic approach to evaluate the multifaceted impacts of the modern agricultural technology diffusion in Bangladesh from the national as well as local perspective by addressing diverse range of issues: regional development, foodgrain sustainability, employment, gender gap, income distribution, poverty, and the environment.

Results revealed that a complex mix of strengths and weaknesses are intertwined with this highly proclaimed technological breakthrough in agriculture that need to be carefully screened in order to pave the way for future agricultural development plans. Despite a number of positive impacts of this technological change in increasing food production, income, employment and factor prices, it has also increased regional disparity, gender gap, income inequality, and poverty and is a threat to the environment, particularly, soil fertility, human health, fisheries resources, and water quality. Also, the declining productivity of the modern rice varieties, a major vehicle of this technological breakthrough, is raising doubts on sustaining foodgrain production in the future. However, an interesting feature emerged from the synthesis of the multifaceted impacts. It is observed that the 'medium adopter' villages, characterized by balanced aoption of modern varieties, diversified cropping system, with larger land endowment, better soil fertility and developed rural infrastructure performed better and is associated with highest per capita income and least income inequality and poverty. This finding, therefore, challenges the conventional notion of intensifying modern technology adoption as the key to agricultural development and economic growth. Rather, it establishes the fact that 'balanced adoption is equitable'.

As such, an integrated model of agricultural development plan is outlined using the SWOT analysis based on the multifaceted impacts of technological change. The proposed strategic development planning is viewed as an integrated model involving (1) balanced modern technology diffusion, (2) crop diversification, (3) soil fertility management, (4) rural infrastructure development, (5) pricing policy and (6) economic diversification.

Balanced adoption of modern agricultural technology along with crop diversification is suggested as one of the major policy based on the experience of 'medium adopter' villages who revealed a balance between modern varieties of rice and wheat as well as non-cereal crops. This suggestion contrasts with almost all of the earlier evaluation of 'Green Revolution' that recommends spreading of modern technology to its fullest extent. Based on the existing land use, yield rates, total costs of production and net profit criterion, specific crop combinations for individual regions are suggested.

In setting the strategies for agricultural development planning, an effective pricing policy is deemed pivotal in enhancing crop diversification by reducing the price risks associated with non-cereal crop production. Based on distributional considerations, subsidies on animal power services and output prices are suggested that can be implemented across the board: from local level to national level. Also, crop insurance policies through public and private insurance agencies and development of marketing, transportation and infrastructural facilities is suggested to reduce the yield risks and marketing risks to promote crop diversification both at the local level as well as the national level.

Human resource development, in terms of providing technical skills in growing non-cereal crops, raising awareness on adverse environmental impacts of technological change, and enterprise development skills are suggested to promote crop diversification as well as economic diversification policies. The strategy to improve technical know-how of the farmers can be undertaken by: (a) intensifying the existing agricultural extension network utilizing a bottom-up planning approach, and (b) collaborating with the national and regional level NGOs working at grassroots.

The key to success in realizing this planning strategy is integration and coordination among facilitators: relevant government agencies, NGOs, financial institutes and the farming communities. The development programs of individual agencies must be integrated in order to enable the farming and rural communities to reap the full benefit of interventions. An uncoordinated implementation of the same tasks will result in failure and which is usually the case. Therefore, at the outset, substantial changes in the attitudes of the government agencies towards development programs along with a major restructuring of individual program scheduling, budgeting, and implementation strategy is a pre-requisite to initiate the tasks.

Finally, it can be concluded that Bangladesh need agricultural technologies that are labor-intensive, provide equal opportunities for men and women, smoothen income inequality, reduces poverty and exerts least effect on the environment. Therefore, a properly designed crop diversification policy and its implementation would be a first step toward the goal of achieving sustainable development. Also, implementation of economic diversification policy and development of rural infrastructure will further complement the pursuit for sustainable agricultural development in Bangladesh.

10.7 Direction for Further Research

Despite the fact that a large number of issues are covered in this study, some other issues of importance could not be analyzed mainly due to limitation posed by the nature of data (multi-period data), time, funding, and scope required for such study. In order to complement the findings of the present study, the following research is suggested:

1. The analysis of impacts on technological change on consumption, nutrition, savings and investment is important. It should be mentioned that research on the impacts of modern agricultural technology on consumption, saving and investment in Bangladesh is conducted at its early stage of diffusion, the 1980s. However, the current scenario, which is expected to be largely different, requires fresh examination. Also, the effect on

nutritional intake is important to develop a nation with healthy population that has direct relevance to working ability, work efficiency, and intellectual development.

2. Analyses of intangible environmental impacts of technological change, such as, soil salinity, compaction of soil, and contamination of water bodies need to be conducted to authenticate the farmers' perception and claims.

3. Empirical estimation of the rates and factor biases of technological change with respect to specific environment, for example, irrigated as well as unirrigated environment, will be valuable for devising national level agricultural development policies.

4. Studies on farmers' behavior under risk and uncertainty is nascent in Bangladesh. Details of farmers' risk taking behavior under changing production environment will assist greatly in devising alternative policies for agricultural development.

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APPENDICES

APPENDIX A

SUPPLEMENTARY TABLES

Table A3.1 Test of representativeness of the sampled households.

Land ownership categories	Mean differences in land ownership (ha) of households between two periods, 1989 and 1996			Remark on representa-tiveness
	Jamalpur region	Jessore region	All region	
Landless (<0.20 ha)	**0.0636** t-ratio = 3.09*** F value = 7.64***	**0.0546** t-ratio = 3.09*** F value = 7.64***	**0.0685** t-ratio = 3.09*** F value = 7.64***	Not repre-sentative
Marginal (0.21 – 0.40 ha)	**0.0186** t-ratio = 0.73 F value = 0.04	**-0.0079** t-ratio = -0.24 F value = 1.38	**0.0163** t-ratio = 0.94 F value = 0.20	Repre-sentative
Small (0.41 – 1.00 ha)	**-0.1347** t-ratio = -1.77 F value = 6.79	**-0.0532** t-ratio = -0.50 F value = 0.11	**-0.0795** t-ratio = -1.65 F value = 1.90	Repre-sentative
Medium (1.01 – 2.00 ha)	**-0.1169** t-ratio = -0.76 F value = 0.41	**-0.2246** t-ratio = -1.25 F value = 0.31	**-0.0761** t-ratio = -0.75 F value = 0.03	Repre-sentative
Large (2.01 > ha)	**-0.4807** t-ratio = -0.61 F value = 0.34	**-0.5523** t-ratio = -0.63 F value = 2.64	**-0.6328** t-ratio = -1.02 F value = 2.66	Repre-sentative
All land categories	**0.5309** t-ratio = 3.46*** F value = 2.22	**0.1082** t-ratio = 0.42 F value = 1.59	**0.1199** t-ratio = 1.01 F value = 2.26	Repre-sentative

Note: t-ratio tests the significance of the mean difference in land owned per household. The non-significance proves that the samples of two periods are not different.
The F value tests the homogeneity of variance between the two populations, here stands for same population for two periods. The non-significance proves that the samples are representative of the population.
*** = significant at 1 percent level ($p<0.01$).

Source: Field survey, 1997 and BRAC-VSP Survey, 1990.

Table A4.1 List of regions used for analyzing regional disparity.

Present Administrative Structure of Bangladesh:

Division	5
Regions/ Former districts	20
District (*Zila*)	64
Police Station (*Thana*)	490
Union (rural and urban)	4451
Mouza	59990
Municipalities	117

	Regions	Districts
1.	Chittagong	Chittagong, Cox's Bazaar
2.	Comilla	Comilla, Brahmanbaria, Chandpur
3.	Chittagong Hill Tracts	Chittagong Hill Tracts, Khagrachari, Rangamati, and Bandarban
4.	Noakhali	Noakhali, Feni, and Lakshmipur
5.	Sylhet	Sylhet, Habiganj, Sunamganj, and Moulavibazaar
6.	Dhaka	Dhaka, Gazipur, Narshingdi, Narayanganj, Manikganj, and Munshiganj
7.	Faridpur	Faridpur, Madaripur, Gopalganj, Rajbari, and Shariatpur
8.	Jamalpur	Jamalpur and Sherpur
9.	Mymensingh	Mymensingh, Kishoreganj, and Netrokona
10.	Tangail	Tangail
11.	Barisal	Barisal, Pirojpur, Bhola, and Jhalkati
12.	Patuakhali	Patuakhali and Barguna
13.	Jessore	Jessore, Magura, Jhenaidah, and Narail
14.	Khulna	Khulna, Bagerhat, and Satkhira
15.	Kushtia	Kushtia, Meherpur, and Chuadanga
16.	Bogra	Bogra and Joypurhat
17.	Dinajpur	Dinajpur, Thakurgaon, and Panchagarh
18.	Pabna	Pabna and Sirajganj
19.	Rajshahi	Rajshahi, Natore, Naogaon, and Nawabganj
20.	Rangpur	Rangpur, Gaibandha, Kurigram, Lalmonirhat, and Nilphamari

Source: BBS (Various Issues).

Table A4.2 Mean values and standard deviation of the explained and explanatory indicators of three periods: Period 1 (1973-75), Period 2 (1981-83) and Period 3 (1991-93).

Indicators	Period 1 (1973-75)	Period 2 (1981-83)	Period 3 (1991-93)
Gross output value per ha of gross cropped area (000 tk/ha)	0.95 (0.25)	3.87 (0.74)	7.79 (1.84)
Cropping intensity (%)	144 (15)	154 (20)	179 (28)
Credit distributed per ha of gross cropped area (tk/ha)	3.05 (7.09)	240.5 (319.0)	418.83 (517.91)
Density per ha of gross cropped area (person/ha)	6.34 (1.85)	6.75 (2.34)	8.20 (3.67)
Fertilizer use per ha of gross cropped area (kg/ha)	30.16 (23.75)	73.55 (32.85)	72.05 (19.43)
Yield of modern variety rice per ha (mt/ha)	2.48 (0.29)	2.33 (0.26)	2.30 (0.26)
Literacy rate (%)	22 (5)	24 (5)	31 (6)
Yield of local variety rice per ha (mt/ha)	0.90 (0.12)	1.00 (0.15)	1.25 (0.23)
Pesticide use per ha of gross cropped area (kg/ha)	- -	0.19 (0.11)	0.40 (0.21)
Percent of modern rice and wheat varieties of gross cropped area (%)	11 (7)	23 (14)	39 (17)
Percent of irrigated area of gross cropped area (%)	10 (6)	12 (6)	22 (10)
Annual rainfall (mm)	2138 (944)	1987 (623)	2277 (632)
Road density per km of land area (km/sqkm)	0.03 (0.02)	0.07 (0.02)	0.10 (0.02)
Ratio of unpave road to paved road (unitless)	- -	1.25 (1.39)	1.17 (1.53)
Improved seed distributed per ha of gross cropped area (kg/ha)	0.99 (0.45)	0.88 (0.57)	1.28 (0.76)
Wheat yield per ha (kg/ha)	0.78 (0.20)	1.81 (0.35)	1.64 (0.31)

Note: Figures in parentheses are standard deviations.
Source: BBS (Various Issues), Hamid (1991), Verma (1974), and Khalil (1991).

Table A4.3 Determinants of Regional Variation: A Stepwise Forward Regression Analyses.

Dependent variable	Explanatory indicator			Adj. R^2	Standard error of regression	F-statistic	
	Indicator	**Coefficient**	t-ratio			F-value	df
			Period 1 (1973-75)				
	Intercept	-0.012	-0.046				
GV	PMVAR	1.882	3.478***	0.759	0.1208	29.279***	2, 16
FOOD	LVYLD	0.829	2.585**				
			Period 2 (1981-83)				
	Intercept	0.515	0.946				
GV	PMVAR	3.496	5.838***	0.797	0.3353	25.897***	3, 16
FOOD	LVYLD	1.921	3.794***				
	RAIN	0.003	2.456**				
			Period 3 (1991-93)				
	Intercept	-4.627	-3.469***				
GV	PMVAR	6.762	5.681***	0.920	0.5135	37.661***	6, 13
FOOD	LVYLD	5.042	6.994***				
	RDQLTY	0.360	3.395***				
	PIRRIG	5.849	2.873***				
	ROAD	26.279	3.166***				
	DENS	-0.109	-2.151**				

Note: *** = significant at 0.01 level (p<0.01); ** = significant at 0.05 level (p<0.05).
Source: Computed.

Table A4.4 Correlation between the explained indicator (GVFOOD) and the explanatory indicators selected from the regression analyses.

	GVFOOD	PMVAR	LVYLD	RAIN	PIRRIG	ROAD	RDQLTY	DENS
				Period 1 (1973-75)				
GVFOOD	1.00							
PMVAR	0.83***	1.00						
LVYLD	0.89***	0.69***	1.00					
				Period 2 (1981-83)				
GVFOOD	1.00							
PMVAR	0.77***	1.00						
LVYLD	0.48**	0.09	1.00					
RAIN	0.53**	0.34	0.10	1.00				
				Period 3 (1991-93)				
GVFOOD	1.00							
PMVAR	0.82***	1.00						
LVYLD	0.53**	0.26	1.00					
PIRRIG	0.67***	0.74***	0.04	-	1.00			
ROAD	0.11	0.15	-0.51**	-	0.23	1.00		
RDQLTY	-0.35	-0.59***	-0.27	-	-0.59***	0.09	1.00	
DENS	0.32	0.39*	0.18	-	0.19	0.50**	-0.23	1.00

Note: *** = significant at 1 percent level (p<0.01); ** = significant at 5 percent level (p<0.05).

* = significant at 10 level (p<0.10).
Source: Computed.
Table A4.5 Estimates of Aggregate Crop Output of Bangladesh, 1960/61 – 1991/92.

Variables	Model 1		Model 2		Model 3	
	Coefficient	t-ratio	Coefficient	t-ratio	Coefficient	t-ratio
Constant	7.5651	33.045***	7.8353	32.305***	7.6146	32.703***
lnLAND	0.8270	18.733***	0.7440	16.364***	0.7845	17.391***
lnLABOR	0.0853	2.467**	0.1127	3.229***	0.0993	2.878***
lnANIMAL	0.1321	3.687***	0.1599	4.406***	0.1344	3.744***
lnFERT	0.0370	3.269***	0.0506	4.653***	0.0606	5.812***
HCAP	0.0340	2.031**	-0.0208	-1.150	0.0023	0.891
ROAD	0.7376	5.625***	0.4172	2.844***	0.4707	3.315***
PIRRIG	0.7484	7.995***	-	-	-	-
PMVAR	-	-	0.4689	7.251***	-	-
PIRRIG*PMVAR	-	-	-	-	1.1692	7.542***
Adj. R-squared	0.911		0.909		0.911	
$F_{(7, 456)}$	665.978***		654.402***		664.505***	
D.W. Statistic	2.05		2.06		2.05	

Note: The estimates are corrected for first degree autocorrelated disturbances using Prais-Winsten method. D.W. Statistics is of the transformed residuals.
*** = significant at 1 percent level (p<0.01); ** = significant at 5 percent level (p<0.05).
Source: Computed from data of Deb (1995).

Table A5.1 Land use and cropping intensity by study regions, 1996.

Crops/ Seasons	Estimated area (ha) in present study				Comparison with other study[5]
	Jamalpur region	Jessore region	Comilla region	All region	
Aus Season (early monsoon)					
Local Aus rice	3.45	ng	1.85	5.30 (1.3)	179.45 (15.8)
Modern Aus rice	2.99	7.95	0.69	11.63 (2.9)	41.88 (3.7)
Jute	3.87	11.48	3.50	18.85 (4.7)	45.98 (4.0)
Aman Season (monsoon)					
Local Aman rice	14.84	2.19	12.80	29.83 (7.5)	375.76 (33.0)
Modern Aman rice	74.59	32.58	19.87	127.03 (31.8)	103.60 (9.1)
Boro Season (dry winter)					
Local Boro rice	0.19	0.25	1.08	1.51 (0.4)	17.22 (1.5)
Modern Boro rice	80.24	28.04	32.76	141.05 (35.3)	98.69 (8.7)
Wheat	3.71	6.77	8.08	18.55 (4.6)	37.79 (3.3)
Potato	2.10	1.42	3.08	6.60 (1.7)	na
Pulses[1]	ng	14.67	0.60	15.27 (3.8)	81.92 (7.2)
Oilseeds[2]	1.00	7.24	4.14	12.38 (3.1)	27.08 (2.4)
Spices[3]	2.55	0.30	0.47	3.32 (0.8)	16.02 (1.4)
Vegetables[4]	1.01	4.05	ng	5.06 (1.3)	28.47 (2.5)
Cotton	ng	3.11	ng	3.11 (0.8)	na
Total cropped area (ha)	190.53	120.06	88.92	399.51 (100)	1137.8 (100)[6]
Net sown area (ha)	103.93	67.37	59.99	231.28	652.00
Cropping intensity (%)	183.33	178.21	148.22	172.84	174.51

Note: [1] Pulses include lentil, gram, and chola.
[2] Oilseeds include sesame, mustard, and groundnut.
[3] Spices include onion, garlic, and chilly.
[4] Vegetables include brinjal, cauliflower, cabbage, arum, beans, gourds, radish, and leafy vegetables.
[5] Selected from DIS Survey by BIDS/BRRI, crop year 1987.
[6] The total area include area under sugarcane, fruits and miscellaneous crops.
Figures in parentheses are percentages of total cropped area.
ng means crop not grown.
na means information not available.

Source: Field Survey 1997, and Hossain *et al.* (1990).

Table A5.2 Yield rate of crops by study regions, 1996.

Crops/ Seasons	Yield rates (mt/ha) in present study				F-ratio for regional difference	Comparison with other studies
	Jamalpur region	Jessore region	Comilla region	All region		
Aus Season (early monsoon)						
Local Aus rice	2.15	ng	1.53	1.99	8.13***	1.55[1]
Modern Aus rice	3.27[a]	3.84[a]	3.92[a]	3.61	1.93	3.09[1]
t-ratio for variety diff	-4.87***	-	-8.51***	-7.20***		
Jute	1.63[a]	2.33[b]	1.74[a]	1.99	11.95***	1.77[1]
Aman Season (monsoon)						
Local Aman rice	2.77[a]	1.60[b]	2.19[cb]	2.38	6.30*	2.30[2]
Modern Aman rice	3.53[a]	3.68[bc]	3.26[c]	3.51	2.65*	3.30[2]
t-ratio for variety diff	-3.83***	-3.17***	-5.81***	-8.57***		
Boro Season (dry winter)						
Local Boro rice	3.62[a]	2.94[a]	1.92[b]	2.60	9.16**	2.66[3]
Modern Boro rice	4.89[a]	4.69[a]	4.71[a]	4.79	1.51	5.07[3]
t-ratio for variety diff	-12.08***	-2.16**	-4.52***	-5.35***		
Wheat	2.14[a]	2.27[a]	2.12[a]	2.18	0.60	2.29[1]
Potato	11.56[a]	8.80[a]	16.04[b]	13.93	9.75***	18.50[1]
Pulses	ng	0.72	0.92	0.76	5.59**	0.70[2]
Oilseeds	1.18[a]	1.02[a]	1.29[a]	1.17	1.15	0.89[1]
Spices	3.32[a]	2.85[ab]	1.55[b]	2.75	3.76**	6.40[2]
Vegetables	8.84	7.72	ng	8.00	0.52	10.70[1]
Cotton	ng	1.30	ng	1.30	-	1.31[1]

Note: F-ratio shows the regional difference in yield levels of each crop.
Same letters in superscript represents similarity in yield levels across regions for individual crop based on LSD at 5 percent level of significance ($p<0.05$).
t-ratio shows the yield difference between local and modern varieties.
*** = significant at 1 percent level ($p<0.01$); ** = significant at 5 percent level ($p<0.05$);
* = significant at 10 percent level ($p<0.10$).
[1]Selected from ADS (Agricultural Diversification Study) Survey of IFPRI/BIDS, crop year 1990/91.
[2] Selected from FLFUS (Farm-level Fertilizer Use Survey) of IFDC, crop years, 1990, and 1991/92.
[3] Selected from DIS (Differential Impact Study) of BIDS/BRRI, crop year 1987.
ng means crop not grown; na means not available.

Source: Field Survey, (1997), Mahmud *et al.* (1994), Sanyal (1993), Sidhu & Ahsan (1991), Hossain *et al.* (1990).

Table A5.3 Chemical fertilizer use rates by study regions, 1996.

Crops/ Seasons	Fertilizer use rates (kg/ha) in present study				F-ratio for regional difference	Comparison with other studies
	Jamalpur region	Jessore region	Comilla region	All region		
Aus Season (early monsoon)						
Local Aus rice	79	ng	91	82	0.09	85[1]
Modern Aus rice	182[a]	252[b]	247[ab]	223	2.98*	242[1]
t-ratio for variety diff	-3.61***	-	-2.85***	-5.84***		
Jute	132[a]	178[b]	78[c]	140	9.67***	136[1]
Aman Season (monsoon)						
Local Aman rice	145[a]	62[b]	59[b]	94	9.30***	76[2]
Modern Aman rice	186[a]	195[a]	267[b]	204	25.20***	192[2]
t-ratio for variety diff	-2.78***	-3.41***	-11.92***	-10.14***		
Boro Season (dry winter)						
Local Boro rice	230[a]	239[a]	39[b]	137	7.75**	57[3]
Modern Boro rice	280[a]	286[a]	286[a]	283	0.25	320[3]
t-ratio for variety diff	-0.80	-0.74	-6.64***	-4.86***		
Wheat	218[a]	225[a]	239[a]	230	0.38	272[1]
Potato	286[a]	392[ba]	387[b]	348	5.11***	327[1]
Pulses	ng	26	95	37	10.32***	55[1]
Oilseeds	175[a]	117[a]	122[a]	125	0.73	207[1]
Spices	301[a]	223[a]	230[a]	271	1.16	223[1]
Vegetables	175	286	ng	258	3.92**	189[2]
Cotton	ng	326	ng	326	-	235[1]

Note: F-ratio shows the regional difference in fertilizer use levels of each crop.
Same letters in superscript represents similarity in fertilizer use levels across regions for individual crop based on LSD at 5 percent level of significance (p<0.05).
t-ratio shows the difference in fertilizer use between local and modern varieties.
*** = significant at 1 percent level (p<0.01); ** = significant at 5 percent level (p<0.05);
* = significant at 10 percent level (p<0.10).
[1]Selected from ADS (Agricultural Diversification Study) Survey of IFPRI/BIDS, crop year 1990/91.
[2] Selected from FLFUS (Farm-level Fertilizer Use Survey) of IFDC, crop years, 1990, and 1991/92.
[3] Selected from DIS (Differential Impact Study) of BIDS/BRRI, crop year 1987.
ng means crop not grown; na means not available.

Source: Field Survey, (1997), Mahmud *et al.* (1994), Sanyal (1993), Sidhu & Ahsan (1991), Hossain *et al.* (1990).

Table A5.4 Average cost and profitability of crop production (all regions), 1996.

Crops/season	Weights[1]	Yield (ton/ha)	Price (Tk/ton)	Gross value (Tk/ha)	Variable cost (Tk/ha)	Profits (Tk/ha)
Aus Season (early monsoon)						
Local Aus rice	0.013	1.99	5,225	11,360	7,435	3,925
Modern Aus rice	0.029	3.61	5,637	21,443	9,170	12,273
t-ratio for variety diff		-7.20***	-4.18***	-7.17***	-2.79***	-6.26***
Jute	0.047	1.99	9,395	20,539	9,089	11,450
Aman Season (monsoon)						
Local Aman rice	0.075	2.38	5,605	14,785	7,118	7,667
Modern Aman rice	0.318	3.51	5,603	20,679	9,369	11,310
t-ratio for variety diff		-8.57***	0.02	-7.20***	-6.31***	-4.54***
Boro Season (dry winter)						
Local Boro rice	0.004	2.60	4,500	12,872	9,505	3,367
Modern Boro rice	0.353	4.79	5,665	28,647	14,490	14,157
t-ratio for variety diff		-5.35***	-7.05***	-5.57***	-4.44***	-3.87***
Wheat	0.046	2.18	7,984	18,082	10,292	7,790
Potato	0.017	13.93	3,790	51,708	24,718	26,990
Pulses	0.038	0.76	19,559	14,650	6,138	8,512
Oilseeds	0.031	1.17	13,058	14,535	7,431	7,104
Spices	0.008	2.75	25,202	46,620	17,400	29,220
Vegetables	0.013	8.00	6,120	42,970	13,203	29,767
Cotton	0.008	1.30	23,546	30,139	11,720	18,419

Note: t-ratio shows the difference in fertilizer use between local and modern varieties.
*** = significant at 1 percent level (p<0.01)
[1] Weights as percent of gross cropped area.
Source: Field Survey, 1997.

Table A5.5 Results of factor analysis of infrastructure variables in 21 villages.

Infrastructure variables	Rotated Factor Matrix			**Communality**	Index used as weights*
	Factor 1	Factor 2	Factor 3		
Agril. ext. office	0.30933	0.28602	0.86679	0.92882	0.884
Bank	0.17048	0.80352	0.51592	0.94088	0.855
Bus stand	0.38236	0.82768	-0.27109	0.90475	0.482
Storage	0.06066	0.19819	0.91650	0.88294	0.739
Growth centre	0.02175	0.87258	0.22920	0.81441	0.608
Primary market	0.94578	-0.02893	0.05863	0.89878	0.526
Health centre	-0.04843	0.63429	0.26890	0.47697	0.464
High school	0.89006	0.01708	0.21613	0.83921	0.617
College	0.67948	0.09781	0.62202	0.85817	0.832
Post office	0.87145	0.18673	0.05127	0.79692	0.621
Rice mill	0.66769	0.31968	0.45524	0.75506	0.857
Paved road	0.22369	0.80426	0.26173	0.76537	0.708
Thana HQ	0.49372	0.33998	0.76000	0.93694	0.937
Union office	0.78711	0.27311	0.27958	0.77230	0.725

Note: * These are the weights used in the construction of indexes (the correlation of IC_i with TC).
Source: Computed from Field Survey, 1997.

Table A5.6 Distances of various infrastructural facilities from the villages.

Infrastructure	Jamalpur		Jessore		Comilla		All region		Difference (F-value)
	Mean	CV	Mean	CV	Mean	CV	Mean	CV	
Haat/Bazar	2.4	15	1.2	52	2.2	49	2.0	43	4.571**
Growth centre	2.8	33	1.2	52	4.9	44	3.0	65	11.136***
Storage	12.3	19	21.8	23	4.4	55	12.4	62	45.448***
Rice mill	10.9	28	1.5	59	2.4	67	5.4	92	43.013***
Paved road	2.1	51	1.8	175	3.8	83	2.6	99	1.278
Bus stand	2.3	53	4.1	89	14.6	21	6.9	90	42.889***
Bank	15.8	11	4.6	80	4.8	46	8.9	46	46.641***
Union office	2.4	45	1.3	60	2.0	44	1.9	51	2.336
AE office	14.1	12	21.5	23	4.7	49	13.1	57	46.123***
Highschool	2.2	44	2.1	45	1.5	47	1.9	47	1.362
College	15.6	12	6.2	54	5.1	49	9.4	59	38.272***
Thana HQ	14.1	12	4.7	82	4.8	51	8.3	64	29.719***
Post office	6.7	28	4.1	89	2.1	26	4.4	66	7.428***
Health centre	2.0	44	6.2	54	3.0	40	3.5	73	8.175***

Note: CV = coefficient of variation expressed as $(\sigma / \mu) * 100$.
*** = significant at 0.01 level ($p<0.01$); ** = significant at 0.05 level ($p<0.05$).
Source: Field survey, 1997; Thana Base Map (1994a, 1994b, and 1994c).

Table A5.7 Multiple comparison of infrastructural status among regions.

Infrastructural variable	**Mean difference of distance among regions**			Homogenous regions
	Jamalpur vs. Jesssore	Jamalpur vs. Comilla	Jessore vs. Comilla	
Haat/Bazar	1.13***	0.14	0.99**	Jamalpur, Comilla
Growth centre	1.61**	2.03***	3.64***	None
Storage	9.55***	7.93***	17.48***	None
Rice mill	9.47***	8.58***	0.89	Jessore, Comilla
Paved road	0.36	1.69	2.05	Jessore, Jamalpur, Comilla
Bus stand	1.80	12.28***	10.49***	Jamalpur, Jessore
Bank	11.20***	11.00***	0.20	Jessore, Comilla
Union HQ	1.09**	0.40	0.69	Jessore, Comilla, Jamalpur
Ag. Ext. office	7.38***	9.41***	16.79***	None
Highschool	0.13	0.73	0.60	Comilla, Jessore, Jamalpur
College	9.43***	10.53***	1.10	Jessore, Comilla
Thana HQ	9.41***	9.34***	0.07	Jessore, Comilla
Post office	2.58**	4.52***	1.94	Comilla, Jessore
Health centre	4.19***	1.07	3.12***	Jamalpur, Comilla

Note: *** = significant at 0.01 level ($p<0.01$); ** = significant at 0.05 level ($p<0.05$).
Source: Field survey, 1997.

Table A5.8 Multiple comparison of soil fertility status among regions (n = 15).

Soil variable	**Absolute mean difference among regions**			LSD limits	Homogenous regions
	Jamalpur vs. Jessore	Jamalpur vs. Comilla	Jessore vs. Comilla		
pH	1.80***	1.20***	0.60	0.63	Com, Jes
OM (%)	4.97***	0.57	5.04***	2.36	Com, Jam
N (µg/g)	3.06	9.52	6.47	10.33	Jam, Jes, Com
P (µg/g)	4.35	6.31	1.95	13.65	Jam, Jes, Com
K (µg/g)	20.20	11.95	32.15***	17.83	Jam, Com
S (µg/g)	2.42	2.27	4.69***	3.21	Com, Jam, Jes
Zn (µg/g)	2.54	0.97	3.51	4.55	Jam, Jes, Com
Sand (%)	11.21***	16.49***	5.28	6.45	Com, Jes
Silt (%)	5.52	17.22***	22.74***	2.57	Jes, Jam
Clay (%)	16.73***	0.71	17.44**	13.05	Com, Jam
CEC (meq/100g)	15.32***	4.94	10.38**	8.26	Jam, Com
EC (µS/cm)	101.20***	37.50	63.70**	44.06	Jam, Com

Note: LSD = least significant difference beyond which the difference becomes significant.
*** = significant at 0.01 level ($p<0.01$); ** = significant at 0.05 level ($p<0.05$).
Source: Field survey, 1997.

Table A5.9 Probit reduced-form seed selection equation, 1996.

Exogenous variables	Estimated coefficients	t-ratio	Exogenous variables	Estimated coefficients	t-ratio
Intercept	-17.7050	-1.422	$\ln P_M' \ln Z_L$	0.0267	0.072
$\text{Ln}P_W'$	-8.5263	-1.293	$\ln P_M' \ln Z_A$	-0.1716	-0.911
$\text{Ln}P_F'$	-4.4114	-0.820	$\ln P_M' \ln Z_I$	0.1140	0.121
$\text{Ln}P_M'$	3.5154	0.608	$\ln P_M' \ln Z_S$	3.3306	0.879
$\frac{1}{2}(\ln P_W')^2$	6.2869	1.759*	$\ln P_M' \ln Z_E$	-0.2586	-0.793
$\frac{1}{2}(\ln P_F')^2$	6.8804	2.962***	$\frac{1}{2}(\ln Z_L)^2$	-0.1408	-1.123
$\frac{1}{2}(\ln P_M')^2$	-1.2978	-0.672	$\frac{1}{2}(\ln Z_A)^2$	-0.0067	-0.170
$\ln P_W' \ln P_F'$	-2.5905	-1.318	$\frac{1}{2}(\ln Z_I)^2$	-1.1513	-1.170
$\ln P_W' \ln P_M'$	-0.4248	-0.212	$\frac{1}{2}(\ln Z_S)^2$	44.0430	2.662***
$\ln P_F' \ln P_M'$	1.4068	0.895	$\frac{1}{2}(\ln Z_E)^2$	-0.6606	-2.521***
$\ln Z_L$	-4.0914	-3.204***	$\ln Z_L \ln Z_A$	0.0565	1.209
$\ln Z_A$	0.6740	1.128	$\ln Z_L \ln Z_I$	0.4047	2.008**
$\ln Z_I$	7.5144	1.495	$\ln Z_L \ln Z_S$	-0.7964	-1.017
$\ln Z_S$	13.5530	0.856	$\ln Z_L \ln Z_E$	0.0587	0.789
$\ln Z_E$	1.0407	1.020	$\ln Z_A \ln Z_I$	-0.1794	-1.758*
$\ln P_W' \ln Z_L$	1.1127	2.316**	$\ln Z_A \ln Z_S$	0.3047	0.746
$\ln P_W' \ln Z_A$	0.1529	0.621	$\ln Z_A \ln Z_E$	0.0182	0.455
$\ln P_W' \ln Z_I$	0.6633	0.541	$\ln Z_I \ln Z_S$	1.3684	-2.754***
$\ln P_W' \ln Z_S$	-11.4820	-2.362**	$\ln Z_I \ln Z_E$	-0.0034	0.434
$\ln P_W' \ln Z_E$	0.3981	1.036	$\ln Z_S \ln Z_E$	-0.1750	-2.449***
$\ln P_F' \ln Z_L$	0.4712	1.440			
$\ln P_F' \ln Z_A$	-0.3063	-1.794*			
$\ln P_F' \ln Z_I$	0.7510	0.897			
$\ln P_F' \ln Z_S$	12.8230	3.232***			
$\ln P_F' \ln Z_E$	-0.1446	-0.517			
Accuracy of prediction			= 88.85 percent		
McFadden $R^2(1-\log L_{max}/\log L_0)$			= 0.233		
Chi-squared ($\chi^2_{44 \text{ degrees of freedom}}$)			= 171.088***		

Note: W = labor price, F = fertilizer price, M = animal power price, L = land area, A = farm capital, I = infrastructure, S = soil quality, E = education of farmer.
*** = significant at 1 percent level ($p<0.01$); ** = significant at 5 percent level ($p<0.05$);
* = significant at 10 percent level ($p<0.10$).
Source: Computed.

Table A5.10 Joint estimation of the normalized profit function and factor share equations for variable input demands for producing local and modern foodgrain varieties, adjusted for selectivity bias, 1996.

Exogenous variables	Para-meters	Modern foodgrain varieties		Local foodgrain varieties	
		Estimated coefficients	t-ratio	Estimated coefficients	t-ratio
Profit function					
Intercept	α_0	-6.3292	-2.678***	-7.3747	-1.645*
$\ln P_W$'	α_W	1.9807	5.307***	2.8191	3.022***
$\ln P_F$'	α_F	0.2791	1.794*	0.9273	2.716***
$\ln P_M$'	α_M	0.5181	3.025***	1.9758	3.564***
½($\ln P_W$')^2	γ_{WW}	-0.7930	-10.236***	-0.8095	-2.832***
½($\ln P_F$')^2	γ_{FF}	-0.1653	-6.488***	-0.2083	-1.936**
½($\ln P_M$')^2	γ_{MM}	-0.1103	-4.889***	-0.3836	-3.501***
$\ln P_W$' $\ln P_F$'	γ_{WF}	-0.1834	-5.677***	-0.0775	-0.697
$\ln P_W$' $\ln P_M$'	γ_{WM}	-0.2852	-8.210***	-0.6456	-4.675***
$\ln P_F$' $\ln P_M$'	γ_{FM}	-0.0408	-2.162**	-0.1422	-1.818*
$\ln Z_L$	β_L	0.0378	0.132	-0.4385	-0.997
$\ln Z_A$	β_A	0.1137	0.829	0.9776	4.531***
$\ln Z_I$	β_I	5.6247	5.905***	1.8110	0.751
$\ln Z_S$	β_S	3.1164	1.181	10.047	1.849*
$\ln Z_E$	β_E	0.1252	0.553	-0.3058	-0.888
$\ln P_W$' $\ln Z_L$	δ_{WL}	0.1387	4.062***	0.3059	3.738***
$\ln P_W$' $\ln Z_A$	δ_{WA}	0.0506	3.299***	-0.0087	-0.193
$\ln P_W$' $\ln Z_I$	δ_{WI}	-0.2047	-3.008***	0.0525	0.285
$\ln P_W$' $\ln Z_S$	δ_{WS}	0.8259	3.098***	0.2850	0.342
$\ln P_W$' $\ln Z_E$	δ_{WE}	-0.0568	-2.068**	-0.1178	-1.841*
$\ln P_F$' $\ln Z_L$	δ_{FL}	-0.0025	-0.178	0.0263	0.965
$\ln P_F$' $\ln Z_A$	δ_{FA}	0.0161	2.531***	0.0158	1.039
$\ln P_F$' $\ln Z_I$	δ_{FI}	-0.0540	-1.936**	-0.1487	-2.269**
$\ln P_F$' $\ln Z_S$	δ_{FS}	0.1699	1.568	-0.2097	-0.781
$\ln P_F$' $\ln Z_E$	δ_{FE}	-0.0238	-2.092**	-0.0241	-1.066
$\ln P_M$' $\ln Z_L$	δ_{ML}	0.0210	1.347	0.0116	0.250
$\ln P_M$' $\ln Z_A$	δ_{MA}	0.0251	3.555***	-0.0351	-1.336
$\ln P_M$' $\ln Z_I$	δ_{MI}	-0.0493	-1.578	-0.0648	-0.607
$\ln P_M$' $\ln Z_S$	δ_{MS}	0.2504	2.058**	0.8684	1.828*
$\ln P_M$' $\ln Z_E$	δ_{ME}	-0.0356	-2.823***	-0.0406	-1.093
½($\ln Z_L$)^2	ψ_{LL}	-0.1143	-3.293***	0.0450	0.908
½($\ln Z_A$)^2	ψ_{AA}	0.0077	0.759	-0.0851	-4.754***
½($\ln Z_I$)^2	ψ_{II}	-1.0934	-5.480***	0.4010	0.754
½($\ln Z_S$)^2	ψ_{SS}	4.6332	1.327	-4.6120	-0.572
½($\ln Z_E$)^2	ψ_{EE}	-0.0325	-0.501	-0.2431	-1.867*

(continued)

Exogenous variables	Para-meters	Modern foodgrain varieties		Local foodgrain varieties	
		Estimated coefficients	t-ratio	Estimated coefficients	t-ratio
<u>Profit function</u>					
$\ln Z_L \ln Z_A$	ω_{LA}	0.0021	0.185	0.0057	0.256
$\ln Z_L \ln Z_I$	ω_{LI}	0.0928	1.862*	0.4382	4.047***
$\ln Z_L \ln Z_S$	ω_{LS}	0.3202	1.808*	-1.2915	-3.080***
$\ln Z_L \ln Z_E$	ω_{LE}	0.0429	2.227**	0.0095	0.283
$\ln Z_A \ln Z_I$	ω_{AI}	-0.0582	-2.764***	-0.0845	-1.318
$\ln Z_A \ln Z_S$	ω_{AS}	-0.2008	-2.340**	-0.0317	-0.119
$\ln Z_A \ln Z_E$	ω_{AE}	-0.1211	-1.288	0.0664	3.451***
$\ln Z_I \ln Z_S$	ω_{IS}	-1.4070	-2.707***	-3.2802	-2.892***
$\ln Z_I \ln Z_E$	ω_{IE}	0.0618	1.524	0.1303	1.707*
$\ln Z_S \ln Z_E$	ω_{SE}	0.0477	0.315	-0.4397	-1.313
Selectivity variable	σ_{1u}, σ_{2u}	0.4873	3.858***	0.0105	0.075
<u>Labor share equation</u>					
Intercept	α_W	1.9807	5.307***	2.8191	3.022***
$\ln P_W$'	γ_{WW}	-0.7930	-10.236***	-0.8095	-2.832***
$\ln P_F$'	γ_{WF}	-0.1834	-5.677***	-0.0775	-0.697
$\ln P_M$'	γ_{WM}	-0.2852	-8.210***	-0.6546	-4.675***
$\ln Z_L$	δ_{WL}	0.1387	4.062***	0.3059	3.738***
$\ln Z_A$	δ_{WA}	0.0506	3.299***	-0.0087	-0.193
$\ln Z_I$	δ_{WI}	-0.2047	-3.008***	0.0525	0.285
$\ln Z_S$	δ_{WS}	0.8259	3.098***	0.2850	0.342
$\ln Z_E$	δ_{WE}	-0.0568	-2.068**	-0.1178	-1.841*
<u>Fertilizer share equation</u>					
Intercept	α_F	0.2791	1.794*	0.9273	2.716***
$\ln P_W$'	γ_{FW}	-0.1834	-5.677***	-0.0775	-0.697
$\ln P_F$'	γ_{FF}	-0.1653	-6.488***	-0.2083	-1.936**
$\ln P_M$'	γ_{FM}	-0.0408	-2.162**	-0.1422	-1.818*
$\ln Z_L$	δ_{FL}	-0.0025	-0.178	0.0262	0.965
$\ln Z_A$	δ_{FA}	0.0161	2.531***	0.0158	1.039
$\ln Z_I$	δ_{FI}	-0.0540	-1.936**	-0.1487	-2.269**
$\ln Z_S$	δ_{FS}	0.1699	1.568	-0.2097	-0.781
$\ln Z_E$	δ_{FE}	-0.0238	-2.092**	-0.0241	-1.066
<u>Animal power share equation</u>					
Intercept	α_M	0.5181	3.025***	1.9758	3.564***
$\ln P_W$'	γ_{MW}	-0.2852	-8.210***	-0.6456	-4.675***
$\ln P_F$'	γ_{MF}	-0.0408	-2.162**	-0.1422	-1.818*
$\ln P_M$'	γ_{MM}	-0.1103	-4.889***	-0.3836	-3.501***
$\ln Z_L$	δ_{ML}	0.0210	1.347	0.0116	0.250
$\ln Z_A$	δ_{MA}	0.0251	3.555***	-0.0351	-1.336

(continued)

Exogenous variables	Para-meters	Modern foodgrain varieties		Local foodgrain varieties	
		Estimated coefficients	t-ratio	Estimated coefficients	t-ratio
lnZ_I	δ_{MI}	-0.0493	-1.578	-0.0648	-0.607
lnZ_S	δ_{MS}	0.2504	2.058**	0.8684	1.828*
lnZ_E	δ_{ME}	-0.0356	-2.823***	-0.0406	-1.093
Adjusted R-squared		= 0.638		0.426	
Wald test: $\chi^2_{(27\ \text{degrees of freedom})}$		= 161.559***		79.451***	
Number of observations (n)		= 932		117	
Selectivity variable		$= -f(\phi_i)/F(\phi_i)$		$f(\phi_i)/[1-F(\phi_i)]$	

Note: W = labor price, F = fertilizer price, M = animal power price, L = land area, A = farm capital, I = infrastructure, S = soil quality, E = education of farmer.
*** = significant at 1 percent level (p<0.01); ** = significant at 5 percent level (p<0.05);
* = significant at 10 percent level (p<0.10).
Source: Computed.

Table A5.11 Input demand and output supply elasticities of foodgrain crops, 1996.

	Output price	Labor price	Fertilizer price	Animal price	Land	Farm capital	Infra-structure	Soil quality	Educa-tion
Local rice varieties (all seasons)									
Output supply	0.8388	-0.3014	-0.0169	-0.1269	0.6611	0.8311	1.5243	14.8540	-0.8919
Labor demand	2.1157	-1.1494	-0.0633	0.0970	0.4763	0.8295	1.4106	14.2107	-0.8394
Fertilizer demand	0.6821	-0.4341	-0.3181	0.4339	0.6052	0.7099	2.5073	15.9724	-0.7908
Animal demand	1.6044	0.1683	0.1098	-0.8825	0.7686	0.8829	1.5793	12.9609	-0.8841
Modern rice and wheat varieties (all seasons)									
Output supply	0.4745	-0.0743	-0.0551	-0.1129	0.5734	0.4028	4.6760	7.0859	-0.2363
Labor demand	0.2510	-0.4282	0.0498	0.1274	0.4391	0.3668	4.8509	6.3821	-0.2018
Fertilizer demand	0.5196	0.1389	-0.5222	-0.1389	0.6634	0.3831	4.7678	6.9235	-0.1871
Animal demand	0.7944	0.2654	-0.1018	-0.9581	0.5852	0.3643	4.6936	6.8509	-0.1750
Total elasticity of demand and supply of foodgrain without variety switching adjustments									
Output supply	0.4977	-0.0797	-0.0569	-0.1177	0.5978	0.4238	4.8342	7.4580	-0.2529
Labor demand	0.2819	-0.4475	0.0493	0.1298	0.4494	0.3812	4.9122	6.6305	-.02149
Fertilizer demand	0.5594	0.1465	-0.5603	-0.1465	0.7129	0.4135	5.1144	7.4889	-0.2042
Animal demand	0.8174	0.2676	-0.1002	-0.9700	0.5960	0.3770	4.7113	7.0361	-0.1880

Note: Figures in parentheses represents percent of improvement due to variety switching adjustments.
Source: Computed.

Table A5.12 Estimation of the normalized profit function and factor share equations for variable input for non-cereal crops, 1996.

Exogenous variables	Para-meter	Estimated coefficients	t-ratio	Exogenous variables	Para-meters	Estimated coefficients	t-ratio
Profit function				$lnZ_L\ lnZ_S$	ω_{LS}	0.0832	0.206
Intercept	α_0	6.1547	1.874*	$lnZ_L\ lnZ_E$	ω_{LE}	0.0603	1.495
lnP_W'	α_W	1.0965	3.176***	$lnZ_A\ lnZ_I$	ω_{AI}	0.0286	0.653
lnP_F'	α_F	0.1175	0.887	$lnZ_A\ lnZ_S$	ω_{AS}	-0.2931	-1.508
lnP_M'	α_M	-0.1355	-0.687	$lnZ_A\ lnZ_E$	ω_{AE}	-0.0189	-0.857
$½(lnP_W')^2$	γ_{WW}	-0.1715	-1.761*	$lnZ_I\ lnZ_S$	ω_{IS}	-1.0156	-1.276
$½(lnP_F')^2$	γ_{FF}	-0.0853	-2.208**	$lnZ_I\ lnZ_E$	ω_{IE}	0.0743	0.960
$½(lnP_M')^2$	γ_{MM}	-0.0709	-1.265	$lnZ_S\ lnZ_E$	ω_{SE}	-0.3161	-1.026
$lnP_W'\ lnP_F'$	γ_{WF}	0.1889	4.007***	Labor share equation			
$lnP_W'\ lnP_M'$	γ_{WM}	0.1742	2.745***	Intercept	α_W	1.0965	3.176***
$lnP_F'\ lnP_M'$	γ_{FM}	-0.0838	-2.415**	lnP_W'	γ_{WW}	-0.1715	-1.761*
lnZ_L	β_L	0.4858	1.208	lnP_F'	γ_{WF}	0.1889	4.007***
lnZ_A	β_A	-0.1638	-0.784	lnP_M'	γ_{WM}	0.1742	2.745***
lnZ_I	β_I	-0.2778	-0.170	lnZ_L	δ_{WL}	-0.0030	-0.072
lnZ_S	β_S	0.0364	0.007	lnZ_A	δ_{WA}	0.0050	0.242
lnZ_E	β_E	0.3087	0.862	lnZ_I	δ_{WI}	-0.2052	-2.493**
$lnP_W'\ lnZ_L$	δ_{WL}	-0.0030	-0.072	lnZ_S	δ_{WS}	0.3276	0.997
$lnP_W'\ lnZ_A$	δ_{WA}	0.0050	0.242	lnZ_E	δ_{WE}	0.0120	0.339
$lnP_W'\ lnZ_I$	δ_{WI}	-0.2052	-2.493***	Fertilizer share equation			
$lnP_W'\ lnZ_S$	δ_{WS}	0.3276	0.997	Intercept	α_F	0.1175	0.887
$lnP_W'\ lnZ_E$	δ_{WE}	0.0120	0.339	lnP_W'	γ_{FW}	0.1889	4.007***
$lnP_F'\ lnZ_L$	δ_{FL}	-0.0331	-2.356**	lnP_F'	γ_{FF}	-0.0853	-2.208**
$lnP_F'\ lnZ_A$	δ_{FA}	0.0090	1.269	lnP_M'	γ_{FM}	-0.0838	-2.415**
$lnP_F'\ lnZ_I$	δ_{FI}	-0.0821	-2.791***	lnZ_L	δ_{FL}	-0.0331	-2.356**
$lnP_F'\ lnZ_S$	δ_{FS}	0.0440	0.386	lnZ_A	δ_{FA}	0.0090	1.269
$lnP_F'\ lnZ_E$	δ_{FE}	-0.0174	-1.424	lnZ_I	δ_{FI}	-0.0821	-2.791***
$lnP_M'\ lnZ_L$	δ_{ML}	-0.0490	-2.393**	lnZ_S	δ_{FS}	0.0440	0.386
$lnP_M'\ lnZ_A$	δ_{MA}	0.0158	1.520	lnZ_E	δ_{FE}	-0.0174	-1.424
$lnP_M'\ lnZ_I$	δ_{MI}	-0.0782	-1.813*	Animal power share equation			
$lnP_M'\ lnZ_S$	δ_{MS}	-0.1472	-0.889	Intercept	α_M	-0.1355	-0.687
$lnP_M'\ lnZ_E$	δ_{ME}	0.0011	0.063	lnP_W'	γ_{MW}	0.1742	2.745***
$½(lnZ_L)^2$	ψ_{LL}	0.0907	1.542	lnP_F'	γ_{MF}	-0.0838	-2.415**
$½(lnZ_A)^2$	ψ_{AA}	0.0331	1.604	lnP_M'	γ_{MM}	-0.0709	-1.265
$½(lnZ_I)^2$	ψ_{II}	0.3582	0.790	lnZ_L	δ_{ML}	-0.0490	-2.393**
$½(lnZ_S)^2$	ψ_{SS}	10.4240	0.956	lnZ_A	δ_{MA}	0.0158	1.520
$½(lnZ_E)^2$	ψ_{EE}	-0.1054	-0.926	lnZ_I	δ_{MI}	-0.0782	-1.813*
$lnZ_L\ lnZ_A$	ω_{LA}	0.0007	0.028	lnZ_S	δ_{MS}	-0.1472	-0.889
$lnZ_L\ lnZ_I$	ω_{LI}	0.1431	1.470	lnZ_E	δ_{ME}	0.0011	0.063

(continued)

Exogenous variables	Para-meter	Estimated coefficients	t-ratio	Exogenous variables	Para-meters	Estimated coefficients	t-ratio
Adjusted R-squared				= 0.378			
Wald test: $\chi^2_{(27\text{ degrees of freedom})}$				= 211.204***			
Number of observations (n)				= 399			

Note: W = labor price, F = fertilizer price, M = animal power price, L = land area, A = farm capital, I = infrastructure, S = soil quality, E = education of farmer.
*** = significant at 1 percent level ($p<0.01$); ** = significant at 5 percent level ($p<0.05$);
* = significant at 10 percent level ($p<0.10$).

Source: Computed.

Table A6.1 Years of growing modern varieties of rice and wheat in the study regions, 1996.

Period of growing modern varieties	Number and percent of farmers responding in the affirmative			
	Jamalpur region	Jessore region	Comilla region	All region
Modern rice				
Within five years	19 (10.9)	23 (21.9)	14 (11.1)	56 (13.8)
Between five to ten years	59 (33.7)	32 (30.5)	40 (31.7)	131 (32.3)
More than ten years	97 (55.4)	50 (47.6)	72 (57.2)	219 (53.9)
Modern wheat				
Within five years	6 (3.4)	6 (5.7)	4 (3.2)	16 (3.9)
Between five to ten years	9 (5.1)	11 (10.5)	9 (7.1)	29 (7.1)
More than ten years	8 (4.6)	11 (10.5)	26 (20.6)	45 (11.1)
Total households	175 (100.0)	105 (100.0)	126 (100.0)	406 (100.0)

Note: Figures in parentheses are percentage of total households.
Source: Field Survey, 1997.

Table A6.2 Trend in productivity of modern varieties of rice and wheat, 1996.

Productivity level	Number and percent of farmers responding in the affirmative			
	Jamalpur region	Jessore region	Comilla region	All region
Increasing	104 (59.4)	64 (61.0)	15 (11.9)	183 (45.1)
Unchanged	57 (32.6)	31 (29.5)	72 (57.1)	160 (39.4)
Decreasing	14 (8.0)	10 (9.5)	39 (31.0)	63 (15.5)
Total households	175 (100.0)	105 (100.0)	126 (100.0)	406 (100.0)

Note: Figures in parentheses are percentages of total households.
Source: Field Survey, 1997.

Table A6.3. Distance of nearest agricultural extension office by study regions, 1996.

Distance of agricultural extension office	Number and percent of households (%)			
	Jamalpur region	Jessore region	Comilla region	All region
Less than one km	**23 (13.1)**	**25 (23.8)**	**9 (7.1)**	**57 (14.0)**
Between one to three km	8 (4.6)	28 (26.7)	97 (77.0)	133 (32.8)
Between three to five km	6 (3.4)	8 (7.6)	20 (15.9)	34 (8.4)
More than five km	138 (78.9)	44 (41.9)	-	182 (44.8)
Total households	175 (100.0)	105 (100.0)	126 (100.0)	406 (100.0)

Note: Figures in parentheses are percentages of total households.
Source: Field Survey, 1997.

Table A7.1 Labor force participation by study region, 1996.

Landownership categories / region	Average family member	Average working members	Participation rate in economic activity	Male worker as proportion of family size	Female worker as proportion of family size
	(persons)	(persons)	(percent)	(percent)	(percent)
Jamalpur region	5.27	1.88	38.49	25.81	12.68
Landless	4.60	1.56	36.44	24.54	11.90
Marginal	5.00	1.94	40.63	27.15	13.48
Small	4.78	1.74	40.76	27.73	13.03
Medium	6.86	2.24	34.99	24.08	10.90
Large	7.33	2.75	42.02	24.97	17.05
Jessore region	6.24	2.47	40.78	29.44	11.34
Landless	5.63	2.17	38.10	28.67	9.43
Marginal	4.86	1.86	42.25	33.07	9.18
Small	6.00	2.00	37.24	26.69	10.56
Medium	7.25	2.94	43.05	29.25	13.80
Large	8.87	4.07	46.44	29.09	17.35
Comilla region	6.90	1.88	29.31	27.88	1.43
Landless	6.51	1.60	27.05	24.59	2.46
Marginal	6.13	1.75	32.00	29.91	2.08
Small	7.73	2.14	28.78	28.78	1.00
Medium	7.64	2.36	31.51	30.96	0.50
Large	na	na	na	na	na
All region	6.02	2.03	36.23	27.39	8.84
Landless	5.49	1.74	33.87	25.67	8.20
Marginal	5.37	1.86	37.92	29.61	8.32
Small	6.08	1.94	35.56	27.96	7.59
Medium	7.15	2.46	36.35	27.12	9.23
Large	8.19	3.48	41.48	27.26	17.21

Note: na means not applicable.
Source: Field Survey, 1997.

Table A7.2 Women labor input by agricultural operations, crop year 1989 (all regions).

Crops/Seasons	Agricultural operations (% of total women's labor input)							
	Land preparation	Sowing/ transp Lanting	Weed-ing	Irriga-tion	Fertili-zing	Harvest-ing	Thresh-ing	All opera-tions
Aus season (early monsoon)								
Local Aus rice	-	-	5.6	-	-	5.6	88.8	100
Modern Aus rice	-	-	-	-	5.0	5.0	90.0	100
Jute	7.2	-	7.2	-	-	7.1	78.5	100
Aman Season (monsoon)								
Local Aman rice	-	-	-	-	-	5.6	94.4	100
Modern Aman rice	-	-	-	-	-	5.9	94.1	100
Boro Season (dry winter)								
Local Boro rice	-	4.4	-	4.4	-	4.3	86.9	100
Modern Boro rice	-	4.0	4.0	4.0	-	4.0	84.0	100
Local wheat	-	-	-	3.8	-	7.7	88.5	100
Modern wheat	-	-	-	-	-	5.0	95.0	100
Potato	7.0	7.0	2.3	23.3	-	34.9	25.5	100
Pulses	-	-	-	-	-	10.0	90.0	100
Oilseeds	-	-	-	-	-	17.4	82.6	100
Spices	8.3	8.3	6.7	3.3	-	26.7	46.7	100
Vegetables	9.8	7.2	2.4	39.1	2.4	34.1	4.9	100
Cotton	7.6	-	-	-	-	70.9	21.5	100

Note: Figures in parentheses are percentages
Source: BRAC-VSP Survey, 1990.

Table A7.3 Determinants of labor use in crop production, 1996.

Variables	Present study (Crop year 1996)			Comparison (BIDS, Crop year 1982)	
	Demand for hired labor		Demand for total labor	Hired labor	Total labor
	OLS estimate	Tobit estimate	OLS estimate	Tobit Estimate	OLS Estimate
Intercept	162.780 (7.537)***	170.900 (7.453)***	155.420 (6.941)***	56.2 (2.16)**	214.7 (8.70)***
AMLND	35.253 (8.409)***	35.981 (8.153)***	57.668 (13.267)***	9.4 (36.2)***	11.1 (10.88)***
MVAR	29.231 (5.415)***	29.694 (5.226)***	16.000 (2.859)***	29.5 (17.40)***	46.9 (17.68)***
TNC	-15.560 (-2.206)**	-14.502 (-1.790)*	29.185 (3.666)***	-2.9 (-1.21)	14.6 (4.19)***
WAGE	-1.007 (-4.037)***	-1.065 (-4.035)***	-1.502 (-5.809)***	-2.81 (-2.62)***	-9.20 (-9.63)***
INFRA	-0.197 (-1.594)	-0.238 (-1.818)*	0.267 (2.088)**	-0.96 (-0.66)	-1.56 (1.22)
SOIL	-54.030 (-5.852)***	-57.608 (-5.860)***	-41.744 (-4.361)***	na	na
SUBP	-2.646 (-2.313)**	-3.027 (-2.481)***	-2.794 (-2.356)**	na	na
WORK	-5.780 (-2.553)***	-6.083 (-2.541)***	-0.248 (-0.106)	-3.10 (0.84)	17.78 (4.08)***
WORKW	1.218 (0.357)	1.575 (0.436)	-3.717 (-1.050)	-8.14 (0.60)	-24.77 (-2.26)***
EDUCH	0.942 (2.173)**	1.096 (2.388)***	0.541 (1.204)	5.37 (4.64)***	3.30 (2.97)***
Adjusted R-squared	0.73	-	0.80	na	0.65
F-value (10, 395)	111.43***	-	163.36***	na	107.4***
Log likelihood	-	-1886.42	-	na	-

Note: *** = significant at 1 percent level ($p<0.01$); ** = significant at 5 percent level ($p<0.05$);
* = significant at 10 percent level ($p<0.10$).
na means not available.
Comparison data is selected from Ahmed and Hossain (1990).
Source: Computed.

Table A7.4 Determinants of labor wage, 1996.

Variables	Rice crops		Foodgrain crops		All crops	
	Coefficient	t-ratio	Coefficient	t-ratio	Coefficient	t-ratio
Constant	36.2970	9.366***	25.1470	7.498***	18.8220	7.584***
LABOR	-0.0463	-4.890***	-0.0295	-3.462***	-0.0226	-2.932***
OWNLND	0.9780	1.341	0.1532	0.796	0.6132	1.960**
MVAR	9.7702	4.764***	8.7489	4.560***	6.4645	4.126***
INFRA	0.0621	2.190**	0.0862	3.373***	0.0832	4.430***
SOIL	3.7374	1.717*	9.2930	4.866***	13.1250	9.273***
Adj. R^2	0.094		0.109		0.137	
F-ratio	9.186***		13.095***		28.024***	
Degrees of freedom	5, 391		5, 491		5, 843	

Note: *** = significant at 1 percent level (p<0.01); ** = significant at 5 percent level (p<0.05);
* = significant at 10 percent level (p<0.10).
na means not applicable.
Source: Computed.

Table A7.5 Buying place of fertilizers by study regions, 1996.

Buying place of fertilizers	Number and percent of households			
	Jamalpur region	Jessore region	Comilla region	All region
Farmers buying fertilizers at				
Primary market	121 (69.1)	79 (75.2)	22 (17.5)	222 (54.7)
Secondary market	49 (28.0)	26 (24.8)	104 (82.5)	179 (44.1)
City market	5 (2.9)	-	-	5 (1.2)
Total households	175 (100.0)	105 (100.0)	126 (100.0)	406 (100.0)

Note: Figures in parentheses are percentages of total households.
Source: Field Survey, 1997.

Table A7.6 Distance of the buying place of fertilizers by study regions, 1996.

Distance of buying place of fertilizers	Number and percent of farmers			
	Jamalpur region	Jessore region	Comilla region	All region
Less than one km	61 (34.9)	54 (51.4)	50 (39.7)	165 (40.6)
Between one to three kms	107 (61.1)	45 (42.9)	76 (60.3)	228 (56.2)
More than three kms	7 (4.0)	6 (5.7)	-	13 (3.2)
Total households	175 (100.0)	105 (100.0)	126 (100.0)	406 (100.0)

Note: Figures in parentheses are percentage of total households.

Source: Field Survey, 1997.

Table A7.7 Problems with buying fertilizers by study regions, 1996.

Problems with buying fertilizers	Number and percent of households			
	Jamalpur region	Jessore region	Comilla region	All region
Farmers citing problems	**100 (57.1)**	**12 (11.4)**	**45 (35.7)**	**157 (38.7)**
High price of fertilizers	52 (29.7)	8 (7.6)	18 (14.3)	78 (19.3)
Shortage in supply	28 (16.0)	2 (1.9)	16 (12.7)	46 (11.3)
Lack of money to buy fertilizers	2 (1.1)	-	9 (7.1)	11 (2.7)
Cheating in weight	9 (5.1)	-	-	9 (2.2)
Adultery	5 (2.9)	2 (1.9)	-	7 (1.7)
Poor communication facilities	4 (2.3)	-	2 (1.6)	6 (1.5)
Farmers citing no problems	75 (42.9)	93 (88.6)	81 (64.3)	249 (61.3)
Total households	175 (100.0)	105 (100.0)	126 (100.0)	406 (100.0)

Note: Figures in parentheses are percentages of total households.
Source: Field Survey, 1997.

Table A7.8 Determinants of fertilizer prices, 1996.

Variables	Rice crops		Foodgrain crops		All crops	
	Coefficient	t-ratio	Coefficient	t-ratio	Coefficient	t-ratio
Constant	5.1003	8.425***	5.9360	11.368***	6.3209	16.679
FERT	-0.0006	-1.083	-0.0004	-0.792	-0.0002	-0.537
OWNLND	0.0915	0.786	0.0306	0.327	0.0022	0.045
MVAR	0.0149	0.041	0.1193	0.358	na	na
INFRA	-0.0134	-2.974***	-0.0172	-4.289***	-0.0229	-7.918***
SOIL	1.3412	3.955***	0.9004	3.045***	0.8053	3.726***
Adj. R^2	0.071		0.060		0.094	
F-ratio	7.082***		7.331***		18.556***	
Degrees of freedom	5, 391		5, 491		5, 843	

Note: *** = significant at 1 percent level (p<0.01). na means not applicable.
Source: Computed.

Table A7.9 Buying place of pesticides by study regions, 1996.

Buying place of pesticides	Number and percent of households			
	Jamalpur region	Jessore region	Comilla region	All region
Primary market	-	-	2 (1.6)	2 (0.5)
Secondary market	152 (86.8)	105 (100.0)	124 (98.4)	381 (93.8)

City market	23 (13.1)	-	-	23 (5.7)
Total households	175 (100.0)	105 (100.0)	126 (100.0)	406 (100.0)

Note: Figures in parentheses are percentages of total households.
Source: Field Survey, 1997.

Table A7.10 Distance of the buying place of pesticides by study regions, 1996.

Distance of buying place of pesticides	Number and percent of farmers (%)			
	Jamalpur region	Jessore region	Comilla region	All region
Less than one km	66 (37.7)	32 (30.5)	70 (55.6)	168 (41.4)
Between one to three kms	81 (46.3)	69 (65.7)	56 (44.4)	206 (50.7)
More than three kms	28 (16.0)	4 (3.8)	-	32 (7.9)
Total households	175 (100.0)	105 (100.0)	126 (100.0)	406 (100.0)

Note: Figures in parentheses are percentage of total households.
Source: Field Survey, 1997.

Table A7.11 Sufficiency of pesticide use by study regions.

Sufficiency of pesticide use	Number and percent of households			
	Jamalpur region	Jessore region	Comilla region	All region
Farmers considering that they use enough	115 (65.7)	76 (72.4)	119 (94.4)	310 (76.4)
Farmers seeking to use more	**60 (34.3)**	**29 (27.6)**	**7 (5.6)**	**96 (23.6)**
Total households	175 (100.0)	105 (100.0)	126 (100.0)	406 (100.0)
Current mean level of pesticide use (Tk/ha)	240	404	633	405

Note: Figures in parentheses are percentages of total households.
Source: Field Survey, 1997.

Table A7.12 Problems with buying pesticides by study regions.

Problems with buying pesticides	Number and percent of households (%)			
	Jamalpur region	Jessore region	Comilla region	All region
Farmers citing problems	**14 (8.0)**	**1 (1.0)**	**7 (5.6)**	**22 (5.4)**
High price of pesticides	5 (2.9)	1 (1.0)	3 (2.4)	9 (2.2)
Shortage in supply	1 (0.6)	-	1 (0.8)	2 (0.5)
Lack of money to buy pesticides	3 (1.6)	-	3 (2.4)	6 (1.5)
Adultery	5 (2.9)	-	-	1 (0.2)
Farmers citing no problems	161 (92.0)	104 (99.0)	119 (94.4)	384 (94.6)
Total households	175 (100.0)	105 (100.0)	126 (100.0)	406 (100.0)

Note: Figures in parentheses are percentages of total households.
Source: Field Survey, 1997.

Table A7.13 Determinants of pesticide use, 1996.

Variables	Rice crops		Foodgrain crops		Non-cereal crops		All crops	
	Coeffi-cient	Asymp. t-ratio	Coeffi-cient	Asymp. t-ratio	Coeffi-cient	Asympt. t-ratio	Coeffi-cient	Asympt. t-ratio
Constant	-187.68	-0.908	-292.34	-1.477	175.86	0.685	-126.80	-0.804
AMLND	134.440	5.223***	178.69	6.736***	224.21	1.447	237.24	9.910**
PMVAR	0.0744	0.189	0.2144	0.639	na	na	0.1632	0.703
PIRRIG	297.52	3.998***	82.128	1.311	199.81	3.309***	145.77	3.422***
AGCR	8.9246	4.164***	7.9109	3.583***	2.6355	1.782*	3.6009	3.000***
INFRA	1.8824	1.338	3.7172	2.668***	0.1059	0.051	2.9868	2.617***
SOIL	28.5200	0.252	31.046	0.278	-306.48	-2.032**	-116.87	-1.315
Log-L	-2176.482		-2297.146		-983.805		-3294.367	
N	397		497		352		849	

Note: *** = significant at 1 percent level (p<0.01); ** = significant at 5 percent level (p<0.05)
* = significant at 10 percent level (p<0.10).
na means not applicable.
Source: Computed.

Table A7.14 Land purchase by types in the past five years by study region, 1996.

Land type, purchase value and present value of land	Value (Tk) of land purchased			
	Jamalpur region	Jessore region	Comilla region	All region
Land purchase by type (No. of farmers)	40 (22.8)	20 (19.1)	14 (11.1)	74 (16.0)
Agricultural land	30 (17.1)	17 (16.2)	10 (7.9)	57 (14.0)
Homestead land	10 (5.7)	3 (2.9)	4 (3.2)	17 (4.2)
Purchase value of land (Tk/household)				
Agricultural land	28,173	27,676	25,050	27,477
Homestead land	27,880	15,367	29,875	26,141
Present value of land purchased (Tk/hh)				
Agricultural land	37,580	43,588	36,050	39,104
Homestead land	34,750	26,733	35,000	33,394
Appreciation in land value (%)				
Agricultural land	33.4	57.5	43.9	42.3
Homestead land	24.6	74.0	17.2	27.7
Total households	175 (100.0)	105 (100.0)	126 (100.0)	406 (100.0)

Note: Figures in parentheses are percentages of total households.
Source: Field Survey, 1997.

Table A7.15 Purpose of land purchase and source of finance by study region, 1996.

Purpose of land purchase and source of finance	Number and percent of households (%)			
	Jamalpur region	Jessore region	Comilla region	All region
Purpose of land purchase				
For cultivation	27 (67.5)	16 (80.0)	10 (71.4)	53 (71.6)
For home construction	8 (20.0)	1 (5.0)	3 (21.4)	12 (16.2)
For family consumption	5 (12.5)	-	1 (7.2)	6 (8.1)
For orchard	-	3 (15.0)	-	3 (4.1)
Source of finance				
Own income (unspecified source)	13 (32.5)	10 (50.0)	-	23 (31.1)
Agricultural income	14 (35.0)	5 (25.0)	3 (21.4)	22 (29.7)
Service income	3 (7.5)	1 (5.0)	7 (50.0)	11 (14.9)
Mortgaged land income	6 (15.0)	1 (5.0)	1 (7.2)	8 (10.8)
Business income	1 (2.5)	3 (15.0)	2 (14.2)	6 (8.1)
Loan from relatives	3 (7.5)	-	1 (7.2)	4 (5.4)
Total land purchasing households	40 (100.0)	20 (100.0)	14 (100.0)	74 (100.0)

Note: Figures in parentheses are percentages of total households.
Source: Field Survey, 1997.

Table A7.16 Land sale by type, actual sale value and present value of land sold in the past five years by study region, 1996.

Type, actual sale value and present value of land sold	Value (Tk) of land sold			
	Jamalpur region	Jessore region	Comilla region	All region
Land sale by type (No. of farmers)	33 (18.9)	17 (16.2)	13 (9.9)	63 (15.5)
Agricultural land	28 (16.0)	16 (15.2)	13 (9.9)	57 (14.0)
Homestead land	5 (2.9)	1 (1.0)	-	6 (1.5)
Sale value of land sold (Tk/household)				
Agricultural land	26,857	28,750	30,053	28,118
Homestead land	26,200	4,800	-	22,633
Present value of land sold (Tk/hh)				
Agricultural land	29,886	30,687	34,285	29,991
Homestead land	44,640	9,000	-	38,700
Appreciation in land value (%)				
Agricultural land	11.3	6.7	14.1	6.7
Homestead land	70.4	87.5	-	70.1
Total households	175 (100.0)	105 (100.0)	126 (100.0)	406 (100.0)

Note: Figures in parentheses are percentages of total households.
Source: Field Survey, 1997.

Table A7.17 Reason for land sale by study region, 1996.

Reason for land sale and purpose of use of the sale proceeds	Number and percent of households (%)			
	Jamalpur region	Jessore region	Comilla region	All region
For daughter's marriage	3 (9.1)	3 (17.6)	4 (30.8)	10 (15.9)
For debt service/release mortgage land	4 (12.1)	4 (23.5)	1 (7.7)	9 (14.3)
To go abroad for job	2 (6.1)	1 (5.9)	6 (46.1)	9 (14.3)
For family consumption	6 (18.2)	1 (5.9)	1 (7.7)	8 (12.7)
To buy better land	3 (9.1)	-	1 (7.7)	4 (6.3)
For treatment	3 (9.1)	-	-	3 (4.8)
For education	1 (3.0)	-	-	1 (1.6)
No reason/ non-response	11 (33.3)	8 (47.1)	-	19 (30.1)
Total land selling households	33 (100.0)	17 (100.0)	13 (100.0)	63 (100.0)

Note: Figures in parentheses are percentages of total households.
Source: Field Survey, 1997.

Table A7.18 Common land rental arrangements in the study villages, 1996.

Region	Villages	Input sharing arrangements (%)				Output sharing (%)
		Animal cost share	Fertilizer cost share	Irrigation cost share	Seed cost share	
Jamalpur	Karanipara	50	50	50	50	50
	Rupshi	nil	nil	nil	100	33
	Munshipara	50	50	50	50	50
	Deuliabari	nil	50	50	50	50
	Jaliarpar	50	50	50	50	50
	Sapleja	nil	50	50	50	50
	Manikbari	nil	nil	nil	nil	33
	Sonakata	50	50	50	50	50
Jessore	Mohanpur	nil	nil	nil	nil	33
	Juranpur	nil	nil	nil	nil	33
	Taherpur	nil	nil	nil	nil	33
	Chandipur	nil	nil	nil	nil	33
	Monaharpur	nil	nil	nil	nil	33
	Subalkati	nil	nil	nil	nil	33

Comilla	Dhakirgaon	nil	nil	nil	nil	33
	Shilmondi	nil	nil	nil	nil	33
	Fatehpur	100	50	nil	100	50
	Begumpur	100	nil	100	nil	50
	Sonaterkandi	100	nil	nil	nil	50
	Uddamdi	nil	nil	100	nil	50
	Khas Uddamdi	nil	nil	nil	nil	50

Note: nil means no sharing.
Source: Field Survey, 1997.

Table A7.19 Estimated land rent for different crops by study regions, 1996.

Crops/ Seasons	Estimated land rent (Tk/ha)			
	Jamalpur region	Jessore region	Comilla region	All region
Aus Season (early monsoon)				
Local Aus rice	4,492	ng	3,774	4,312
Modern Aus rice	7,997	8,511	8,475	8,298
Jute	6,613	8,109	6,721	7,340
Aman Season (monsoon)				
Local Aman rice	7,138	3,440	5,378	5,968
Modern Aman rice	8,692	7,410	6,473	7,947
Boro Season (dry winter)				
Local Boro rice	4,567	4,065	3,694	4,005
Modern Boro rice	10,709	9,569	11,017	10,541
Wheat	6,428	5,795	8,145	7,000
Potato	15,136	12,045	27,911	22,124
Pulses	ng	5,525	7,038	5,763
Oilseeds	5,536	4,856	7,010	6,036
Spices	21,535	7,618	22,299	20,282
Vegetables	14,100	18,179	ng	17,160
Cotton	ng	10,983	ng	10,983
All crops (mean land rent)	9,900	8,377	10,143	9,508

Note: ng means crop not grown. na means information not available.
Source: Field Survey 1997.

Table A7.20 Determinants of land rent, 1996.

Variables	Rice crops		Foodgrain crops		Non-cereal crops		All crops	
	Coeffi-cient	t-ratio	Coeffi-cient	t-ratio	Coeffi-cient	t-ratio	Coeffi-cient	t-ratio
Constant	0.0190	0.007	1.1093	0.436	2.6713	2.695***	2.5644	1.684*
LANDPC	10.4510	4.448***	6.9611	3.495***	1.5166	2.325**	2.9760	2.844***
MVAR	4.9001	3.473***	6.1544	4.809***	na	na	10.5940	13.004***
IRRIG	14.3190	9.823***	13.1820	9.860***	6.3386	9.353***	10.0570	11.405***
TNC	4.2068	3.976***	2.2964	2.581***	2.0265	4.945***	2.0213	3.557***

CAPL	0.0102	6.507***	0.0831	6.046***	0.0082	1.567	0.0376	4.762***
INFRA	0.0342	1.773*	0.0379	2.032**	-0.0069	-0.900	0.0173	1.518
SOIL	-0.9941	-0.659	-1.6897	-1.181	-1.0631	-1.875*	-1.9322	-2.242**
Adj.R^2	0.674		0.628		0.284		0.629	
F-ratio	118.188***		120.810***		24.212***		206.770	
Df	7, 389		7, 489		6, 345		7, 841	
D.W.	2.04		2.08		2.03		2.06	

Note: *** = significant at 1 percent level (p<0.01); ** = significant at 5 percent level (p<0.05)
* = significant at 10 percent level (p<0.10). na means not applicable.
Source: Computed.

Table A7.21 Sources of credit by study region, 1996.

Sources	Number and percentage of households (%)			
	Jamalpur region	Jessore region	Comilla region	All region
Indebted households	82 (46.9)	38 (36.2)	44 (35.0)	164 (40.4)
Institutions/NGOs	24 (13.7)	25 (23.8)	25 (19.8)	74 (18.2)
Money lender	4 (2.3)	3 (2.9)	2 (1.6)	9 (2.2)
Friends/relatives	54 (30.9)	10 (9.5)	17 (13.6)	81 (20.0)
Non-indebted households	93 (53.1)	67 (63.8)	82 (65.0)	242 (59.6)
Total households	175 (100.0)	105 (100.0)	126 (100.0)	406 (100.0)

Note: Figures in parentheses are percentages of total.
Source: Field Survey, 1997.

Table A7.22 Type and amount of loan by study region, 1996.

Uses	Average loan amount per household (Tk)			
	Jamalpur region	Jessore region	Comilla region	All region
Agricultural loan	**1,599 (50.8)**	**5,259 (78.6)**	**1,702 (53.7)**	**2,578 (63.3)**
Insitutional	658 (20.9)	4,819 (72.0)	1,377 (43.5)	1,957 (48.1)
Non-institutional	941 (29.9)	440 (6.5)	325 (10.3)	621 (15.3)
Non-agricultural loan	1,550 (49.2)	1,436 (21.4)	1,464 (46.3)	1,494 (36.7)
Institutional	385 (12.2)	341 (5.1)	385 (12.1)	374 (9.1)
Non-institutional	1,165 (36.9)	1,095 (16.4)	1,079 (34.1)	1,120 (27.5)
Total loan	3,149 (100.0)	6,695 (100.0)	3,167 (100.0)	4,072 (100.0)
Institutional	1,044 (33.1)	5,160 (77.1)	1,762 (55.6)	2,331 (57.2)
Non-institutional	2,105 (66.8)	1,535 (22.9)	1,405 (44.4)	1,741 (42.8)

Note: Figures in parentheses are percentages of total loan.
Source: Field Survey, 1997.

Table A7.23 Uses of loan by study region, 1996.

Uses	Number and percentage of households (%)

	Jamalpur region	Jessore region	Comilla region	All region
Agriculture	50 (28.6)	27 (25.7)	28 (22.2)	105 (25.9)
Business	2 (1.1)	3 (2.9)	4 (3.2)	9 (2.2)
Consumption/Other	30 (17.2)	8 (7.6)	12 (9.6)	50 (12.3)
Indebted households	82 (46.9)	38 (36.2)	44 (35.0)	164 (40.4)
Non-indebted households	93 (53.1)	67 (63.8)	82 (65.0)	242 (59.6)
Total households	175 (100.0)	105 (100.0)	126 (100.0)	406 (100.0)

Note: Figures in parentheses are percentages of total.
Source: Field Survey, 1997.

Table A7.24 Determinants of agricultural credit, 1996.

Variables	Rice crops		Foodgrain crops		Non-cereal crops		All crops	
	Estimate	t-ratio	Estimate	t-ratio	Estimate	t-ratio	Estimate	t-ratio
Constant	-3.4516	-0.368	-5.7977	-0.735	-35.585	-1.531	-14.919	-1.334
OWLND	-3.3328	-1.596	-2.4910	-1.507	7.5648	2.387**	3.8321	2.114**
MVAR	12.265	1.277	12.837	1.738*	na	na	2.0955	0.245
IRRIG	-13.210	-1.366	-14.187	-1.859*	-3.2198	-0.167	-5.4675	-0.557
TNC	-3.7680	-1.127	-4.2969	-1.531	-8.5920	-1.110	-5.2128	-1.349
CAPL	0.6277	10.995***	0.6031	11.472***	0.5177	4.146***	0.5229	7.776***
WORK	-0.4275	-0.529	-0.5933	-0.802	-8.0553	-3.719***	-3.8422	-3.711***
FAMILY	0.3939	0.903	0.1904	0.488	0.7879	0.694	0.3322	0.604
EXPCE	-0.1542	-2.264**	-0.1359	-2.261**	-0.1628	-1.054	-0.1609	-1.996**
INFRA	-0.0347	-0.499	-0.0462	-0.765	-0.2122	-1.251	-0.1495	-1.786*
SOIL	4.9982	0.341	7.3962	1.645*	35.047	2.726***	18.417	2.915***
Adj.R^2	0.656		0.624		0.305		0.359	
F-ratio	22.185***		23.558***		6.604***		15.144***	
Df	10, 101		10, 126		9, 106		10, 242	
D.W.	1.96		2.01		2.06		2.07	

Note: *** = significant at 1 percent level ($p<0.01$); ** = significant at 5 percent level ($p<0.05$)
* = significant at 10 percent level ($p<0.10$). na means not applicable.
Source: Computed.

Table A7.25 Farm level prices of different crops by study regions, 1996.

Crops/ Seasons	Farm level crop output prices (Tk/ton)			
	Jamalpur region	Jessore region	Comilla region	All region
Aus Season (early monsoon)				
Local Aus rice	5,128	ng	5,516	5,225
Modern Aus rice	5,722	5,630	5,250	5,637
Jute	9,493	9,739	8,641	9,395

Aman Season (monsoon)				
Local Aman rice	5,848	5,722	5,413	5,605
Modern Aman rice	5,737	5,723	5,069	5,603
Boro Season (dry winter)				
Local Boro rice	4,750	4,250	4,500	4,500
Modern Boro rice	5,670	5,670	5,632	5,665
Wheat	7,700	7,364	8,570	7,984
Potato	3,928	3,833	3,689	3,790
Pulses	ng	20,106	16,590	19,559
Oilseeds	12,275	14,093	12,400	13,058
Spices	22,107	9,500	37,000	25,202
Vegetables	4,409	6,691	ng	6,120
Cotton	ng	23,546	ng	23,546

Note: ng means crop not grown.
Source: Field Survey 1997.

Table A7.26 Selling point of farm products by study regions, 1996.

Selling point of farm products	Number and percent of households			
	Jamalpur region	Jessore region	Comilla region	All region
Farmers selling farm products at				
Farmgate	6 (3.4)	8 (7.6)	15 (11.9)	29 (7.1)
Primary market	165 (94.3)	96 (91.4)	57 (45.2)	318 (78.3)
Secondary market	4 (2.3)	1 (1.0)	54 (42.9)	59 (14.5)
Total households	175 (100.0)	105 (100.0)	126 (100.0)	406 (100.0)

Note: Figures in parentheses are percentages of total households.
Source: Field Survey, 1997.

Table A7.27 Distance of the markets by study regions.

Distance of markets[1]	Number and percent of households			
	Jamalpur region	Jessore region	Comilla region	All region
Less than one km	63 (36.0)	36 (34.3)	28 (22.2)	127 (31.3)
Between one to three kms	92 (52.6)	56 (53.3)	79 (62.7)	227 (55.9)
More than three kms	14 (8.0)	5 (4.8)	4 (3.2)	23 (5.7)
Total households	175 (100.0)	105 (100.0)	126 (100.0)	406 (100.0)

Note: Figures in parentheses are percentage of total households.
[1] Do not include selling at farmgate.
Source: Field Survey, 1997.

Table A7.28 Problems with marketing by study regions, 1996.

Problems with marketing	Number and percent of households

	Jamalpur region	Jessore region	Comilla region	All region
Farmers citing problems	**14 (8.0)**	**-**	**15 (11.9)**	**29 (7.1)**
Long distance, poor communication	8 (4.6)	-	4 (3.2)	12 (3.0)
Low price	6 (3.4)	-	5 (4.0)	11 (2.7)
High cost of illegal brokerage	-	-	6 (4.7)	6 (1.4)
Farmers citing no problems	161 (92.0)	105 (100.0)	111 (88.1)	377 (92.9)
Total households	175 (100.0)	105 (100.0)	126 (100.0)	406 (100.0)

Note: Figures in parentheses are percentages of total households.
Source: Field Survey, 1997.

Table A7.29 Determinants of crop prices, 1996.

Variables	Rice crops		Foodgrain crops		Non-cereal crops		All crops	
	Coeffi-cient	t-ratio	Coeffi-cient	t-ratio	Coeffi-cient	t-ratio	Coeffi-cient	t-ratio
Constant	5.1786	20.392***	6.1437	7.317***	19.739	3.369***	13.967	4.576***
QTY	-0.1680	-0.185	-0.0513	-3.419***	-1.0713	-2.957***	-0.1025	-0.666*
OWLND	-0.0027	-0.071	0.1939	3.280***	0.0554	0.173	0.1124	0.663
PMVAR	-0.0001	-0.385	-0.0006	-0.134	Na	na	0.0055	3.653***
INFRA	-0.0039	-2.159**	-0.0157	-2.548***	-0.0540	-1.266	-0.0413	-1.836*
SOIL	0.3463	2.436***	0.2686	0.562	-2.7366	-0.814	-2.1383	-1.226
Adj. R^2	0.048		0.161		0.150		0.122	
F-ratio	5.023***		20.010***		16.456***		24.628***	
Df	5, 391		5, 491		4, 347		5, 843	
D.W.	2.10		2.51		2.44		2.50	

Note: *** = significant at 1 percent level (p<0.01); ** = significant at 5 percent level (p<0.05);
* = significant at 10 percent level (p<0.10). na means not applicable.
Source: Computed.

Table A7.30. Distance of the storage facilities by study regions, 1996.

Distance	Number and percent of farmers			
	Jamalpur region	Jessore region	Comilla region	All region
Less than one km	-	-	-	-
Between one to three kms	-	-	27 (96.4)	27 (87.1)
More than three kms	1 (100.0)	2 (100.0)	1 (3.6)	4 (12.9)

Total number of godowns	1 (100.0)	2 (100.0)	28 (100.0)	31 (100.0)

Note: Figures in parentheses are percentage of total households.
Source: Field Survey, 1997.

Table 7.31 Problems with storage facilities by study regions, 1996.

Problems with storage facilities	Number and percent of households (%)			
	Jamalpur region	Jessore region	Comilla region	All region
Farmers citing problems	**4 (2.6)**	**-**	**28 (22.2)**	**32 (7.9)**
Lack of space at home	-	-	26 (20.6)	26 (6.4)
Insect damage crops	2 (1.1)	-	2 (1.6)	4 (0.9)
Leakage of roof requiring maintenance	1 (0.8)	-	-	1 (0.3)
Threat of burglary	1 (0.7)	-	-	1 (0.3)
Farmers citing no problems	171 (97.4)	105 (100.0)	98 (77.8)	374 (92.1)
Total households	175 (100.0)	105 (100.0)	126 (100.0)	406 (100.0)

Note: Figures in parentheses are percentages of total households.
Source: Field Survey, 1997.
Table A7.32 Joint determination of input demand functions, 1996.

Variables	Joint estimates of input demand functions using Three Stage Least Squares				
	Fertilizer demand	Labor demand	Animal power demand	Modern technology adoption	Irrigation demand
Intercept	-82.714 (-1.662)*	118.030 (4.543)***	32.463 5.651)***	0.147 (0.692)	-0.359 (-1.701)*
FP	-4.578 (-1.348)	-	-	-	-
WAGE	-	-1.110 (-3.228)***	-	-	-
ANIMP	-	-	-0.328 (-10.890)***	-	-
AMLND	158.350 (3.240)***	84.485 (3.609)***	13.601 (3.016)***	-0.478 (-2.339)**	1.056 (22.069)***
MVAR	119.290 (2.497)***	27.436 (2.329)**	24.144 (6.130)***	-	-
CAPL	1.294 (2.337)**	-	-	0.002 (0.844)	0.005 (2.633)***
AGCR	-0.659 (-1.394)	-0.012 (-0.060)	0.056 (0.368)	0.004 (1.801)*	-0.005 (-2.458)**
INFRA	0.957 (1.617)	0.316 (1.289)	-0.115 (-2.001)**	0.004 (2.441)**	0.005 (3.156)***
SOIL	23.219 (0.914)	-34.733 (-3.241)***	-0.229 (-0.086)	-0.097 (-0.853)	0.101 (0.853)
IRRIG	-	-	-	1.404	-

				(7.450)***	
Adjusted R^2	0.80	0.74	0.86	0.53	0.67
F – ratio	225.56***	195.40***	427.91***	77.81***	167.25***
Degree of fdm	7, 398	6, 399	6, 399	6, 399	5, 400
D.W. Statistic	1.90	1.95	1.85	1.90	1.79

Note: *** = significant at 1 percent level ($p<0.01$); ** = significant at 5 percent level ($p<0.05$);
* = significant at 10 percent level ($p<0.10$).

Source: Computed.

Table A8.1. Determinants of rural household income, 1996.

Variables	Crop income (CROPI)	Agricultural income (AGI)	Non-agricultural income (NAGI)	Total household income (INC)
Constant	9.1281	9.2674	7.2600	10.2650
	(29.487)***	(26.080)***	(2.182)**	(21.182)***
lnAMLND	0.9619	0.6758	-0.7407	0.4457
	(34.475)***	(21.093)***	(-2.470)**	(10.205)***
lnWORK	-0.0014	0.1138	0.8180	0.1096
	(-0.034)	(2.357)**	(1.810)*	(1.665)*
lnCAPL	0.0429	0.1416	-0.0871	0.1130
	(3.324)***	(9.555)***	(-0.628)	(5.591)***
lnAGE	-0.0368	-0.0225	-0.2063	0.0494
	(-0.614)	(-0.326)	(-0.320)	(0.526)
PTNC	-0.1106	-0.2643	0.3952	-0.1714
	(-1.335)	(-2.780)***	(0.444)	(-1.322)
PMVAR*PIRRIG	0.2376	0.1646	-2.4707	-0.1801
	(3.26)***	(1.967)**	(-3.154)***	(-1.578)
EDUCH	-0.0196	-0.0046	0.0044	0.0038
	(-3.513)***	(-0.711)	(0.073)	(0.435)
INFRA	-0.0013	-0.0020	-0.0551	-0.0066
	(-0.887)	(-1.132)	(-3.368)***	(-2.751)***
SOIL	0.2866	0.2980	-0.1933	-0.0903
	(2.486)**	(2.252)**	(-0.156)	(-0.500)
Adj. R-squared	0.826	0.747	0.067	0.455
$F_{(9, 396)}$	213.967***	133.814***	4.230***	38.627***
D.W. Statistics	1.74	1.75	1.80	2.02

Note: Figures in parentheses are t-ratios.
*** = significant at 1 percent level (p<0.01); ** = significant at 5 percent level (p<0.05)
* = significant at 10 percent level (p<0.10)
Source: Computed.

Table A9.1 Soil reaction.

pH range[1]	Interpretation[2]	Jamalpur	Jessore	Comilla	**All region**
4.5 – 5.5	Highly *acidic*	1 (20)	-	-	1 (7)
5.6 – 6.5	Slightly *acidic*	3 (60)	-	1 (100)	4 (27)
6.6 – 7.3	*Neutral*	2 (40)	-	2 (100)	3 (20)
7.4 – 8.4	Slightly *alkaline*		5 (100)	2 (100)	7 (46)
Total		5 (100)	5 (100)	5 (100)	15 (100)
Mean and standard deviation		6.0 [0.5]	7.8 [0.2]	7.2 [0.5]	6.9 [0.9]
pH index		6.0	7.9	7.1	6.7
Index Interpretation		Slightly *acidic*	Slightly *alkaline*	*Neutral*	*Neutral*

Note: Figures in parentheses are percentage. Figures in square brackets are standard deviation.

[1]In case of *Bangladesh*, the Soil Resource Development Institute (SRDI) provided a four group classification based on a given range of *soil* pH which is different from standard classification (SRDI, 1991).

[2] The interpretation is based on classification provided by SRDI (1991). The SRDI also provided three group classification based on a given range of levels of nutrients for all macro and micro-nutrients which were utilized in analyzing *available* N, P, K, Zn, and S, respectively (Tables 6.4 – 6.9).

pH index = $\{(m_1 * n_1) + (m_2 * n_2) + (m_3 * n_3) + (m_4 * n_4)\}/ n$

where m_1 .... m_4 are the mid points of pH ranges and n_1 ... n_4 are respective number of sample in each class. n = sample size.

Source: Field survey, 1997.

Table A9.2 *Organic matter* content (%) in the soil.

OM (%) range	Interpretation	Jamalpur	Jessore	Comilla	**All region**
< 1.72	Low	3 (60)	1 (20)	4 (80)	8 (53)
1.72 – 3.44	Medium	2 (40)	-	1 (20)	3 (20)
3.44 >	High	-	4 (80)	-	4 (27)
Total		5 (100)	5 (100)	5 (100)	15 (100)
Mean and Standard deviation		2.01 [0.79]	6.47 [2.84]	1.45 [0.35]	3.32 [2.82]
OM index		1.55	2.60	1.20	1.73
Index Interpretation[1]		Low	High	Low	Medium

Note: Figures in parentheses are percentage. Figures in square brackets are standard deviation.

[1]The index value is rated as **< 1.67 = low, 1.67 – 2.33 = medium,** and **> 2.33 = high** following Motsara (1994) and Dahal (1996). This index value rating is utilized in analyzing all other *soil fertility* parameters (Tables 6.5 – 6.12).

OM index = $\{(n_1 * 1) + (n_2 * 2) + (n_3 * 3)\}/ n$

where n_1 ... n_3 are respective number of sample in each class, and 1, 2, 3 are the weights for low, medium, and high class.n = sample size.

This procedure of index construction is followed in analyzing the remaining *soil fertility* parameters (Tables 6.5 – 6.12).

Source: Field survey, 1997.

Table A9.3 *Available Nitrogen* in the soil.

N (μg/g) range	Interpretation	Jamalpur	Jessore	**Comilla**	**All region**
< 76	Low	5 (100)	5 (100)	5 (100)	15 (100)
76 – 150	Medium	-	-	-	-
151 – 300	High/Best	-	-	-	-
Total		5 (100)	5 (100)	5 (100)	15 (100)
Mean and standard deviation		16.0 [6.7]	19.1 [8.2]	25.5 [7.5]	20.2 [8.1]
Nitogen index		1.00	1.00	1.00	1.00
Index Interpretation		Low	Low	Low	Low

Note: Figures in parentheses are percentage.
Figures in square brackets are standard deviation.

Source: Field survey, 1997.

Table A9.4 *Available Phosphorus* in the soil.

P (μg/g) range	Interpretation	Jamalpur	Jessore	Comilla	**All region**
< 13	Low	-	-	-	-
13 – 25	Medium	2 (40)	4 (80)	5 (100)	11 (73)
26 – 75	High/Best	3 (60)	1 (20)	-	4 (27)
Total		5 (100)	5 (100)	5 (100)	15 (100)
Mean and standard deviation		26.7 [6.4]	22.3 [15.8]	20.4 [2.0]	23.1 [9.6]
Phosphorus index		2.60	2.20	2.00	2.27
Index Interpretation		High	Medium	Medium	Medium

Note: Figures in parentheses are percentage.
Figures in square brackets are standard deviation.

Source: Field survey, 1997.

Table A9.5 *Available Potassium* in the soil.

K (μg/g) range	Interpretation	Jamalpur	Jessore	Comilla	**All region**
< 79	Low	5 (100)	5 (100)	5 (100)	15 (100)
79 – 156	Medium	-	-	-	-
157 – 585	High/Best	-	-	-	-
Total		5 (100)	5 (100)	5 (100)	15 (100)
Mean and standard deviation		32.2 [16.6]	52.4 [13.8]	20.3 [6.0]	34.9 [18.2]

Potassium index	1.00	1.00	1.00	1.00
Index Interpretation	Low	Low	Low	Low

Note: Figures in parentheses are percentage.
Figures in square brackets are standard deviation.
Source: Field survey, 1997.

Table A9.5 *Available Sulfur* in the soil.

S (µg/g) range	Interpretation	Jamalpur	Jessore	Comilla	**All region**
< 13	Low	5 (100)	3 (60)	5 (100)	13 (87)
13 – 25	Medium	-	2 (40)	-	2 (13)
26 – 75	High/Best	-	-	-	-
Total		5 (100)	5 (100)	5 (100)	15 (100)
Mean and standard deviation		7.8 [2.9]	10.2 [3.7]	5.5 [0.7]	7.8 [2.9]
Sulfur index		1	1.40	1.00	1.53
Index Interpretation		Low	Low	Low	Low

Note: Figures in parentheses are percentage. Figures in square brackets are standard deviation.
Source: Field survey, 1997.

Table A9.6 *Available Zinc* in the soil.

Zn (µg/g) range	Interpretation	Jamalpur	Jessore	Comilla	**All region**
< 2.1	Low	1 (20)	-	2 (40)	3 (20)
2.1 – 4.0	Medium	1 (20)	1 (20)	-	2 (13)
4.1 – 18.0	**High/Best**	3 (60)	4 (80)	3 (60)	10 (67)
Total		5 (100)	5 (100)	5 (100)	15 (100)
Mean and standard deviation		5.0 [3.7]	7.6 [3.2]	4.1 [2.9]	5.5 [3.4]
Zinc index		2.40	2.80	2.20	2.47
Index Interpretation		High	High	Medium	High

Note: Figures in parentheses are percentage. Figures in square brackets are standard deviation.
Source: Field survey, 1997.

Table A9.7 *Cation exchange capacity* of the soil

CEC range[1] (meq/100g)	Interpretation	Jamalpur	Jessore	Comilla	**All region**
0 – 20	Low	5 (100)	1 (20)	4 (80)	10 (67)
21 – 40	Medium	-	4 (80)	1 (20)	5 (33)
41 >	High	-	-	-	-

Total	5 (100)	5 (100)	5 (100)	15 (100)
Mean and standard deviation	10.9 [3.5]	26.2 [8.7]	15.8 [4.5]	17.6 [8.6]
CEC index	1.00	1.80	1.20	1.33
Index Interpretation	Low	Medium	Low	Low

Note: Figures in parentheses are percentage. Figures in square brackets are standard deviation.

This classification is based on Thompson and Troeh (1973) and Brady (1974). Thompson and Troeh (1973) revealed that CEC of 10 – 20 meq/100g is observed for *clay*s found in highly weathered soil in tropical and subtropical areas, 40 – 80 meq/100g for *clay*s in temperate climates and 100 – 200 meq/100g for *organic matter*s. Brady (1974) revealed that representative CEC of silicate clay (0.5 meq for each 1 percent) and for well-humified organic matter (2.0 meq for each 1 percent) can be ascertained. For example, silt loam soils in US vary from 9.4 – 26.3 meq/100g.

Source: Field survey, 1997.

Table A9.8 *Electrical conductivity* of the soil

EC range (μS/cm)	Interpretation	Jamalpur	Jessore	Comilla	**All region**
< 200	Low	5 (100)	4 (80)	5 (100)	14 (93)
200 +	Optimum	-	1 (20)	-	1 (7)
Total		5 (100)	5 (100)	5 (100)	15 (100)
Mean and standard deviation		75 [30]	176 [34]	113 [32]	121 [52]
EC index		1.00	1.2	1.00	1.07
Index Interpretation		Low	Low	Low	Low

Note: Figures in parentheses are percentage.
Figures in square brackets are standard deviation.
Source: Field survey, 1997.

Table A9.9 Soil texture

Soil texture class	Jamalpur	Jessore	Comilla	**All region**
Silt loam	4 (80)	1 (20)	4 (80)	9 (60)
Silty clay loam	-	-	1 (20)	1 (7)
Silty clay	-	3 (60)	-	3 (20)
Clay loam/Clay	1 (20)	1 (20)	-	2 (13)
Total	5 (100)	5 (100)	5 (100)	15 (100)
Textural Interpretation	*Silt loam*	*Silty clay*	*Silt loam*	*Silty clay loam*

Note: Figures in parentheses are percentage.
Source: Field survey, 1997.

Table A9.10 Regression results of soil fertility and crop productivity relations, 1996.

Dependent variable	Independent variables			Adj. R^2	S.E. of regression	F – value	
	Variable name	Coeff-icient	**t - ratio**			Value	df
ln local Aman	Constant	5.958	5.523***	0.417	0.3386	5.524***	3,16
	ln K	0.323	1.669				
	pH	-0.401	-3.193***				
	ln CEC	0.557	1.853*				
ln MV Aman	Constant	7.523	27.976***	0.195	0.1211	5.364**	1,17
	ln N	0.169	2.316**				
ln MV wheat	Constant	7.154	28.620***	0.239	0.2584	4.775**	1,11
	ln Zn	0.217	2.185**				
ln MV rice	Constant	7.750	27.366***	0.102	0.1314	3.263*	1,19
	ln N	0.137	1.806*				
ln foodgrain (all varieties of rice and wheat	Constant	7.749	33.135***	0.314	0.098	5.570**	2,18
	ln K	0.144	3.044***				
	pH	-0.048	-2.011*				
ln jute	Constant	5.973	16.716***	0.556	0.1499	17.249***	1,12
	ln K	0.349	4.153***				
ln pulses	Constant	22.517	7.404***	0.786	0.1597	13.880***	2,5
	pH	-2.352	-5.031***				
	ln K	0.457	2.767***				
ln spices	Constant	9.380	6.914***	0.781	0.3697	20.593***	2,9
	pH	-0.935	-6.471***				
	ln K	1.200	3.287***				
ln vegetables	Constant	5.754	5.450***	0.951	0.1143	51.582***	5,8
	ln K	-1.246	-14.894***				
	pH	1.004	10.128***				
	ln S	1.829	8.605***				
	EC	-0.011	-6.316***				
	ln N	-0.547	-4.009***				

Note: *** = significant at 0.01 level ($p<0.01$); ** = significant at 0.05 level ($p<0.05$).
* = significant at 0.10 level ($p<0.10$).
Source: Field survey, 1997.

Table A9.11 Farmers' opinion on present level of pesticide use by study regions, 1996.

Opinion on present level of pesticide use	Number and percent of households (%)			
	Jamalpur region	Jessore region	Comilla region	All region
Farmers thinking present use as appropriate	41 (23.4)	13 (12.4)	103 (81.7)	157 (38.7)
Farmers considering need to use more	24 (13.8)	29 (27.6)	4 (3.2)	57 (14.0)
Farmers considering need to reduce use	**27 (15.4)**	**8 (7.6)**	**4 (3.2)**	**39 (9.6)**
Farmers not thinking about pesticide use	13 (7.4)	17 (16.2)	4 (3.2)	34 (8.4)
Non-responding farmers	70 (40.0)	38 (36.2)	11 (8.7)	119 (29.3)
Total households	175 (100.0)	105 (100.0)	126 (100.0)	406 (100.0)

Note: Figures in parentheses are percentages of total households.
Source: Field Survey, 1997.

Table A9.12. Source of water for drinking and washing purpose by study regions, 1996.

Sources of water	Number and percent of households (%)			
	Jamalpur region	Jessore region	Comilla region	All region
Source of water for drinking				
Tube well	126 (100.0)	175 (100.0)	105 (100.0)	406 (100.0)
Source of water for washing/cleansing				
Pond	85 (48.6)	44 (41.9)	101 (80.2)	230 (56.7)
Tube well	126 (72.0)	81 (77.1)	7 (5.6)	214 (52.7)
Canal	3 (1.7)	-	13 (12.4)	16 (3.9)
River	1 (0.6)	-	11 (8.7)	12 (3.0)
Total households	175 (100.0)	105 (100.0)	126 (100.0)	406 (100.0)

Note: Figures in parentheses are percentages of total households.
Multiple responses.
Source: Field Survey, 1997.

Table A9.13 Quality of water by sources by study regions, 1996.

Quality of water of various sources	Number and percent of households (%)			
	Jamalpur region	Jessore region	Comilla region	All region
Good quality				
Rain water	172 (98.2)	105 (100.0)	123 (97.6)	400 (98.5)
Hand pump	5 (2.9)	32 (30.5)	23 (18.3)	60 (14.8)
Shallow tube well	-	-	7 (5.6)	7 (1.7)
Deep tube well	2 (1.1)	-	3 (2.4)	5 (1.2)
Low lift pump	2 (1.1)	-	2 (1.6)	4 (1.0)
Poor quality				
Rain water	3 (1.7)	-	3 (2.4)	6 (1.5)
Hand pump	63 (36.0)	19 (18.1)	79 (63.0)	162 (39.9)
Shallow tube well	8 (4.6)	-	11 (8.7)	19 (4.7)
Deep tube well	7 (4.0)	-	3 (2.4)	10 (2.5)
Low lift pump	7 (4.)	-	15 (11.9)	22 (5.4)
Total households	175 (100.0)	105 (100.0)	126 (100.0)	406 (100.0)

Note: Figures in parentheses are percentages of total households. Multiple responses.
Source: Field Survey, 1997.

Table A9.14 Remarks about water quality by sources by study regions, 1996.

Quality of water of various sources	Number and percent of households (%)			
	Jamalpur region	Jessore region	Comilla region	All region
Ground water (tube well)				
Clean/not polluted/good	69 (39.4)	20 (19.0)	68 (54.0)	157 (38.7)
Good for bath/cooking	26 (14.9)	11 (10.1)	55 (43.7)	92 (22.7)
Low iron content	73 (41.7)	59 (56.2)	3 (2.4)	135 (33.2)
Heavy iron content	7 (4.0)	15 (14.3)	-	22 (5.4)
Surface water (river/canal)				
Clean/not polluted/good	2 (1.1)	-	8 (6.3)	10 (2.5)
Polluted/dirty	5 (2.9)	-	19 (15.1)	24 (5.9)
Causes diarrhoea/rheumatism	2 (1.1)	-	3 (2.4)	5 (1.2)
No response on surface water qlty	166 (94.9)	105 (100.0)	96 (76.2)	367 (90.4)
Surface water (pond)				
Clean/not polluted/good	49 (28.0)	8 (7.6)	6 (4.8)	63 (15.5)
Good for bath/cooking	-	-	15 (11.9)	15 (3.7)
Low iron content	3 (1.7)	3 (2.9)	-	6 (1.5)
Polluted/dirty	21 (12.0)	24 (22.9)	77 (61.1)	122 (30.0)
Causes diarrhoea/rheumatism	12 (6.9)	12 (11.4)	6 (4.8)	30 (7.4)
Non-response on pond water qlty	90 (51.4)	58 (55.2)	22 (17.5)	170 (41.9)
Total households	175 (100.0)	105 (100.0)	126 (100.0)	406 (100.0)

Note: Figures in parentheses are percentages of total households. Multiple responses.
Source: Field Survey, 1997.

TableA9.15 Sufficiency of water supply for irrigation by study regions, 1996

Sufficiency of water supply for irrigation	Number and percent of households (%)			
	Jamalpur region	Jessore region	Comilla region	All region
Sufficient	**153 (87.4)**	**95 (90.5)**	**100 (79.4)**	**348 (85.7)**
Not sufficient	22 (12.6)	10 (9.5)	26 (20.6)	58 (14.3)
Load shedding/ no electricity supply	13 (7.4)	5 (4.8)	4 (3.2)	22 (5.4)
River/canal/pond dry	1 (0.6)	-	14 (11.1)	15 (3.7)
Not under/ far from irrigation scheme	1 (0.6)	3 (2.9)	8 (6.3)	12 (3.0)
High prices for irrigation water	3 (1.7)	2 (1.8)	-	5 (1.2)
Mechanical problem of machines	4 (2.3)	-	-	4 (1.0)
Total households	175 (100.0)	105 (100.0)	126 (100.0)	406 (100.0)

Note: Figures in parentheses are percentages of total households.
Source: Field Survey, 1997.

APPENDIX B

COORDINATION SCHEMA FOR THE FARM-SURVEY COMPONENT OF THE STUDY

PARAMETER	COMPLEX VARIABLE	SIMPLE VARIABLE	VALUE
Ideographic Features	Respondent's Profile	Age	Year
		Gender	Male/Female
	Socioeconomic profile	Education level	Degree obtained Years of schooling completed
		Major occupation	Fact (Occupation code list) (e.g., farmer, trader, student, etc)
		Minor occupation	Fact (occupation code list)
		Other skills/training	Description
	Household composition	Size	Number
	Status of other household members	Gender	Male/female
		Age	Year
		Educational level	Years of schooling completed
		Major occupation	Fact (occupation code list)
		Minor occupation	Fact (occupation code list)
		Other skills	Description
Major sources of income	Employment in activities	Agriculture	Fact
		Non-agriculture	Fact
		Wage	Fact
		Salaried	Fact
		Remittance from abroad	Fact
Resources owned by the household	Fixed assets	Homestead (in numbers and estimated value at present)	House Storage Shed
	Land assets	Types of land owned	Homestead Cultivated Rented-out Mortgaged-out
		Amount of land owned by (also estimated value at present)	Husband Wife Other members

PARAMETER	COMPLEX VARIABLE	SIMPLE VARIABLE	VALUE
	Changes in land assets during last 5 years	Consolidation	Consolidated Fragmented
Resources owned by the household (continued)		Total land	Increased Decreased
		Purchase (amount and value)	Fact
		Sale (amount and value)	Fact
		Perceived quality at present	Declining/Getting better
	Other Assets (in no.and estimated present value)	Equipments	Fact (Assets code list)
		Transport	Fact
		Household durables/ furnitures	Fact
		Ornaments	Fact
		Artisans/Carpenters kits	Fact
		Shops/godowns	Fact
		Rice/oil mills	Fact
Production Structure	Tenurial status	Type of land under cultivation (in decimals)	Owned land Rented-in land Mortgaged-in land Leased-in land
Liabilities of the household	Credit	Sources of credit (amount and time when taken)	Institution Money lender Friends/Relatives
		Types (amount and value for kind)	Cash Kind
		Credit conditions	Interest rate Period Collateral deposited
		Uses of credit	Land purchase Equipment purchase Agril. production Business Consumption Ceremony Others (specify)
Agricultural production	Production practice	Crops grown (area and production under each crop)	Crop code list (e.g., MV rice, wheat, etc.)

PARAMETER	COMPLEX VARIABLE	SIMPLE VARIABLE	VALUE
	Utilization of agricultural produce	Mode of utilization (amount and value for each crop types)	Consumption Debt service Sale Preserved as seed Present stock Payment for landlord
		Selling station (amount, distance and transportation cost)	Farmgate Local market Secondary market
Agricultural production (continued)		Mode of selling	Household member Broker
		Food self sufficiency	Proportion of a year
	Input Use	Material inputs (amount and value)	Seed, Fertilizer, Manure Chemicals
		Equipments (own and hired with rental value)	Tractor/power tiller, Thresher, Plough, Draught animal
		Irrigation (area irrigated and cost)	Modern (DTW, STW,LLP) Traditional (dhone)
	Labor Use	Operations (working days of family and hired labor in each crops by gender)	Land preparation, Sowing Weeding, Irrigation Fertilizing, Harvesting Threshing
		Wages	Cash, Food + cash
Use of modern technology	Irrigation	Land categories (amount of land irrigated)	Owned Rented-in Mortgaged-in Leased-in
		Mode of irrigation	Deep Tube Well Shallow Tube Well Low lift pump (LLP) Hand pump (HP) Others (specify)
	Land preparation	Land categories (amount of land prepared)	Owned, Rented-in Mortgaged-in, Leased-in
		Mode of land preparation	Tractors Power tillers Draft animals
Farm machineries	Modern equipments	Irrigation equipment (number and present value)	DTW, STW, LLP, HP Other (specify)

PARAMETER	COMPLEX VARIABLE	SIMPLE VARIABLE	VALUE
owned by the household		Agricultural implements (number and present value)	Spade/Sickle, Plow, Ladder Tractor, Power tiller
Payments for renting land (Land rent)	Payments for rented-in, mort-gaged-in and leased-in land	Terms of payment (proportion, quantity,value)	Crop share Cash
		Terms of sharing (quantity and value)	Input cost sharing No input cost sharing
Income from land renting by the household	Leased-out/ mortgaged-out/ rented-out land	Relation with the landlord	Within the village Out of the village
		Amount of land	Within the village Out of the village
		Period of lease	Start/End
Income from land renting by the household (continued)		Payment received	Proportion of harvest Cash
		Cost sharing	Irrigation cost Seed/fertilizer cost Land preparation cost Proportion of total cost
Livestock raising	Raising pattern	Type of livestock	Cattle, Buffalo, Goat/sheep, Chicken/Duck Others (specify)
		Head	Figure
		Present value	Amount
		Purchase cost	Amount
		Purpose of raising	Milk, meat, draft power, eggs
	Labor used	Family labor	Days
		Hired labor	Days
		Wage	Taka
	Feed cost (purchased)	Forage	Amount
		Fodder	Amount
	Income from last one year	Head Sale	Amount
		Slaughtered	Amount
		Lost/dead	Amount
	Production and selling	Yield	Calves/chicks Milk/meat/egg Manure Draft power Load hauling

PARAMETER	COMPLEX VARIABLE	SIMPLE VARIABLE	VALUE
		Selling place	Farmgate Local market Outside market
		Mode of selling	Household member Broker

PARAMETER	COMPLEX VARIABLE	SIMPLE VARIABLE	VALUE
Wage Earning	Wage laborer	Type	Daily Contract/Annual Occasional
		Type of work	Farm work Household work Nonfarm work Earth digging Construction Porter Others (specify)
		Working days	Dry season Wet season
		Wage rate	Cash Food + cash
Service	Service	Type	Personal Public Private NGO Others (specify)
		Nature	Temporary Permanent Daily
		Period of service	Year
		Annual earning	Amount
		Remittance	Amount
Business	Operation	Types of business	Business code list (e.g. grocery)
		Period of operation	Years
		Family labor	Days
		Hired labor	Days
		Wage	Taka
		Purchase cost of goods	Taka
		Rent and storage cost	Taka
		Transportation cost	Taka
		Sale price of good	Taka
		Annual sales	Taka

PARAMETER	COMPLEX VARIABLE	SIMPLE VARIABLE	VALUE
Cottage industries and agro-process-ing industries	Operation	Types	Cottage industries code list (e.g., husking, net making, etc.)
		Period of operation	Years
		Nature	Permanent/Temporary/Contract
		Name of item produced	Fact
		Quantity produced	Number
		Amount of investment	Taka
		Sale price	Taka
		Family labor cost	Taka
		Hired labor cost	Taka
		Other costs	Taka
Household expenditure	Categories of expenses	Clothes	Amount
		Education	Amount
		Ceremonies	Amount
		Health care	Amount
		Groceries	Amount
		Basic food items	Amount
		Miscellaneous	Amount
	Sources of money for expenditure	Household income	Proportion of total expense
		Other sources (proportion of total expense from each source)	Borrowing Bank loan Money lender Gift Sale of land Sale of valuables Others (specify)
	Utilization of borrowed money	Specification	Ceremonies Health care Education Others (specify)

PARAMETER	COMPLEX VARIABLE	SIMPLE VARIABLE	VALUE
Technological information	Modern technology in crop production	MV crop varieties	MV Aus paddy MV Aman paddy MV Boro paddy MV Wheat MV Potato
		Years using MVs	Years
		Source of knowledge on MV (for each type)	Extension worker Demonstration plot Field day Media (Radio/TV) Neighbor
		Reason for using MVs	High yield High price Short maturity Good quality Other (specify)
		Reason for not using MVs	Poor quality Seed unavailable Unreliable yield Lack of irrigation Unavailability of fertilizers/pesticides Low price Disease prone/low resistance Labor intensive No fodder for livestock Others (specify)
	Traditional technology in crop production	Reason for using traditional varieties	High quality High price Reliable yield High resistance to disease Low labor requirement No need of irrigation Others (specify)
		Reason for not using traditional varieties	Low yield Low price Low quality Long production period Others (specify)

PARAMETER	COMPLEX VARIABLE	SIMPLE VARIABLE	VALUE
Access to Infrastructure	Physical infrastructure	Types of infrastructure	Wholesale market Primary market/Haat/Bazaar Storage Fertilizer sales centre Automatic rice mill Upazila headquarter Union office Extension office Bank Post office Paved road Bus stop River transport Railway station Electricity Health care centre Primary school Secondary school (boys/girls)
		Distance	Within village Miles from village
		Cost of travel	Taka
		Time takes	Hours
Environmental impact of modern agricultural technology	Impact integral to the production process	Type of impact (farmers' perception and their relative rankings)	Reduce soil fertility Increase soil erosion Increase salinity Compact soil Chemical residues in soil Water logging Pest and disease attack Pesticide resistance Human disease Eutrophication of water/pond Chemical runoff in water

Note: The present co-ordination schema is a summarized version of the detailed schema.
Source: Prepared from the Household Level and Village Level Survey Questionnaires utilized for the local-level component of the present study.

APPENDIX C

SOCIO-ECONOMIC AND ENVIRONMENTAL IMPACTS OF TECHNOLOGICAL CHANGE IN BANGLADESH AGRICULTURE

HOUSEHOLD QUESTIONNAIRE

Strictly Confidential
Only for Research

General Particulars:

District ______________________________
Thana ______________________________
Union ______________________________
Village ______________________________
Household No.______________________________
Name of Household Head (HHH) ______________________________

Name of the Interviewer ______________________________
Date of Interview ______________________________

Scrutinized __________
Spot-checked __________
Re-interviewed __________
Edited __________
Coded __________

A1 HOUSEHOLD INFORMATION

1. Relationship with household head (HHH): ______.
2. Age of household head: ____ yrs. Education: _____ completed years of schooling.
   Primary occupation: _________. Secondary occupation: _______________.
   Farming experience:_________ yrs. Marital status: ___________.
3. Total household members: ______ persons. Total working men: _____ persons.
   Total working women: _____ persons.
4. Educated members of household: ______ persons (minimum above Class V).
   Educated men: _____ persons. Educated women: ______ persons.
5. Highest level of any household members:
   Men: _____ (Yrs. of schooling). Women: ______ (Yrs. of schooling).
6. Membership in any organization: Yes ☐ No ☐.
   (If yes) Total members: Men: _____ persons. Women: _____ persons.
   Name of organization of the men members: _______________________________.
   Name of organization of the women members: ____________________________.
   Length of membership: Men: _______ yrs. Women: ________ yrs.

A2 LAND OWNERSHIP AND TENURIAL STRUCTURE

1. How much is your total owned land? _______ decimals. (Spell out following categories).

(Units in decimals)

Homestead	Cultivated	Rented out	Leased out	Mortgaged out

2. How much is your farm size last year? ________ decimals

3. About your farm size last year. How much is your own and how much is rented-in/leased-in/mortgaged-in in last year? (Spell out the following categories).

(Units in decimals)

Owned land	Rented-in land	Leased-in land	Mortgaged-in land

4. What **Rental Arrangements** you had for the rented-in land of yours last year?

Arrangement		Irrigated land	Rainfed land
Fixed rent System	Cash		
	Kind (Specify)		
Crop sharing System (Specify both In % and Value)	Output share		
	Fertilizer share		
	Irrigation share		
	Labor share		
	Draft power share		
Others	Specify		

A3 CROP PRODUCTION

1. What types of crops did you grow in the last year? (First record types of crops grown by the farmer and then ask details).

____.

Name Of crop	Variety	Area cultivated (dec.)	Land owning category	Total production (kg)	Use of total production (kg.)						
					Consump tion	Kept as seed	Sold	Price (Tk/kg)	Value of sale	Stored	Debt service
1	2	3	4	5	6	7	8	9	10	11	12

A4 CROP DAMAGE

	Aus local	Aus HYV	Aman local	Aman HYV	Aman pajam	Boro local	Boro HYV	Wheat local	Wheat HYV
Percent damaged									
Area cultivated year before									
Production obtained then									

A5 COSTS OF CROP PRODUCTION

Name of crop	Land owning category	Area cultivated (dec.)	Seed cost			Ploughing cost			Fertilizer cost	
			Own (kg)	Buy (kg)	Price (Tk/kg)	Own (A. day)	Buy (A. day)	Price (Tk/AD)	Qty (Kg)	Price (Tk/kg)
1	2	3	4	5	6	7	8	9	10	11

Name of crop	Manure cost			Labor cost			Irrigation cost (Tk)	Pesticide cost (Tk)	Other equipment hiring cost (Tk)
	Own qty. (kg)	Purchased qty. (kg.)	Price (Tk/kg)	Own (Mandays)	Hired (Mandays)	Wage (Tk/manday)			
1	12	13	14	15	16	17	18	19	20

A6 FERTILIZER USE INFORMATION

What types of fertilizers did you use in your crop land?

Name of crop	Types of fertilizers							
	Urea		Triple Super Phosphate (TSP)		Muriate of Potash (MP)		Gypsum	
	Quanity	Value	Quantity	Value	Quantity	Value	Quantity	Value
HYV paddy								
Local paddy								
Wheat								
Potato								
Vegetables								
Others (Specify)								

1. Do you think you are applying enough fertilizers and pesticides for your farm?
   Fertilizers: Yes □. No. □.

2. (If "No") How much more you need? (Specify the fertilizer and chemical types):
   Fertilizers: __________ kg.

3. Where do you buy your fertilizers?
   Place: _________________. Distance from village: ______________ km

4. Do you have any problems in buying fertilizers?
   Fertilizers: Yes □. No □.

   (If "Yes") What are those problems? Please provide details.
   ____
   ____.

A7 PESTICIDE USE INFORMATION

Which type of pesticide do you use? (Specify each types used for different crops)

Crop Name	Names and prices of pesticides			
Paddy				
Wheat				
Potato				
Vegetables				
Others (Specify)				

1. Do you think that you use appropriate amount of pesticides for your crops?
   Yes □. No □.

2 (If "No") How much more you would like to use?
Pesticide: _______ kg. or litre.

3. Where do you buy your pesticides?
Place: _________________. Distance from village: ______________ km

4. Do you have any problems in buying pesticides?
Pesticides: Yes □. No □.

(If "Yes") What are those problems? Please provide details.
____
____.

5. How many times you generally use pesticides: ________ times.

6. What are the good and harmful effects of using pesticides? (Please write in details).

Good effects	
Harmful effects	

7. What do you think about the current use-level of pesticides for your farm operation?
____
____
____

A8 DETERMINANTS OF MODERN VARIETY SELECTION

1. How long have you been growing MV/HYVs ?
HYV paddy: ______ yrs. HYV Wheat: _______ yrs.

2. What are the sources for your HYV paddy and wheat seeds?

Source	Aus HYV	Aman HYV	Boro HYV	Wheat HYV	Potato HYV
Own					
Purchase					

3. Please provide your opinion on the following questions. Why do you grow HYV? What is the most important factor regarding these HYV? If you do not grow HYV, please provide your reasoning for that too. (Spell out all the "reasons for growing HYV" first and ask to **rank** these reasons over a **five- point scale**. Then repeat the procedure with "reasons for not growing HYV").

Reasons for Growing HYV	1 = Yes 2 = No	If "Yes" Then Rank
High yield		
High price		
Ready market		
Short maturity period		
High quality		
Higher profit		

Reasons for not growing HYV	1 = Yes 2 = No	If "Yes" then Rank
Seed unavailability		
Unreliable yield		
Lack of irrigation		
Fertilizer shortage		
Pesticide shortage		
Low price		
Poor quality		
Disease/Pest prone		
Labor intensive		
No fodder output		
High production cost		
Others (Specify)		

4. Please provide your opinion on the following questions. Why do you grow local variety? What is the most important factor regarding these local varieties? If you do not grow local variety, please provide your reasoning for that too. (Spell out all the "reasons for growing local variety" first and ask to **rank** these reasons over a **five-point scale**. Then repeat the procedure with "reasons for not growing local variety").

Reasons for Growing Local Variety	1 = Yes 2 = No	If "Yes" then Rank
Reliable yield		
High price		
Ready market		
High quality		
Higher profit		
Low labor requirement		
Disease resistance		
No need irrigation		
Low production cost		
High fodder output		
Others (Specify)		

Reasons for not growing Local Variety	1 = Yes 2 = No	If "Yes" then Rank
Low yield		
Low price		
Poor quality		
Also need fertilizer		
Also need pesticide		
Long maturity		
Nobody do it		
Others (Specify)		

A9 PRODUCTION TRENDS

1. Do you think that the over the past five year, the per bigha production of HYV is:
Increasing ☐ Decreasing ☐ or At the same level ☐ ?

2. (If "decreasing") Please explain why? ____
____.

A10 MODERN TECHNOLOGY USE

Land Owner Category	Area tilled by Power Tiller/Tractor	Area under irrigation				Area under land type		
		DTW	STW	Others	Traditional	Single cropped	Double cropped	Tripple cropped
1	2	3	4	5	6	7	8	9
Owned								
Rented-in								
Leased-in								
Mortgaged-in								

A11 ENVIRONMENTAL IMPACT OF MODERN TECHNOLOGY

1. Are you aware that there are environmental impacts associated with the adoption of modern agricultural technology? Yes □. No □
(If "Yes"), provide examples:________________________________
(If "No"), explain reason: ________________________________

2. Do you agree that the following environmental effects occur as a result of the use of modern agricultural technology?

Effects	1 = Yes 2 = No	If yes then rank the inidividual effects on a five-point scale
Reduces soil fertility		
Increase soil erosion		
Increase soil salinity		
Compact the soil		
Leaves chemical residues in soil		
Creates water logging		
Increase pest attack		
Increase disease		
Effects human health		
Deteroriates nearby water body		
Causes chemical runoff in water		
Reduces fish catch		
Others (Specify)		

A12 INCOME FROM RENTED-OUT/LEASED-OUT/MORTGAGED-OUT LAND

1. Now I would like to ask you about the income from your rented-out land?

Leased-out area (dec.)	Any written condition	Share of output received			Share of input cost	
		Type	Qty (kg)	Value (Tk)	Share type	Value (Tk)
1	2	3	4	5	6	7

A13 LIVESTOCK INCOME

1. Now I would like to ask you about the livestock you own. How many of the following livestock do you own?

Types	Number	Estimated present value (Tk)	Weekly caring expenditure				Use of this livestock asset in last one year					
			Own labor (Days)	Hired labor (Days)	Wage (Tk/ day)	Food cost (Tk)	Sold (Tk)	Con-sumed (Tk)	Lost (Tk)	Milk/ Eggs (Tk)	Manure (Ton)	Draft power (Days)
1	2	3	4	5	6	7	8	9	10	11	12	13
Cattle/Bull												
Cow												
Buffalo												
Goat/Sheep												
Poultry												
Others												

A14 FISHERIES INCOME

1. Now I would like to ask you about Pond Fisheries.

Serial Number Of pond	Area	Owner ship	Use last year	Fish types	Expenditure incurred last year (in Tk)					Returns in last year (Tk)			
					Pond prepare	Fry release	Ferti-lizer	Fish harvest	Pond rent	From sale	Con-sumed	Pond owner	Present Stock
1	2	3	4	5	6	7	8	9	10	11	12	13	14

A15 OFF-FARM INCOME

1. Now I would like to ask you about Off-farm income of each of the members of your household for the last one week. Who did what type of work in last week?

Name of person (household members)	Worked during last week		Earnings	
	Details of work	Days worked	Type	Amount (Tk)
1	2	3	4	5

Col.4 : Type of earnings:1 = Daily; 2 = Weekly; 3 = Monthly; 4 = Contract (for the week)
5 = Goods sold; 6 = Paddy husking; 7 = Small trade; 8 = Shop.
9 = Crop sale (crops that are continuously harvested); Others (Specify) _____.

2. If earned through shop/trade, then what is the amount and value of stock? (Fill up all categories in Taka value)

Stock	Credit to be received	Current debt	Own consumption

A16 ASSET OWNERSHIP

1. Do you have the following agricultural implements and assets?

Type of implements	1 = Yes 2 = No.	Number	Present value
1	2	3	4
Plow and Yoke			
Spade/Da/			
Sickle/Khurpi			
Ladder			
Power tiller/Tractor			
DTW			
STW			
Hand pump			
LLP			
Thresher			
Rice mill			
Fishing net			

A17 MARKETING OF AGRICULTURAL PRODUCTS

1. Where do you sell your crops?

Place	Distance from village (km)	Carrying cost (include labor cost) (Tk/ton)	Transportation cost (Tk/ton)
At the farmgate			
Nearest market (Haat)			
Central market			
Others (Specify)			

2. Do you have problems with marketing? Yes □. No □
(If "Yes", provide details): ____
____
____

A18 FOOD STOCK AND STORAGE

1. Do you have sufficient food stock at present? Yes □. No □

2. Where do you usually store your paddy/wheat and other crops?

Place	Distance from village (km)	Carrying cost (Tk/ton)	Transportation cost (Tk/ton)	Storage charge (Tk./ton)
Own storehouse				
Private arat				
Public godowns				
Others (Specify)				

3. Do you have problems with storage facilities? Yes □. No □
(If "Yes", provide details): ____
____

A19 ROLE OF WATER

1. What source of water do you use?

Purpose	Tubewell	Dug well	River	Canal	Pond	Others
Drinking						
Cleaning						

2. What is your opinion about the quality of water that you use from the following sources?

Source	Good	Bad	Open remarks about quality
Tubewell			
Dugwell			
River			
Canal			
Pond			
Others			

3. Which of the listed water sources do you usually use for irrigation?

Sources	Kharif season (Monsoon season)	Rabi season (Winter season)
Rain-fed		
DTW		
STW		
LLP		
Hand pump		
Traditional		
Others (Specify)		

4. Do you think the water supplied by irrigation system is sufficient and timely?
Yes ☐. No ☐

Explain reason in case of “No”: ____

____

5. Do you have any drainage or flooding problems? Yes ☐. No ☐.

6 Do you face the drainage or flooding problems every season? Yes ☐. No ☐.

7. (If “Yes”) What do you do to solve the problem? (Write in details also note the costs involved): ____

____

A20 KNOWLEDGE OF MODERN TECHNOLOGY

1. From where are you getting information on modern technology for your crop (Please rank them)

Type of technology received

Co-farmers ☐ ______________________

Block Supervisor ☐ ______________________

Thana Extension Officer ☐ ______________________

District Extension Officer ☐ ______________________

Demonstration Plot ☐ ______________________

Media/TV/Radio □ ______________________
Field Day □ ______________________
Others (Specify) □ ______________________

2. Did you have any training in rice and wheat production in last 7 years?
Yes □. No □
(If "No") Why? ______________________________

(If "Yes", provide details).

Training types	Duration	Organizers

3. How far is the nearest Agricultural Extension Office from your village? _____ km.

4. How many times the Agricultural Extension Officer visited you in the past one year? _______ times. Why? ______________________________

5. How many times did you visit the nearest Agricultural Extension Office in the past one year? _______ times. Why? ______________________________

A21 LAND ACQUISITION AND CONSOLIDATION

1. Did you purchase any land in the last 5 years? Yes □ No □
(If "Yes" provide details)

Land type	Purpose/Use	Purchase value	Present value	Source of finance
Homestead land				
Cultivated land				
Others (Specify)				

2. Did you sell any land in the last 5 years? Yes □. No □
(If "Yes" provide details)

Land type	Sale value	Present value	Reason for sale
Homestead land			
Cultivated land			
Others (Specify)			

A22 DEBT SITUATION

1. Is anyone of your household members has taken loan and still under debt?
Yes □. No □.
(If "Yes") Please provide details.

Person	Source of loan	Type of loan	Duration of loan	Amount of loan	Use of loan	Rate of interest	Collateral given	
							Type	Value
1	2	3	4	5	6	7	8	9

A23 ECONOMIC CONDITION

The economic condition for the household for the last year.

Condition	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Surplus												
Level												
Deficit												

A24 HOUSEHOLD EXPENDITURE

Now I would like to ask you about the household expenditure incurred last week? (Spell out each items and fill up accordingly).

Item	Purchased			Own source		
	Quantity		Total expense (Taka)	Quantity		Market value (Taka)
	Unit	Total		Unit	Total	
1	2	3	4	5	6	7
Weekly expenditure on following items						
Rice						
Paddy						
Wheat flour						
Fish						
Meat						
Egg						
Milk						
Potato						
Vegetables						
Oil						
Spices						
Sugar						
Beetle nut/cigar.						

Item	Purchased			Own source		
	Quantity		Total expense (Taka)	Quantity		Market value (Taka)
	Unit	Total		Unit	Total	
1	2	3	4	5	6	7
Monthly/Annual expenditure on following items						
Dress/clothing						
Fuelwood						
Education						
Savings						
Running capital						
Debt service (non-formal)						
Bank debt service (formal)						
Investment						
Interest payment						
Maintenance						
Social Work						
Religious Work						
Transport cost						
Others (specify)						

THANK YOU VERY MUCH FOR YOUR TIME

APPENDIX C

SOCIO-ECONOMIC AND ENVIRONMENTAL IMPACTS OF TECHNOLOGICAL CHANGE IN BANGLADESH AGRICULTURE

VILLAGE LEVEL QUESTIONNAIRE

Strictly Confidential **Only for Research**

General Particulars:

District ______________________________
Thana ______________________________
Union ______________________________
Village ______________________________
Household No.______________________________
Name of Household Head (HHH) ______________________________

Name of the Interviewer ______________________________
Date of Interview ______________________________

Scrutinized __________
Spot Checked __________
Re-interviewed __________
Edited __________
Coded __________

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1. What is the total area of this village? ____________ bigha

2. What is the total agricultural area? ____________ bigha

3. What is the total number of households? ____________ HHs.

4. What is the estimated number of population? ____________ persons

5. What are the major soil types?

Soil type	Percent of land area
Loam	
Sandy loam	
Clay loam	
Clay	
Silt	
Silt loam	
Silt sand	
Others (Specify)	

6. What are the composition of low, medium, and high land?

Elevation	Percent of land area
Highland	
Medium highland	
Medium land	
Low land	
Very low land	

7. What are general cropping pattern of this village?

Pattern	Crop sequences
1	
2	
3	
4	
5	
6	

8. What are the approximate area of rice and wheat crops in this village?

Crop Types	Area under cultivation	Year first started
Aus Local		
Aus HYV		
Aman Local		
Aman HYV		
Boro Local		
Boro HYV		
Wheat HYV		

9. What types of irrigation facilities are available in this village?

Irrigation type	Number	Land area under irrigation	Year first installed
Deep tube well			
Shallow tube well			
Hand pump			
Low lift pump			
Irrigation canal			
Traditional			
Others (Specify)			

10. What is the composition of land ownership categories?

Ownership category	Total land area under these	Number of households
Landless		
0.01 - 0.50 dec		
0.51 - 1.00 dec.		
1.01 - 2.50 dec		
2.50 - 5.00 dec		
5.01 - above		

11. What is the tenurial structure of this village?

Tenurial Category	Number of households
Owner operated	
Tenant operated/ Sharecropper	
Part tenant operated	

12. What are the general terms of tenancy?

____

____

13. What is the wage structure for agricultural and non-agricultural activities in this village?

Employment category	Only cash (no food)	Cash and food
Peak season		
Slack season		
Contractual agreement		

14. What is the wage of hired labor for specific agricultural operations?

Operation	Wage (Tk./man-day)		Contractual Arrangement (Tk)
	Cash only (no food)	Cash and Food	
Land preparation			
Sowing			
Weeding			
Irrigation			
Fertilizing			
Harvesting			
Threshing and Winnowing			
Others (Specify)			

15. Does labor shortage occur during peak season?

Yes ☐ No ☐

16. (If "Yes") How the problem is solved? ____

____

____

17. What are the hiring charges for draft power, power tiller and irrigation fee? (Specify unit)

Implements	Peak season	Slack season
Tractor/Power tiller		
Draft animal pair		
Deep tube well		
Shallow tube well		
Low lift pump		
Others		

18. Please provide details of the following infrastructural facilities?

Type of infrastructure	Number	Distance from village	Approximate commuting time	Approximate transport cost
Haat/Bazaar				
Wholesale market				
Local storage depot				
Central storage depot				
Fertilizer sale centre				
Public procurement centre				
Automatic rice mill				
Thana headquarter				
Union office				
Agril. Extension office				
Bank				
Post office				
Paved road				
Bus stop				
River transport				
Railway station				
Petrol sale point				
Health care centre				
Secondary school				
Primary school				
Others (Specify)				

19. Does the village have electricity?

Yes ☐ No ☐

(If "Yes") When installed? ________________________.

20. Does the village have supply?

Yes ☐ No ☐

(If "Yes") When installed? ________________________.

THANK YOU VERY MUCH FOR YOUR TIME