SUSTAINABILITY OF RICE-WHEAT SYSTEM IN EASTERN UTTAR PRADESH: AN ECONOMIC PERSPECTIVE

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SUSTAINABILITY OF RICE-WHEAT SYSTEM IN EASTERN UTTAR PRADESH: AN ECONOMIC PERSPECTIVE

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This is to certify that the thesis entitled "**Sustainability of Rice-Wheat System in Eastern Uttar Pradesh: An Economic Perspective**" submitted to the Post Graduate School, Indian Agricultural Research Institute, in partial fulfilment of the requirements for the award of the degree of **Doctor of Philosophy** in **Agricultural Economics**, by **Mahendra Singh** embodies the results of bonafide work carried out by him under my supervision and guidance. He has submitted no part of the thesis for any other degree or diploma.

I further certify that such help or information, as have been availed during the course of investigation, have been duly acknowledged by him.

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ACRONYMS AND ABBREVIATIONS

CIMMYT	International Maize and Wheat Improvement Centre
CMIE	Centre for Monitoring Indian Economy
DVM	Dummy Variable Model
ECM	Error Component Model
EMP	Estimated Marginal Product
EVMP	Estimated Value of Marginal Product
EVMIRR	Estimated Value of Marginal Internal Rate of Return
FAI	Fertiliser Association of India
FAO	Food and Agriculture Organization
HYV	High Yielding Variety
IARI	Indian Agricultural Research Institute
ICAR	Indian Council of Agricultural Research
IRRI	International Rice Research Institute
IFPRI	International Food Policy Research Institute
ISNAR	International Service for National Agricultural Research
NARS	National Agricultural Research System
NPV	Net Present Value
PFP	Partial Factor Productivity
PRAs	Priority Research Areas
RPAs	Research Programme Areas
SIs	Sustainability Indicators
TFP	Total Factor Productivity

CHAPTER I

INTRODUCTION

Agriculture will face two major challenges in the twenty-first century; in spite of significant advances made in the past: how to feed the growing population, and how to respond to increasing concerns of sustainable use of natural resources (McCalla, 2000). These challenges are especially important for India having large population (around 16 percent of the world population) and relatively less endowed with land and natural resources (2 percent of the world arable land). India's population is projected to rise from 1 billion to 1.3 billion by 2020 AD. On the other hand, on the basis of various cereal demand and supply projection scenarios, cereal supply could be increased up to 260 million tonnes, assuming a reasonable increase in fertilizer and irrigation use along with improvements in genetic potential of crops and efficiency of resource use. However, cereal demand will increase to 296 million tonnes, if the per caput income increases 3.7 per cent per annum, resulting in a demand-supply gap of 36 million tonnes by 2020 (Bhalla *et al.*, 1999).

The contribution of rice and wheat to food and nutritional security in India is significant. These two crops together account for over 55 percent of the area under food grains and over 75 percent of the food grain production in the country (Government of India, 2000). A little over 80 percent of the daily per caput cereal availability is currently contributed by rice and wheat. Since cereals continue to be an important source of carbohydrates and protein, the contribution of rice and wheat to the daily calorie intake of people is significant. However, growth in the production of these two crops has decelerated. The which declined to 3.64 percent in the nineties. In rice, the growth rate was 4.29 percent per annum, which decelerated to 1.60 percent during the corresponding period. This slow down in the production growth was largely because of slowing down of productivity growth. The production of coarse cereals and pulses, in spite of regular normal monsoon years during the last twelve years, also remained stagnant.

Much of the production of rice and wheat comes from the rice-wheat system followed in the Indo-Gangetic Plains under irrigated conditions. Rice crop is grown in *Kharif* season and wheat crop in *Rabi* season in the same field in an agricultural year. However, other crops, such as legumes, oilseeds, sugarcane, etc. are also grown in this system frequently. The rice-wheat system is practiced in Uttar Pradesh since 1872 AD and has spread to the erstwhile combined Punjab by 1920 A.D. (Woodhead *et al.,* 1994). Now the system is widely practiced in the states of Uttar Pradesh, Punjab, Bihar, Haryana and West Bengal.

1.1 Concept of Sustainability

Expansion of the rice-wheat area resulted from three main components: (i) increased adoption of rice-wheat sequences by farmers in those zones (particularly in Uttar Pradesh) where rice-wheat system was a long-established practice; (ii) introduction of post-rice wheat into predominantly rice growing zones (as in Bihar and West Bengal) perhaps displacing pulses, oilseeds and coarse grains; and (iii) introduction of monsoon season rice into predominantly wheat growing zones (as in Haryana and Punjab) usually displacing maize, millet, chickpea, or cotton (Woodhead *et al.,* 1994).

Broadly speaking, sustainability can be defined as striking a balance among productivity, natural resources, and the environment at different levels of equilibrium for different agro-ecological situations. This can be basically achieved through the application of eco-technologies, which are rooted in the principles of ecology, economics, and equity. A crop production system using recommended levels of inputs may be economically sustainable, but if it contributes to pollution of groundwater through agro-chemicals it is not ecologically sustainable. In a dynamic sense, a system must be highly productive, harnessing new technologies for increasing yields so as to be able to respond to the demands of increasing human population, with available natural resources.

An operational definition of sustainability as suggested by several researchers, is the maintaining productivity level equal to or greater than its historical average, without depleting natural resource base (Lynam and Herdt, 1989). The most appropriate measure of productivity to determine sustainability of a cropping system is total factor productivity (TFP), which is defined as the value of all outputs produced by the system divided by the value of all inputs used (Herdt and Lynam, 1992). The use of TFP as a measure of sustainability is gaining support over time, and it is observed that much of the increase in crop production in India since 1980s could be attributed to intensification of inputs use, particularly fertilizers, water, machinery, etc.

1.2 Rationale of the Study

Attaining substantial increases in crop yields in future will be much more difficult. Prospects for expanding low-cost irrigation and converting marginal lands into productive arable land are limited. More significantly, the yield-increasing technologies introduced over the past three decades are already being used on much of the land and the use of agro-chemicals is now expected to decrease because of environmental and human health considerations

(Yudelman *et al.,* 1998). The slower rate of yield growth may also result from mining of soil nutrients, declining organic matter levels, increasing salinity, falling water tables and build-up of pests. While there are some new technologies, such as genetically engineered transgenic plants and new plant ideotype in offering for increasing crop yields, their effect on sustainability of production systems is yet to be established. Therefore, a number of questions have been raised about sustainability of the prominent production systems, including the rice-wheat system.

Increasing complexity of agricultural systems along with increasing concerns of society for quality of environment require that agricultural production system be evaluated as a whole rather than in pieces. We must assess total impact of a practice, not just the impact on one component of the system. Identification of technical and socio-economic constraints limiting productivity and sustainability of a system is essential for development and adoption of location specific technologies.

There are considerable variations in productivity, constraints and opportunities in the rice-wheat system. The entire rice-wheat system in the country may be grouped into the regions of high and low productivity. The high productivity region of north India is primarily characterized by fertile lands, assured irrigation, high level of input uses, mechanized farming and scarcity of ground water. On the other hand, the low productivity region of eastern India is characterised by inadequate irrigation, low level of input use, traditional practices, frequent flooding and other weather-induced risks and sufficient availability of ground water. Thus, the rice-wheat system of the eastern region requires a different technological, infrastructure, and policy support.

Agro-ecological specific, micro-level studies on the rice-wheat system sustainability of the rice-wheat system in north India, particularly Punjab and Haryana where deceleration in the productivity growth is being witnessed (Sidhu and Byerlee, 1992; Evenson, 1999). However, these studies were at the aggregate (state) level with greater focus on macro-level issues. The eastern region accounts for a larger proportion of the total area under rice-wheat system in the country, and there is a dearth of systematic studies in this region. The present study is, therefore, an attempt to provide insights into the sustainability of the rice-wheat system in eastern Uttar Pradesh, using secondary as well as primary data.

1.3 Objectives

Following are the specific objectives of this study:

1. To study the temporal changes in agriculture;
2. to study trends and determinants of crop productivity in the rice-wheat system;
3. to characterize the rice-wheat system and resource use pattern in the context of long- term sustainability;
4. to identify the constraints to accelerate and sustain productivity of the rice-wheat system; and
5. to suggest priority research areas and policy measures to accelerate and sustain productivity of the rice-wheat system.

1.4 Organization of the study

Apart from the introductory chapter, the study is organized into six chapters. Chapter II reviews the relevant studies related to the study. Chapter III describes the biophysical and socio-economic characteristics of the study area (eastern Uttar Pradesh). Chapter IV presents the analytical methods used for fulfilment of different objectives of the study. Results of the study are discussed in Chapter V. Finally, last chapter summarises the main findings and

CHAPTER II

REVIEW OF LITERATURE

This chapter presents a brief review of the literature related to the present study. For lucidity and convenience, the review is organized under following sub-heads:

2.1 Growth in Agriculture;

2.2 Instability in Crop Production;

2.3 Measurement of Total Factor Productivity;

2.4 Measurement of Sustainability of Production System;

2.5 Characterization of Agricultural Production Systems; and

2.6 Analysis of Yield Gap and Production Constraints.

2.1 Growth in Agriculture

A large number of studies have been conducted to estimate the growth in agriculture and changes in cropping pattern in terms of 'expansion' and 'substitution' effects by calculating crop area-gross cropped area elasticity of various crops. Some of the pertinent studies relating to different aspects are presented here.

Alagh and Sharma (1980) studied productivity changes in crop sector at all India level for two periods: 1960-61 to 1969-70 and 1969-70 to 1978-79. They had chosen the cut-off point as the year (1969-70) in which the coverage of HYVs rose to around 10 percent of the area under food grains. They reported that growth rate in the second period was generally higher than those in the period first.

Dandekar (1980) discussed the methodology for estimating growth rates in agriculture. He suggested that in strict logic, the choice of growth functions should be on a priori grounds, such as the theory or a hypothesis underlying the set of observations. He further suggested that semi-log equation was preferred over the linear equation for estimating growth rates in the case of agricultural production and resources.

Venkataramanan and Prahladachar (1980) analysed the growth rates in area, yield and output of major crops in six states, namely; Punjab (including Haryana), Rajasthan, Uttar Pradesh, Bihar, Maharashtra and Andhra Pradesh in the period 1950-51 to 1974-75 and studied the impact of disparity in the growth rates on cropping pattern in these states. This study differed from earlier studies in two important aspects. Firstly, by relating the disparity in the rates of growth in individual crops to the changes in cropping pattern, it was an attempt to offer a plausible explanation for the state level changes in the cropping pattern. Secondly, it suggested a method of measuring the aggregate change in the cropping pattern of a state in terms of 'substitution' and 'expansion' effects by comparing area growth rates of individual crops with the corresponding growth rate in gross cropped area. They reported that farmers were rational in their production behaviours and that they could maximize their net returns through input allocation decisions including area allocation. There were decisions based on expectations relating to price and yield of a crop in relation to its competitive crops.

Rao *et al.* (1981) estimated compound growth rates of area, production and productivity of rice in different states of India by using the semi-log equation for the pre-HYVs period (1955-56 to 1964-65) and post-HYVs period (1965-66 to 1977-78). The results revealed that the growth rates in area were lower in the post-HYVs period but the productivity growth increased during the post-HYVs period. The growth rates in production were higher in the post-

Pandey *et al.* (1985) studied the growth in inputs and outputs for various districts of Haryana during the pre-green revolution period (1956-57 to 1965-66), the green revolution period (1966-67 to 1973-74) and the post-green revolution period (1974-75 to 1981-82). They reported that in spite of rapid growth in use of modern inputs, growth in the productivity has declined and agricultural output nearly stagnated in the post-green revolution period.

Sharma (1988) examined the production performance of Punjab agriculture. The growth rates of area and yield of major crops were calculated at the district level for the period of 1965-66 to 1984-85. He observed that the cropping pattern has witnessed a major shift in favour of wheat in *rabi* season and rice in *kharif* season. Area under wheat has increased mainly at the cost of gram, rapeseed and mustard, whilst the area under rice had increased at the cost of maize, groundnut, and cotton.

Gupta and Jain (1992) studied regional and temporal variations in bovine stock in India. They reported that the bovine population in India is fast changing in favour of milch animals. On the other hand, a fall in male population of cattle and buffaloes indicates the impact of mechanisation of agriculture on draught animal population in several states.

Sharma and Pandey (1992) examined the trends in different land use classes in various states of India. They reported that area under permanent pastures and grazing lands, barren and unculturable lands showed negative trends. The area under non-agricultural uses, cultivable wastes and fallow showed a positive growth in most of the states.

Dhindsa *et al.* (1995) studied the growth in area, production and productivity of various crops in relation to the cropping pattern changes in the state of Punjab during the period of 1965-66 to 1990-91. The relative contribution of various components to the growth of crop output in the state was worked out using seven factors additive model suggested by Minhas (1966). The aggregate changes in the cropping pattern in terms of expansion and substitution effects were measured by calculating crop area-gross cropped area elasticity of various crops. They also analysed the contribution of various crops in terms of total returns. The study revealed that total changes in cropping pattern in terms of substitution and expansion effect showed greater contribution of expansion effect than the substitution effect on crop areas. The cropping pattern was unbalanced and in favour of food grains crops and within food grains shift had taken place in favour of cereals against pulses, which were the major source of protein in the diet of the people. The study suggested that there was a need for diversifying the cropping pattern of the state. To do so, substitutable crops vis-à-vis wheat and rice had to be made relatively more profitable. Also, rice-wheat system should be de-emphasized to avoid the depletion of underground water and fertility of land.

Sundaravaradarajn *et al.* (1998) analysed the performance of agriculture sector in Pondicherry during the period of 1956-57 to 1994-95. They observed that the production of non-food crops such as sugarcane increased at the rate of 0.44 percent per annum due to area expansion. On the other hand, a decline in area under food crops was more than compensated by increase in productivity resulting a growth of 3.18 percent in the production.

2.2 Instability in Crop Sector Production

Instability in area, production, yield and prices of crops were studied from time to time in various contexts. Some of the pertinent studies are as follows:

Sen (1967) examined relationship between growth and instability in Indian agriculture production. He hypothesized that instability in agricultural production increased due to expansion of cultivation to the marginal lands and increased use of purchased inputs.

Mehra (1981) studied how the improved seed and fertilizer-based technologies have contributed to increase in the instability of agricultural production. Instability was measured around the trend and dividing the time period into the pre and post-green revolution periods carried out the analysis. The results showed that out of 18 crops examined, the standard deviation (SD) of production rose in 15 crops and the coefficient of variation (CV) of production rose in 12 crops. Higher yield variability was dominant source of production variability. However, the instability in the non-food grain crops has decreased. Further, it was observed that larger area under wheat, rice, potato and sugarcane was irrigated and hence, these crops showed lower yield variability in the post-green revolution period. Similarly, states having larger irrigated area showed less variability in crop production.

Hazell (1982) studied the instability in Indian food grain production from 1954-55 to 1977-78. He divided whole period into two periods: pre-green revolution (1954-55 to 1964-65) and post-green revolution (1967-68 to 1977-78) period. The variance measured around the trend, of total cereal production in the country increased by 342 percent between the two periods. Of this increase, only about 6 percent can be attributed directly to increases in the variances of individual crop yield measured at the state level. The lion's share of the increase (82 percent) was attributed to increases in the covariance of production between crops grown in the same and different states. Furthermore, increases in intercrop and interstate yield covariance were the dominant sources of the increases in these production co-variances. He concluded that "production instability is an inevitable consequence of rapid agricultural growth and there is little that can effectively be done about it". However, he suggested that redistributing the production among different states in more risk efficient way could reduce the variance of production, but it was difficult to implement in the existing agricultural policy situation.

Pal (1986) also examined the impact of new technology on change in variance of production during the post-green revolution period over the pre-green revolution period. He concluded that the adoption of modern cultivars could be positively correlated with the increased production instability. The absolute variability can increase with the rapid growth of production but the relative variability could be reduced under efficient management conditions. He suggested the use of multivariate analysis based on micro-level data for explaining area and yield variability and to desired policy variables to be manipulated for achieving greater stability.

Singh and Byerlee (1990) analysed the data from 57 wheat-producing countries of the world. They reported that relative variability in wheat yield declined over time and expansion of modern wheat varieties have contributed to the decrease in the variability of wheat yield.

Bahl and Pal (1995) examined the magnitude and causes of instability in crop production at district and showed its implications at aggregate level. They used CV to measure the magnitude of risk in area, production and gross returns per hectare for all the crops. The probability of actual yield and gross returns per hectare falling 5 per cent or more below their respective trends values were also estimated. They reported that yield fluctuation was major source of instability. The instability was comparatively higher in the lower Gangetic Plains, Western Plateau and Gujarat Plains. The analysis of causes of price instability indicated that price instability originated on demand side. In the event of price stabilization, this would have adverse effect on farm income perhaps through depressing prices realised by farmers. Nevertheless, government interventions in food grain markets have been successful in achieving stability in prices and availability of food grains, but at a very high cost-food subsidy. They suggested that reduction in grain losses, storage at proper locations and rational movement of stocks would reduce the food subsidy significantly.

Menon (1996) examined the regional and temporal variation in the growth and instability of productivity of wheat in India. He divided the study period (1956 to 1995) into 4 sub-periods, namely, pre-green revolution period (1956 to 1965), green revolution period (1966 to 1975), post-green revolution period (1976 to 1985), and current decade (1986 to 1995). Growth in productivity was quantified by average annual increment in productivity measured by the regression coefficient of productivity on time scale. The CV of productivity between years adjusted for regression quantified instability. He reported that in the most of the states the instability was highest during the second period, when growth was also highest. After the second decade, there was a general declining trend in the instability during the subsequent periods. This might be due to stabilization effect of the new technology.

Deb *et al.* (1999) examined nature and extent of growth and variability in sorghum yield and tested the hypothesis that rapid technological change increased yield and also instability in sorghum production. They analysed data from 146 major sorghum-producing districts of India. They used Cuddy-Della Valle (Weber and Sievers 1985) index of instability, which a CV corrected form. They concluded that modern sorghum cultivars contributed to the increase in yield and reduced relative variability in yield.

2.3 Measurement of Total Factor Productivity

Productivity is generally defined in terms of the efficiency with which the factor inputs such as land, labour, seeds, fertilizers, etc. are converted to measures of productivity: partial factor productivity (PFP) and total factor productivity (TFP). The ratio of output to a single input measures the PFP of that input. The ratio of output to all inputs combined is the TFP. Earlier approaches to productivity measurement were based upon partial productivity indices, typically land and labour productivity. Although partial productivity measures provide insights into the efficiency of an input in the production process, they mask many of the factors accounting for observed productivity growth and they are, incomplete as measures of economic efficiency. They are very sensitive to both the composition of outputs and the relative intensity of various inputs. For example, increases over time in an index of output per man-day may simply reflect the substitution of capital for the labour input, the realization of economics of scale, rather than purely technological progress. For this reason, the use of TFP measures, in which changes in output is related to changes in all inputs, is recommended. This will yield a more accurate measure of productivity advancement. Conceptually, TFP measure is a clear improvement over single factor measures, since they are based on comprehensive aggregates of outputs and inputs, and changes in the quantity and quality of all inputs can be accounted for (Capalbo and Antle op cit.). A sustainable system should have a non-negative trend in TFP over period (Lynam et al., 1989 and Ehui and Spencer 1990).

Evenson and Jha (1974) worked out growth in TFP for different states during 1953 to 1971. Their output index had constant weights but the input index was more close to the Divisia index. They concluded that during 1953-56 to 1958-61, most of the states performed well in terms of the growth in TFP. But the growth pattern started changing during 1958-61 to 1963-65 and a clear deceleration in the TFP was noticed during 1963-65 to 1969-71.

Ball (1985) constructed Tornqvist-Theil indices for outputs, inputs and TFP to measure the productivity in U.S.A. agriculture for the period of 1948-79. He reported that TFP grew at an average annual rate of 1.75 per cent, compared with 1.70 per cent per year estimated by the U.S. department of agriculture.

Evenson and Kinsey (1991) reported new estimates of productivity change in Indian agriculture by states for the period of 1956-57 to 1983-84. They estimated that TFP grew at a rate of 1.35 per cent annually over the study period. They decomposed the estimates of TFP for the period 1972-74 to 1982-84. They chose the period because it corresponded to the years following the Green Revolution and thus reflected the contribution of Indian research rather than the research output from outside of India that made the Green Revolution possible. By controlling and separating out the contribution of factors such as irrigation, infrastructure and markets, they concluded that the public agricultural research has been a major contributor to the TFP growth in India. Research that yielded varietal improvements was responsible for one-third of the increase in TFP during the decade, while research resulting in non-varietal improvements accounted for one-fifth. Thus, the public agricultural research was responsible for more than half of the gain in the TFP growth.

Sidhu and Byerlee (1991) estimated TFP for wheat in Indian Punjab for the period of 1971-72 to 1985-86. They reported that input index did not change over time because the increase in the use of chemicals and machinery was neutralised by a decline in labour and animal power inputs. They estimated a growth rate of 2 percent per year in TFP index and the most important source of the growth was the labour saving technology.

Kumar and Mruthyunjaya (1992) estimated TFP for wheat in Indian states during the period 1972-89. They reported that the TFP index increased 1.9 per cent in Punjab, 2.7 percent in Haryana and Rajasthan, 2.6 percent in

Uttar Pradesh and 0.4 per cent in Madhya Pradesh. The TFP growth rates was responsible for 37 to 53 per cent of the total output growth in Punjab, Haryana, and Uttar Pradesh, 17 per cent in Madhya Pradesh, and about all the output growth in Rajasthan.

Rosegrant and Evenson (1992) estimated the annual growth in TFP for the crop sector in Bangladesh, India and Pakistan for the period 1957-88. In India, the TFP grew steadily over time, with slight variation in growth rate over period. The variation in the TFP around trend was due to variation in output as total input use increased overtime. The output growth increased at 3 percent per annum and TFP growth accounted for nearby one third of the total output growth in Indian crop sector.

Dholakia and Dholakia (1993) examined sources of growth in Indian agriculture for three time periods: the pre-green revolution period (1950-51 to 1966-67), initial phase of the green revolution (1967-68 to 1980-81), and the modernization phase (1981 onwards). They reported that technical progress as measured through TFP growth has been the main driving force behind the acceleration of overall economic growth in Indian agriculture during the 1980s. The main determinants of TFP growth were use of modern inputs like fertilizer, HYV seeds and irrigation.

Hobbs and Morris (1996) reviewed the importance of rice-wheat system in meeting present and future food needs of South Asia. They have reviewed several factor productivity studies and concluded that growth in the productivity of South Asia's, rice-wheat system is levelling off and in some areas, it is declining.

Fan (1997) measured the growth in TFP in Chinese agriculture, using newly estimated production and productivity growth indices. He observed that earlier studies overestimate the impact of rural reforms on the growth of production and productivity. Both production and productivity grew at a respectable rate during the reform period. The study also found that in order to promote the long-term growth, which was much needed to feed the Chinese population in the future, it was imperative for the government to increase investment in agriculture as the effects of recent institutional changes has been exhausted.

Fan and Pardey (1997) identified and quantified the effects of a number of growth factors that influenced Chinese agricultural performance during 1965 to 1993. They compared Cobb-Douglas and quasi-translog specification model. They concluded that the importance of any one factor varied markedly over time and across regions. Over the longer run, the increased use of traditional inputs such as land and labour, at least when measured in quality-unadjusted terms, contributed little to contemporary gains in agricultural output, while the increased use of modern inputs like power, irrigation infrastructure, and fertilizer explained more than a third of the growth in output.

Kalirajan and Shand (1997) studied the sources of output growth in Indian agriculture. They estimated technical change as a shift in the production frontiers distinguishing from improvement in the technical efficiency and treated the total input growth as the residual. They used Stochastic Frontier Production Function Model to estimate the TFP. They concluded that TFP growth in the pre-reform period was negative in 4 out of 15 states and that, by the end of decade, it was small for those states where the contribution of TFP growth was positive. The contribution of technology to output growth declined substantially and technical efficiency increased slowly.

Evenson *et al.* (1999) examined the sources and contribution of productivity growth to the growth of total output. They used Tornqvist-Theil productivity, as measured by indices of TFP. These gains had been varied by period and by region but TFP has increased in virtually every district of India. The growth in TFP has contributed 1.1 to 1.3 percent per year to the growth in the crop production. The contribution of conventional inputs was about 1.1 percent per year. The TFP and conventional inputs have thus contributed roughly 2.3 percent to the growth of crop production enabling on increase in per capita food production despite high population growth and limited land resources. They reported that public agricultural research explains nearly 30 percent of the TFP growth between 1956 and 1987 and almost half of it since the Green Revolution. The investment in agricultural extension programs has substantial effects on the growth of TFP. Improved rural markets, irrigation, improvement and modern inputs have also contributed to the TFP growth. They also examined the hypothesis of deceleration in the contribution of the public research and other investments to TFP growth over time. The marginal effect of public research on TFP were moderately higher during 1966-76, than in 1956-65. More importantly, during 1977-87, when returns could be expected to fall in the regions such as Punjab that has been quick to adopt modern varieties, research has higher impact on TFP (50 percent higher than that before the Green Revolution and 17 percent higher than the early Green Revolution period). The marginal impact of the expansion of irrigated area on TFP also increased over time. They suggested that the determinants of TFP could be disaggregated by agro-climatic zone. One of the most important extensions of this work would be research on the effects of changes in the environment on TFP.

2.4 Measurement of Sustainability of Production System

There is no commonly accepted methodology for analysing sustainability of a production system because sustainability has many dimensions such as economic, ecological, etc. However, TFP is a largely applied economic approach, as it captures the effects of a number of variables. In this section all pertinent studies covering TFP and non-TFP approach are reviewed.

Ehui and Spencer (1993) estimated spatial and temporal pattern of growth in TFP of alternative farming systems, paying special attention to valuation of natural stock and flows. They reported that the sustainability and economic viability measures are sensitive to changes in the stock and flow of soil nutrients the inputs and outputs.

Harrington *et al.* (1993) conducted two diagnostic surveys during the rice and wheat seasons in 1992 in Karnal and Kurukshetra districts of Haryana and developed a preliminary assessment of both near-term and potential longer-term problems in the rice-wheat cropping pattern. The survey obtained information on farmers' crop management practices (crops and cropping patterns, water and soil fertility management, Pest and disease management and practices from sowing to harvest). Information on interactions between rice and wheat growing farmers and other entrepreneurs in the farming system was obtained as well. The major problems affecting wheat were (in order of importance) weed competition, declining soil health, poor groundwater quality, low plant population and late planting. In rice, insect pests and diseases were identified as problems. Leaf folder and white-backed plant hopper were the most severe, followed by blast, stem borer, foot rot and bacterial leaf blight. Problems of declining soil fertility and soil health, poor groundwater quality, and groundwater depletion were long-term problems that have implications for the sustainability of the rice-wheat system. They suggested actions to address these problems including additional diagnosis, monitoring to assess the longer-term effects of farmers' practices and alternative technologies, research on alternative solutions to problems that were thought to be well understood, extension and research on policy implications.

Tisdell (1996) examined the difficulty of quantifying the sustainability of a farming system. Economic viability as one the dimension of sustainability, however, depends upon the level of economic returns and uncertainty of returns. Economic viability is also related to the sustainability of the productivity of soil and other natural resources on which economic production partially depends. Economic indicators thus depend in part up on non-economic factors requiring a holistic approach.

Kydd *et al.* (1997) analysed sustainability of commodity system and used Policy Analysis Matrix (PAM). They suggested that PAM is a useful procedure for the integration of technological and economic analysis and can make a substantial contribution to the identification of 'best-bet' lines of technological development. They also suggested how PAM might be modified to incorporate environmental costs and benefits and so address more adequately the sustainability of commodity systems.

Pingali *et al.* (1997) evaluated the successes and shortcomings of growth in rice during Green Revolution period in Asia. They concluded that productivity gains from the Green Revolution technologies are close to exhaustion and sustainability of rice productivity may come through technical change.

Ali and Byerlee (1999) addressed the critical issue of long-term productivity and sustainability of Pakistan's irrigated agriculture. They used Tornqvist-Theil indexing procedure to measure the TFP and translog cost function to analyse underlying effects of resource degradation. They reported that average growth in TFP was moderate high at 1.25 per cent for both crops and livestock but wide regional variation in productivity growth was observed-relatively high growth in wheat-cotton and wheat-mungbean, systems, modest in mixed system of wheat and negative growth in the rice-wheat system. The continuous and widespread resource degradation, as measured by soil and water quantity variables, has a significant effect on the productivity with the largest effect being in the rice-wheat system. Actions at both the technological and policy levels to are needed arrest the degradation of resources.

Islam *et al.* (1999) identified the socio-economic and policy issues constraining sustainability of the R-W system in Bangladesh. The issues identified were mainly the concerns of policy makers, researchers and the farmers for achieving sustainable food self-sufficiency in the country. They used ranking procedure to categorize the socio-economic constraints. Low output price and high input cost were important socio-economic constraints. They suggested that to ensure the application of fertilizers at right time in a balanced dose, farmers should be provided with loan on easy terms and conditions.

Kumar *et al.* (1999) used TFP approach to measure sustainability of the rice-wheat cropping system in India. They also examined the role of legumes in improving the sustainability of this most important and productive system. They observed that the growth in TFP of the system has either declined or stagnated. Legumes can play an important role in improving the sustainability of the system. Ironically, rice and wheat have replaced the principal legumes over a period of time. With the availability of high-yielding and short-duration varieties of important legumes such as green gram, chickpea, black gram and pigeonpea can be incorporated into the rice-wheat cropping system to improve its sustainability and meet the demand for food grains in future without degradation of natural resource.

Pingali and Shah (1999) reviewed the existing evidence on intensification-induced degradation in the rice-wheat systems of the Indo-Gangetic Plains of South Asia. They suggested that the progression towards global integration and competitiveness of domestic cereal agriculture could only be maintained through dramatic reductions in the cost per unit of production. New technologies designed to significantly reduce the cost per unit of output produced, either through a shift in the yield frontier or through an increase in input use efficiencies would substantially enhance profitability of the production systems. Increasing input use efficiency could also contribute significantly to the sustainability of intensive crop production system.

2.5 Characterization of Agricultural Production Systems

Characterization of a production system helps to identify micro-level indicators of un-sustainability. This section reviews studies conducted on this aspect.

Paris *et al.* (1982) analysed cropping systems in different environments in Philippines and found that biophysical factors were the main determinants for the cropping systems. Among socio-economic factors, farm size was a dominant factor, but farmer's age and education did not have any influence on the system.

Saunders and Klatt (1987) examined the characteristics of tropical wheat environments and identified production constraints in Thailand, Indonesia and Philippines. They reported that high input cost was major constraint in the region and in some cases; fertilizer use was decreasing due to increase in its prices.

Pathak (1991) characterized the rice growing environments in eastern Uttar Pradesh, using block-level information as well as field survey data. The field survey comprised information on land use, landscape, hydrology, irrigation productivity and problems of farmers in rice cultivation. He reported that in eastern Uttar Pradesh rice is largely grown under lowland environments, where irrigation requirement is rather low. This has increased the share of rainfed rice in the region.

Hobbs *et al.* (1992) conducted a diagnostic survey to examine farmers' practices, system interactions, productivity and sustainability of the rice-wheat system in Faizabad district of eastern Uttar Pradesh. They suggested that opportunities such as removal of the constraints to improve the productivity of the rice-wheat system should not be neglected and there is a need for further in-depth analysis of production constraints in the system.

Hansen and Jones (1996) developed framework for diagnosing constraints to sustainability of a farming system. They suggested that for a dynamic and purposeful system, sustainability is defined as its ability to continue into the future. They also pointed out issues, which normally arise in applying the framework to a particular farm, such as selection of an appropriate time frame, making assumptions about the future behaviour of system inputs, specifying criteria for system failure and identifying potential determinants of sustainability.

Wood and Pardey (1997) described how biophysical data are used in conjunction with agro-ecological concepts to systemically evaluate the effects of agricultural R & D in ways that inform research priority setting and resource allocation decisions. Agro-ecological zones can be devised to help estimate the varying site-specific responses to new agricultural technologies and to evaluate the potential for research to spill over from one agro-ecological zone to another.

Adhikari *et al.* (1999) conducted benchmark survey to collect data on farmers' resources and production practices in the rice-wheat system in Nepal. They reported that rice and wheat were major crops grown in summer and wheat area sown by broadcasting. In rice crop, median date of transplanting was 15th July, and in case of wheat, its ranges between 22 October to 22 December. They suggested that soil fertility, crop establishment and pest management were important for sustainability of the system.

Ouatta *et al.* (1999) reviewed the main characteristics of physical environment that determine water supply of rainfed crops as well as consequences for the production system in Burkira Faso. They concluded that the collection of runoff water for complementary irrigation is a reliable mean of securing stability of agricultural production under harsh climatic conditions.

Taimeh *et al.* (1999) characterised the agro-climatic region in Iran and they suggested that agro-climatic characterization for improving rainfall efficiency is necessary. Such studies will help design cropping patterns, develop water-harvesting systems and apply supplementary irrigation.

2.6 Analysis of Yield Gap and Production Constraints

Agricultural research priority setting is the process of making choices amongst a set of potential research activities. Research prioritisation must take into account the magnitude and frequency of factors that limit productivity. This section reviews the studies analysing biophysical and socio-economic constraints of a production and prioritise them for developing research programmes.

Hobbs *et al.* (1990) conducted a diagnostic survey of the rice-wheat system in *Tarai* region of Uttar Pradesh to examine farmers' practices and perceptions. Problems in the Rice-wheat system were identified and prioritised. They reported that nutrient depletion, rats, brown plant hopper, inefficient fertilizer use, bacterial leaf blight, delayed transplanting of rice and wheat and yellow stem borer were major constraints in the system. They concluded that deceleration in rice yield was due to increase in soil pH, soil born pathogens, decline in organic matter and degradation of physical properties of soil. They opined that the rice-wheat system is not sustainable.

Widawsky *et al.* (1990) studied technical constraints in rice production in eastern India. They identified technical constraints, ranked them in the forms of their importance (crop losses) and assessed their suitability for being solved through varietal improvement. They reported that a substantial increase in production could also be achieved if rice research help reduce production losses due to various biotic and abiotic stresses in rice eco-systems. The gap between the maximum yield obtained in on-farm experiments and the average farm yield is about 50 percent in the rainfed lowland ecosystem and 34 percent for the dry season irrigated rice ecosystem. A large part of the gap (about 40 percent of the yield for the wet season rainfed crop and 15 percent for the dry season irrigated crop) is due to biotic and abiotic stresses. The priority research problem areas are submergence, tungro virus, bacterial leaf blight, weeds and brown plant hopper for the wet season and the brown plant hopper, drought and blast for the dry season.

Islam *et al.* (1992) studied farm level constraints for wheat cultivation in Bangladesh for the year 1987-88. They collected data from 15 districts and reported that 33 percent farmers mentioned about decline in yield due to various constraints, 27 percent farmers realised lower profits, 17 percent have difficulty in threshing and about in 13 percent cases crop sowing was delayed.

Fujisaka *et al.* (1994) conducted diagnostic survey to established long-term priorities in the rice-wheat system in South Asia such as selected locations in Bangladesh, India, Nepal and Pakistan. They reported that short term system problems included poor wheat populations caused by the poor soil structure and plough pan formed for puddle rice, late wheat planting resulting from late rice harvesting and losses to grassy weeds encouraged by continuous rice-wheat system, were soil nutrition depletion and possible build-up of insects, weeds and diseases. They suggested that the system research must continue define and understand long-term trends, to seek ways of improving nutrient cycling and increasing organic matter in the system and diminish the negative effects of rice cultivation on wheat, while remaining aware of the many tradeoffs and drawbacks involved in potential solutions.

Evenson (1996) applied the priority-setting method to review the 130 rice biotechnology programmes in 26 countries. He used net present value (NPV) method for estimation of future benefits and hedonic estimate for estimation of trait value in rice. He reported that if research benefits were delayed by one year, the NPV loss would be $8 billion.

Lin *et al.* (1996) studied rice production constraints in China. They reported that the national average experimental yields are 12260, 11220 and 15790 kg per hectare for early, late and single season rice respectively. Most of the gap between the experimental yields is due to yield gap I. They suggested that there are opportunities for further increasing rice yield in China with research focused on few well-defined constraints. Yield gap I research should concentrate on improving plant structure, photosynthesis efficiency, growth duration and ability to overcome short duration of sunshine and soil conditions. The main areas for yield gap II research include low soil fertility, cold water-logged and acid soil, drought, submergence, lodging, weeds, sheath blight, and stem borer.

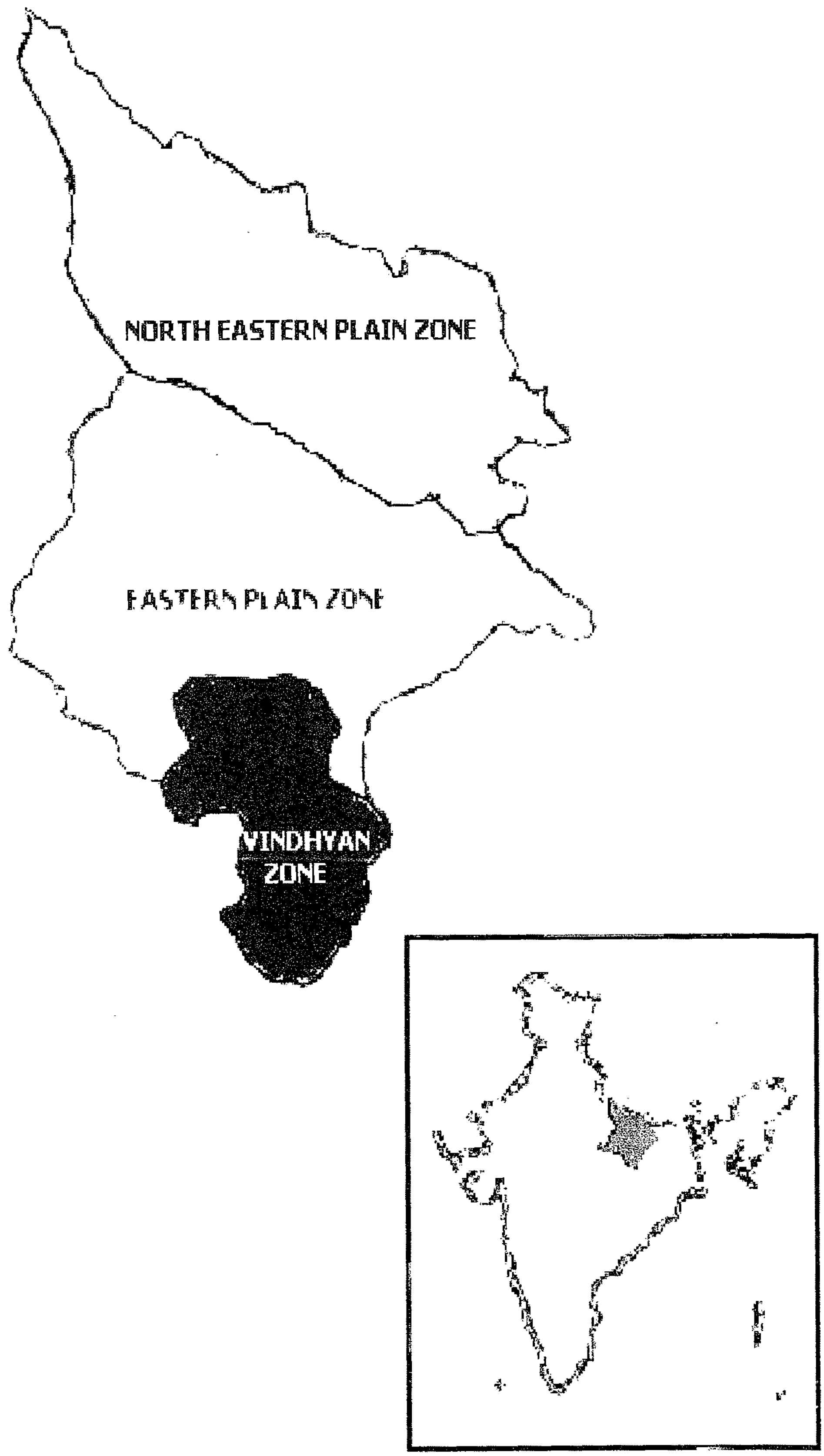
Upadhyaya (1996) conducted survey to prioritise the research areas in Nepal. The marginal value product of research for a particular research problem can be obtained from yield change. Expected yield increases could be approximated by the intensity of the problem or opportunity of each research problem area (RPA). He reported that the severities of the most of technical annual production loss, drought, blast and gandhi bug were the three most important problems. The amount of production loss due to all of the identified technical constraints ranged from 56 to 66 per cent in which the share of diseases was 15 to 19 percent, insects 14 to 21 per cent, storage insects 6 to 13 per cent, 7 to 8 percent due to drought, and 0 to 4 percent due to other constraints, such as lodging, flood, rodents, etc. Hence, technical constraints seem to be responsible for only part of the gap between potential and actual yields.

Ramasamy *et al.* (1997) used ex-ante approach for priority setting in rice research in south India. They used systematic methodology developed by Herdt and Riely (1987) for research priority setting. They also considered losses attributable to socio-economic constraints as the difference between production losses as due to yield gap II and total losses due to all technical constraints. They argued that even yield gap I is not our immediate concern, undoubtedly, it was our long-term concern to meet the food needs of the country. This gap was 33 percent of experiment station yield in Tamil Nadu, 47 per cent in Andhra Pradesh, 44 per cent in Karnataka and 42 per cent in Kerala. The yield gap II in *kharif* season ranged from 162 kg per hectare in Kerala to 658 kg per hectare in Andhra Pradesh and in *Rabi* season, it ranged from 10 percent in Tamil Nadu to 17 percent in Andhra Pradesh. They estimated that the insects in total production loss was 34 percent, followed by diseases 22 percent, physical constraints 12 percent, agronomical and other constraints 22 percent and residual 11 percent was considered due to socio-economic constraints. They suggested that improving the photosynthetic efficiency must enhance yield potential of rice. This could be made possible by biotechnological research and exploitation of hybrid vigour.

Roy and Dutta (2000) prioritised the production constraints in the rice-production losses. A large number of biotic, abiotic and socio-economic constraints were responsible for substantial production losses. Among biotic factors rice blast topped the list, followed by leaf blight, *Phalaris minor*, leaf folder and poor seed quality. Important abiotic constraints were late sowing and problem of brackish water followed by zink deficiency, water stress and low plant population. Socio-economic constraints were related to irregular and inadequate supply of quality inputs like power, water, seed and labour, price risk and low output prices. They suggested that possible research interventions include application of biotechnology to develop cultivars with multiple resistances to various biotic and abiotic constraints. The socio-economic constraints can be addressed through research and policy interventions. The most urgent need is to ensure regular power supply to the farm sector and development of labour saving devices suitable for the rice-wheat system. Similarly, fertilizer subsidy needed to be restructured in favour of potassium and phosphoric fertilizers and use of biological inputs should be promoted. Input supply system should be strengthened through ensuring timely availability of quality inputs.

It is clear from the studies reviewed above that a wide range of issues are important for assessing sustainability of a production system. These issues may relate to macro-level changes in agriculture to micro-level evidences at farm level. Therefore, a realistic approach would be imperative to examine broad trends in agriculture at aggregate-level for a specific eco-region and trace the causes of such changes using both macro and micro (farm-level) evidences. The present study is an attempt in this direction.

Figure 3.1 : EAST U.P AGRO-CLIMATIC ZONES



CHAPTER III

DESCRIPTION OF THE STUDY AREA

Eastern Uttar Pradesh comprising twenty-seven districts occupies one-third of the net sown area of the state. The region supports 38 percent of the state's population. This region is flanked by Nepal on its north, Bihar on its east and Madhya Pradesh, on its south. On the basis of climatic and physical characteristics, eastern Uttar Pradesh is divided into three agro-climatic zones. The Eastern Plain Zone covers 13.4 percent of the geographical area and supports 20.7 percent of the population of the state. The North-Eastern Plain zone covers 11.8 percent of the area and 15.37 percent of population. The Vindhyan Zone is comparatively smaller and covers 3.8 percent of the area and 2 percent population.

Table 3.1 Zonal classification of the districts of eastern Uttar Pradesh.

Zone	Districts
Eastern Plain Zone	Allahabad, Ambedkarnagar, Azamgarh, Ballia, Chandauli, Faizabad, Ghazipur, Jaunpur, Kaushambhi, Maunathbhanjan, Pratapgarh, Sultanpur and Varanasi.
North-Eastern Plain Zone	Bahraich, Balrampur, Basti, Deoria, Gonda Gorakhpur, Kushinagar, Maharajganj, Sant Kabir Nagar, Siddharth Nagar and Shrawasti.
Vindhyan Zone	Mirzapur, Sant Ravidas Nagar and Sonebhadra.

Source: Ghosh, 1991.

There have been numerous reorganizations of the districts. However, for consistency in the analysis, we have maintained those individual districts that existed in 1950. Where new districts have been carved out, data for the resultant district has been added to its parent district. Some districts, which currently exist will therefore, only appear in the agro-ecological zones, but not in the data set.

3.1 Biophysical and Demographic Characteristics

With the ever-increasing human and animal population, demand for food, fuel and fodder has been increasing. However, capacity of lands to produce is constrained by type of soil, management and climatic condition. It is, therefore, imperative that soils and climatic conditions, along with socio-economic conditions of the farming community are considered for assessing performance of different cropping systems.

Climate

Climate of the region varies from semi-arid (moist) to sub-humid (dry). Annual rainfall in the region ranges from 980 mm in Allahabad to 1259 mm in Gorakhpur. The region receives around 90 percent of annual rainfall during four months of monsoon.

Flood is an almost annual feature in certain areas of Azamgarh, Basti, Bahraich, Deoria, Faizabad, Gorakhpur and Gonda. The Gandak, the Ganga, the Ghagra, the Rapti and the Sarju rivers cause heavy flood damages. Floods of the Ganga affect large areas in the district of Mirzapur, Ghazipur and Ballia, while the Gomti affects large areas of Sultanpur and Jaunpur districts. Average area affected from flood accounted for more than 15 percent of net cropped area (Table 3.2) of eastern Uttar Pradesh. Some parts of the region such as trans-Yamuna areas of Allahabad and some parts of Mirzapur and Varanasi districts often experience drought. Rainfall distribution is uneven even within rainy season. In particular, at the time of flowering there is moisture stress or drought, which varies from 15 to 30 days. As a result of frequent occurrence of drought and flood, a large number of poor people migrate to other regions even out of the state to Punjab, Haryana, Delhi, Mumbai, Kolkata, etc.

Table 3.2 District-wise area affected by floods in eastern Uttar Pradesh, 1981-90.

(Area in '000 hectares)

District	Number of years affected during 1981-90	Average area affected	Percent of net cropped area
Allahabad	6	38.47	8.31
Azamgarh	9	45.64	10.69
Bahraich	8	168.61	37.58
Ballia	10	22.76	9.79
Basti	10	113.24	19.98
Deoria	10	48.74	11.43
Faizabad	10	26.91	9.27
Ghazipur	8	24.97	9.65
Gonda	8	151.31	30.94
Gorakhpur	9	74.53	15.19
Jaunpur	7	11.92	4.14
Mirzapur	6	24.00	11.65
Pratapgarh	2	47.33	21.2
Sultanpur	3	27.65	9.57
Varanasi	7	19.83	6.24
Eastern U. P.	8	845.90	15.61

Source: *Statistical Diary* (various issues), Department of Economics & Statistics, State Planning Institute, Uttar Pradesh, Lucknow.

Soils

Soils of the region are generally alluvial. In the Eastern Plain Zone, type of soils includes sandy loam, loam, black soil and red soil. Problem soils in the zone consist of sodic soils and karail soil. In the North Eastern Plain Zone mainly two types of soils are dominant; one is alluvial type and another is calcareous. The alluvial soil includes sandy, sandy loam and clay loam. The main problem in the zone is of water logging. The Vindhyan Zone is dominated by clay loam, black and red lateritic soils. Availability of nitrogen and phosphorus in soil is rather low but potash's availability is moderate to high (Table 3.3).

Table 3.3 Fertility status of soils of eastern Uttar Pradesh, 1998-99.

Nutrient status	Number of districts		
	Nitrogen	Phosphorus	Potash
Very low	1	6	0
Low	14	9	0
Medium	0	0	9
High	0	0	6
Total	15	15	15

Source: *Fertilizer and Allied Agricultural Statistics*, 1999-2000 (Northern Region), Fertilizer Association of India, New Delhi.

Demography

Eastern Uttar Pradesh is a densely populated region. The decadal compound growth rate of population during 1990s was 2.22 per cent per annum, which is more than the decadal population growth of the country as a whole (1.79 percent). A lion's share of the population resides in rural area. As per 1971 census, 92 percent of the total population was living in rural area, which declined to 88 percent in 1991. The share of agricultural labourers was 9 percent that declined to 7 percent in 1991. Literacy rate in the region increased from 19 percent in 1971 to 31 percent in 1991 (Table 3.4). It was also observed that major share of literate and comparatively young and energetic population migrated from the region due to various socio-economic reasons, which might have affected the growth of agriculture in the region. At the same time, a rapid increase in population has put tremendous pressure on food demand, especially for rice and wheat.

3.2 Land Utilization Pattern

Agriculture in eastern Uttar Pradesh is dominated by crop production. Net sown area accounted for 65 percent of the land and area under desirable ecological sector (forests, pastures, etc.) was only 13 percent. Cropping

Table 3.4 Demographic features of eastern Uttar Pradesh, 1971-2001.

Particular	Units	Year				Decadal compound growth rate (%)		
		1971	1981	1991	2001[c]	1970s	1980s	1990s
Population[a]	('000 s)	33178	41652	52721	65654	2.32***	2.41***	2.22***
Population density[a]	No. Person / Sq. Km	386	485	614	766	2.51***	2.43***	2.31***
Rural population[a]	(%)	91.8	89.3	88.4	88.4	2.03***	2.31***	2.22***
Literacy rate[a]	(%)	19.4	24.5	30.5	30.5	4.79***	4.73***	2.22***
Rural literacy rate[a]	(%)	17.1	21.5	27.7	27.7	4.44***	4.99***	2.22***
Percentage cultivators[b]	(%)	17.3	17.1	16.2	16.2	2.19***	1.81***	2.22***
Percentage agricultural labours[b]	(%)	9.0	5.6	6.6	6.6	-2.41***	4.11***	2.22***

Note: ***significant at 1% level; **significant at 5% level; and *significant at 10% level.

Sources: a) *General Population Tables*, (various issues), Directorate of Census Operation, Uttar Pradesh, Lucknow.
b) *Agricultural Census in Uttar Pradesh,* (various issues), Board of Revenue, Uttar Pradesh, Lucknow.
c) *Projected population of India and major states, 1996-2016*, Census of India, New Delhi.

Table 3.5 Land utilization pattern in eastern Uttar Pradesh, 1996.

Particular	Area ('000 ha)	Percent of reported area
Reported area for land utilization	9220	100
Desirable ecological sector	1179	13.52
Undesirable ecological sector	186	2.13
Non-agricultural sector	924	10.60
Agricultural sector	6391	73.29
Net sown area	5662	65.38
Cropping intensity		153

Notes: a) Desirable ecological sector include, area under forests, permanent pastures, other miscellaneous trees and culturable wasteland
b) Undesirable ecological sector includes, area under barren land
c) Non-agricultural sector includes, area under non-agricultural use.
d) Agricultural sector include, area under net area sown, current fallow and other fallow.

Source: *Uttar Pradesh Ke Krishi Ankre* (Various issues), Directorate of Agriculture, Uttar Pradesh, Lucknow.

Table 3.6 Distribution of operational holdings by farm size in eastern Uttar Pradesh, 1991.

Particular	Numbers of holding ('000)	Area ('000 ha)	Average size of holding (ha)
Marginal (< 1 ha.)	7083 (82.3)	2509 (43.4)	0.35
Small (1.0 to 2.0 ha.)	997 (11.6)	1376 (23.8)	1.38
Semi Medium (2.0 to 4.0 ha.)	397 (4.6)	1068 (18.5)	2.69
Medium (4.0 to 10.0 ha.)	116 (1.4)	643 (11.1)	5.53
Large (≥10.0 ha.)	11 (0.1)	187 (3.2)	16.69
All Holdings	8605 (100.0)	5782 (100.0)	0.67

Note : Figures in parentheses are percentage of the total.

Source: *Statistical Abstract*, (Various issues) Department of Economics and Statistics, State Planning Institute, Uttar Pradesh, Lucknow.

Agrarian Structure

Marginal and small farmers accounted for 94 percent of total farmers in the region and they occupied 66 percent of the total operated area. Large farmers occupied only 3 percent of the net sown area. It implies that there is large socio-economic disparity in the study area. The average size of holding is even less than one ha (Table 3.6).

Livestock

Livestock population indicates, to some extent, the extent of off-farm income and degree of diversification. It also influences the soil health in the region through supply of organic matter. As shown in Table 3.7, milch animals largely dominate livestock population. Cows and buffaloes are in equal number. Bullocks are also maintained for draught purposes. In total livestock population other animal such as goats, horses and donkey, etc. also included.

Table 3.7 Livestock population in eastern Uttar Pradesh, 1992.
('000 numbers)

Particular	Number of animals	No. of animals/ha GCA
Milch Animals		
Cow	4452	0.52
Buffalo	4024	0.47
Draft Animals		
Bullock	4481	0.53
Buffalo	131	0.02
Total Livestock	21771	2.56

Source: *Livestock Census* (various issues), Directorate of Economics & Statistics, Ministry of Agriculture, Government of India, New Delhi.

3.3 Rural Infrastructure

The role of institutional credit in accelerating growth of agriculture is very important. Timely availability of credit can help farmers to use their scarce

Rs 437 per hectare in 1998 (Table 3.8). The percent of villages electrified was 84 percent in 1998. The road density in the region is 351 km/thousand of square km.

3.4 Performance of Agriculture

Cropping Pattern

Rice and wheat crops dominate the cropping pattern and these two crops together occupied 70 percent of the gross cropped area during 1997-99. The expansion of area under rice and wheat crops was influenced by components of the Green Revolution strategy such as evolution of high yielding varieties seed, use of agro-chemicals, expansion of irrigated area and government policies. The area under coarse cereals and pulses was 9 percent each in 1997-99. The area under oilseed and commercial crops was 2 and 5 percent respectively (Table 3.9).

Yield and Production of Principal Crops

The performance of yield growth for all the crops (except maize) was remarkable. The compound growth rates of area for rice, wheat, potato, oilseeds and sugarcane were positive and significant, but for other crops (except maize) the growth rate was negative and significant. The growth in the production of rice, wheat, oilseeds, potato and sugarcane was positive and significant and for other crops it was negative and significant. The production of pearl millets and maize remained stagnant. It may be noted that the growth in yield contributed to increased production of rice, whereas it was growth in both area and yield contributing to the growth of wheat production (Table 3.10). Further, in spite of impressive growth, yield of rice and wheat was about 2 tonnes/ha during 1997-99.

Table 3.8 Use of pesticides and credit disbursement in eastern Uttar Pradesh, 1998.

Particular	
Pesticide Consumption ('000 kg.)	
Insecticides	901.2
Fungicides	120.5
Weedicides	114.6
Fumigants (kg)	10.4
Total Pesticides	1146.7
Total pesticides use Per ha. GCA	0.13
Credit Disbursement:	
Total Short Term Loan ('000 Rs)	3130273
Percentage Share of Com. & RRB	55.2
Percentage Share of PACS	44.8
Total Credit Disbursement per ha. GCA (Rs)	437

Source: *Kharif & Rabi Utpadan Karyakram, 1999-2000*, Directorate of Agriculture, Uttar Pradesh, Lucknow.

Table 3.9 Cropping Pattern, yield and production of principal crops in eastern Uttar Pradesh, 1997-99.

Crop	Area ('000 ha)	Percent of gross cropped area	Yield (qt/ha)	Production ('000 tonnes)
Rice	2892	33.5	20	6054
Wheat	3182	36.9	23	7518
Sorghum	72	0.8	9	68
Pearl millet	123	1.4	12	125
Maize	371	4.3	9	319
Barley	91	1.1	15	137
Small millets	42	0.5	9	19
Total pulses	776	9.0	6	88
Total oilseeds	143	1.7	9	759
Potato	123	1.4	168	1944
Sugarcane	327	3.8	466	14910

Source: a) *Uttar Pradesh Ke Krishi Ankre* (Various issues), Directorate of Agriculture, Uttar Pradesh, Lucknow

b) Kharif and Rabi Utpadan Karyakram, 1999-2000, Directorate of Agriculture, Uttar Pradesh, Lucknow.

Table 3.10 Compound growth rates of area, yield and production of principal crops in eastern Uttar Pradesh, 1950-99.

(Percent per annum)

Crop	Area	Yield	Production
Rice	0.77***	3.20***	3.99***
	(9.054)	(6.415)	(7.716)
Wheat	3.73***	2.94***	6.78***
	(12.387)	(9.958)	(13.811)
Sorghum	-1.00***	1.14*	-1.00***
	(-4.081)	(1.536)	(-4.081)
Pearl Millet	-0.18	0.94*	0.77
	(-0.653)	(1.398)	(1.128)
Maize	-0.09	0.92	0.83
	(-0.296)	(0.956)	(0.892)
Barley	-5.94***	-1.34***	-4.67***
	(-10.046)	(-6.717)	(-7.872)
Small Millets	-5.87***	0.90**	-5.02***
	(-6.095)	(1.935)	(-4.924)
Total Pulses	-1.38***	0.66***	-0.67**
	(-8.294)	(2.337)	(-2.106)
Total Oilseeds	1.64***	1.15**	2.80***
	(5.827)	(2.170)	(4.954)
Potato	3.00***	2.46***	5.54***
	(16.531)	(6.473)	(10.798)
Sugarcane	0.29**	1.49***	1.78***
	(1.825)	(4.770)	(4.280)

Note: i) Figures in parentheses are estimated 't' values.
*** significant at 1% level
** significant at 5% level.
*significant at 10% level.

Source: *Uttar Pradesh Ke Krishi Ankre* (Various issues), Directorate of Agriculture, Uttar Pradesh, Lucknow.

3.5 Use of Inputs

Fertilizers Consumption: The use of fertilizers increased tremendously with the expansion of area under HYVs. Also, the share of inorganic fertilizers increased in the total supply of NPK. The consumption of nitrogen increased significantly from 15 kg/ha in 1970 to 111 kg/ha in 1998, registering an

Table 3.11 Growth in inputs use and infrastructure development in eastern Uttar Pradesh, 1970-98.

Particular	Units	1970-71	1980-81	1990-91	1998-99[d]	Compound growth rate percent per annum (1970-98)
Fertilizer consumption[a]						
Fertilizer consumption	(Kg/ha of GCA)					
Nitrogen		14.83	42.08	69.19	110.61	7.57***
Phosphorus		4.03	9.78	19.66	26.58	8.10***
Potash		2.74	4.35	5.08	4.58	1.47^{NS}
Total NPK		21.60	53.77	93.92	141.77	7.26***
NPK ratio		5:1:1	9:2:1	14:4:1	24:6:1	
Farm machinery and implements[b]	('000 numbers)					
Tractor		24	27	66	90*	18.01***
Pumpset diesel		17	243	480	549*	13.78***
Pumpset electric		27	75	120	126*	7.14***
Other input variable[c]						
Rice HYVs area	(%)	22	51	76	96	5.03***
Wheat HYVs area	(%)	63	75	93	99	1.50***
Infrastructure variable[c]						
Village electrified	(%)	18	32	71	84	5.21***
Road length	(Km. '000 Sq. Km./ Area)	127	195	285	351	3.81***
Net irrigated area	('000 ha)	2346	2979	3344	3586	0.22***
Gross irrigated area	('000 ha)	2493	3310	4162	4539	0.34***

Note: [1] Indicate data for the year 1992.

Source: a) *Fertilizer Statistics*, (various Issues), Fertilizer Association of India, New Delhi.

b) *Livestock Census* (various issues), Directorate of Economics & Statistics, Ministry of Agriculture, Government of India.

c) *Statistical Abstract and Statistical Diary* (various issues), Department of Economics & Statistics, State Planning Institute, Uttar Pradesh, Lucknow.

d) *Kharif and Rabi Utpadan Karyakram, 1999-2000*, Directorate of Agriculture, Uttar Pradesh, Lucknow.

impressive growth of 7.57 percent. The consumption of phosphorus also increased from 4 kg/ha to 27 kg/ha during the corresponding period. However, the use of phosphorus remained much lower than which is recommended for rice and wheat crops. The consumption of potashic fertilizers did not change much. The consumption of NPK was in the ratio of 5:1:1 in 1950, which rose disproportionately to 24:6:1 in 1998. This ratio is highly imbalanced against a recommended ratio of 4:2:1 (Table 3.11).

Farm Machinery and Implements: As seen from Table 3.11, were has been rapid mechanization of agriculture in the region. The numbers of tractors and pumpsets increased significantly during the last three decades. The rate of increase was particularly high in 1980s.

Adoption of HYVs: The expansion of area under HYVs particularly in case of rice and wheat was quite impressive. HYVs area under rice increased from 22 percent in 1970 to 96 percent in 1998 and in case of wheat, it increased from 63 to 99 percent in the corresponding period. However, it may be noted that adoption of HYVs under wheat was much faster as 63 percent of wheat area in 1970 was under HYVs as against 22 percent of rice area (Table 3.11).

Groundwater Utilization: Eastern Uttar Pradesh is endowed with rich groundwater aquifers and all the districts were extracting water less than its recharge from various sources. The average utilization of groundwater was only 36 percent, which shows that groundwater utilization has not crossed sustainable limits. It does not, implies that water should not be used economically in future (Table 3.12).

Table 3.12 Groundwater utilization in eastern Uttar Pradesh, 1997.

District	Net recharge (million cubic metre)	Net extract (million cubic metre)	Groundwater utilization (%)
Allahabad	1586	564	36
Azamgarh	1649	799	48
Bahraich	1943	774	40
Ballia	986	370	38
Basti	2951	1075	36
Deoria	2293	658	29
Faizabad	1442	694	48
Ghazipur	1124	416	37
Gonda	2140	881	41
Gorakhpur	2449	734	30
Jaunpur	1255	632	50
Mirzapur	1443	253	18
Pratapgarh	1030	290	28
Sultanpur	1500	512	34
Varanasi	1295	367	28
Eastern U.P.	25085	9019	36

Source: *Statistical Diary, 1998.* Department of Economics & Statistics, State Planning Institute, Uttar Pradesh, Lucknow.

3.6 Comparison of Indicators for Agriculture Development

Eastern Uttar Pradesh is characterised by intensive crop production, dominated by marginal and small farmers, small size of holdings, lower irrigation intensity and low level of mechanisation as compared to Uttar Pradesh as a whole, Punjab or country as a whole. On the other hand, intensity of area under food grains, irrigated area under wheat, and rice yield were similar to Uttar Pradesh and all India but different from Punjab (Table 3.13). The fertilizer consumption in eastern Uttar Pradesh is lower than Punjab but is much higher than Uttar Pradesh as a whole and all India; however, the productivity of rice and wheat crop is much lower than the other three regions reflecting inefficient use of the resources.

Table 3.13 Comparative statistics of agricultural development in eastern Uttar Pradesh, Uttar Pradesh, Punjab and all India, 1998.

Indicator	Eastern U. P.	U. P.	Punjab	India
Net sown area of reported area[a] (%)	65.38	58.65	82.40	46.84
Percent of marginal and small farmers in total operational holdings [a]	94	89	45	78
Average size of operational holdings (ha) [a]	0.67	0.90	3.61	1.57
Net irrigated area[b] (%)	56	68.66	92.95	55.14
Area under food grains (%)	87.9	90.42	77.02	65.78
No. of tractors (per '0000 ha GCA)	96	137	282	66
Irrigated area under rice[b] (%)1996	44.61	63.88	99.13	51.05
Irrigated area under wheat[b] (%)	93.09	93.09	96.84	86.21
Fertiliser use (kg/ha)	142	120	177	90
Rice yield (kg/ha)	1879	1958	3152	1928
Wheat yield (kg/ha)	2207	2510	4332	2583

Note : a and b superscript denotes data for the year 1991 and 1996 respectively.
Source: a) *Agricultural Statistics At A Glance, 2000*. Directorate of Economics & Statistics, Ministry of Agriculture, Government of India.
b) *CMIE, Agriculture 2000*. Mumbai.
c) *Fertilizer Statistics*, (Various Issues), Fertilizer Association of India, New Delhi.
d) *Livestock Census* (Various issues), Directorate of Economics & Statistics, Ministry of Agriculture, Government of India.
e) *Statistical Abstract and Statistical Diary* (Various issues), Department of Economics & Statistics, State Planning Institute, Uttar Pradesh, Lucknow.
f) *Kharif and Rabi Utpadan Karyakram, 1999-2000*, Directorate of Agriculture, Uttar Pradesh, Lucknow.

Agricultural development in the region is constrained by lack of infrastructure development and poor reach of government development programmes. Owing to differences in agrarian structure, endowment of natural resources, development of infrastructure and technological penetration, eastern Uttar Pradesh may require a different development strategy than that is suitable for other developed regions. This study was therefore undertaken with this perspective to identify constraints in the existing production system, to develop

CHAPTER IV

METHODOLOGY

This chapter presents the concepts, analytical methods and data used to address the objectives of the study.

4.1Growth in Agriculture

In order to examine the temporal changes in agriculture, growth rates in inputs, outputs and other important variables were worked out using semi-log trend function. The study covered a period of 50 years from 1950-51 to 1999-2000, which was divided into the following four sub-periods:

1) Pre-Green Revolution Period (1950-68);

2). Green Revolution Period (1969-79);

3) Post-Green Revolution Period I (1980-89); and

4) Post-Green Revolution Period II (1990-99).

4.1.1 Changes in Area, Production and Productivity of Crops

If the proportion of area under all crops remains constant over time, then it implies that the rate of growth in area under individual crops must equal the rate of growth in gross cropped area. But a difference between the rates of growth in area of individual crops and gross cropped area provides the evidence of change in cropping pattern (Venkataramanan and Prahaladachar, 1980). A similar measure is the crop area-gross cropped area elasticity that measures aggregate change in cropping pattern in terms of substitution and expansion effects (Dhindsa and Sharma, 1995; Sundaravaradarajan and Jahanmohan, 1998). Total change in cropping pattern is measured from the decline in area under some crops and corresponding increase in area under other substitutable crops and the expansion effect (effect of increase in gross cropped area). On the basis of crop area-gross cropped area elasticity crops can be categorized into following three groups (Venkataramanan and Prahaladachar, 1980).

i) Crops whose growth rate of area equals to or exceed the rate of growth of gross cropped area, i.e. their elasticities being equal to one or more than one.

ii) Crops whose area growth rate is less than that of gross cropped area but positive, i.e., their elasticities being positive but less than one.

iii) Crops whose area growth rates are negative, i.e., their elasticities being less than zero.

Crops in groups I and II gain area at the cost of area under crops in group III, which is the sum of substitution and expansion effects. The substitution effect is measured from decline in acreage under group III.

4.1.2 Estimation of Area Under Rice-Wheat System

Woodhead *et al.* (1994) estimated area under the rice-wheat system as a fraction (85 percent) of area under rice or wheat whichever is less. The remaining 15 percent of the area was assumed to be under oilseeds, pulses, sugarcane, maize, millets, fodder, green manure and other crops. We also applied this methodology for estimation of the rice-wheat area using state and district-level secondary data. In case of Madhya Pradesh, this methodology was not used because rice and wheat were grown in different regions; rice is grown predominantly in eastern region (in sequence with pulses, oilseeds, other crops, or fallow) and wheat is mostly grown in the western region (in sequences such as cotton-wheat, soybean-wheat and sorghum-wheat). For this state, as indicated by earlier studies, (Woodhead *et al.*, 1994) 19 percent area of rice area was taken as the area under the system.

At the district-level, this methodology was applied with minor correction in rice area. In the deep-water land even at the time of harvesting water is in the field and wheat cannot be grown under such conditions. Therefore, deep-water area was deducted from rice area for computing the area under rice-wheat system. We also estimated the rice-wheat area using primary data. For this purpose, plot-wise information was collected (from sample farms) and actual area under the rice-wheat system was taken.

4.1.3 Measurement of Instability in Crop Production

Sustainability can be achieved by emphasising crop productivity as well as its stability, i.e., a continuous process of increasing productivity in steps with stability. Before going to the next level of productivity, stabilise it at the first level, and then increase productivity and stabilize it at the next level, and so on (IRRI, 2000). Growth in crop productivity was also measured by annual absolute increase in productivity, as given by linear trend function. Instability was defined as the deviations from the trend. In the present study, yield instability was measured in relative terms by the Cuddy-Della Valle index, which is commonly used as a measure of instability in time-series data (Singh and Byerlee, 1990 and Deb *et al.*, 1999). Since the simple coefficient of variation over estimates the level of instability in time-series data characterised by long-term trends, the Cuddy-Della Valle index corrects the coefficient of variation as follows:

$$CV = (CV^*)\ (1-R^2)^{1/2}$$

Where

CV is the Cuddy-Della Valle index of instability;

CV* is coefficient of variation without trend-adjusted data; and

R^2= Coefficient of multiple determination from a time trend regression adjusted by the number for degrees of freedom.

4.2 Trends and Determinants of Productivity of the Rice-Wheat System

Sustainable increase in the productivity of a cropping system requires that growth in yields must come from increase in economic efficiency of resources. The partial factor productivity (PFP) and total factor productivity (TFP) measures are often used to examine the resource use efficiency. We also used these two measures. Trends in inputs and outputs were measured with the help of semi-log function for the period of twenty-eight years, i.e. from 1970-71 to 1997-98. The entire period was divided into following three sub-periods:

i) Green-Revolution Period (1970 to 80);

ii) Post-Green Revolution Period I (1981 to 90); and

iii) Post- Green Revolution Period II (1991-97).

Partial Factor Productivity (PFP)

Productivity indices are commonly constructed to measure the relationship between input and output. The most widely used productivity measures express output per unit of a particular input such as land or labour.

These measures are known as PFP and basically, conceived as a tool for measuring production efficiency over a short period of time (Alston *et al.*, 1995). The PFP measure is generally defined as:

$PFP_i=Q/X_i \qquad i=1\ldots, n$

Where, Q represents output and X_i represents i^{th} input.

A more careful representation is:

$PFP_i = Q^*/X_i^* \equiv QI/XI_i \qquad i = 1\ldots, n.$

Where Q^* represents aggregate output, X_i^* represents an aggregate of input X_i and QI and XI_i are the corresponding indices of aggregate output and input X_i respectively.

The denominator in a PFP index often groups together different classes or qualities of input X_i. Within such a factor grouping, there are aggregation problems arising from heterogeneity that are analogous to the problems of aggregating dissimilar factors such as land, labour, and capital. Even if properly constructed, PFPs pose particular problem for distinguishing (research-induced) technical change from (price-induced) substitution effect. Also, PFPs are affected not only by advances in the state of technology but also by changes in effective quantities of other inputs used in the production. These and some other problems are addressed through measurement of multifactor productivity or TFP.

Total Factor Productivity (TFP)

TFP can be defined, as a measure of the increase in total output that is not accounted for by increases in the quantity of inputs. TFP, as a residual, cannot be considered as simple technical or technological change but is produced by changes in infrastructure, skills, institutions as well as technology (Evenson *et al.,* 1999).

The Tornqvist-Theil index is the most frequently used index to computing the TFP as it has several useful properties. It is a superlative index that is exact for a linear homogeneous translog production function (Diewert, 1976). Furthermore, Christensen (1982) and Diewert (1982) have shown that Tornqvist-Theil index is also superlative under general production structures, that is, when returns to scale are nonhomogeneous and nonconstant. This index should, therefore, provide consistent aggregation of inputs and outputs across a range of production structures. Because current factor prices are used to construct the weights, quality improvements in inputs are incorporated, to the extent that these are reflected in higher wage and rental rates (Capalbo, 1988). In the present study, Tornqvist-Theil TFP index was used, which can be expressed in logarithmic form as:

$$\ln (TFP_{t+1}/TFP_t)=1/2\sum(R_{jt+1}+R_{jt}) \ln (Q_{jt+1}/Q_{jt})-1/2\sum (S_{it+1}+S_{it}) \ln (X_{it+1}/X_{it}) \quad (1)$$

Where R_{jt} is the share of j^{th} output in the total revenue, Q_{jt} is output j, S_{it} is the share of i^{th} input in the total input cost, and X_{it} is input i, in period t. Specifying that the index is equal to 100 in 1971 and accumulating the measure based on equation (1) provides the TFP index. The TFP is measured for each district of eastern Uttar Pradesh, using the district-level data on inputs and outputs for the period 1970 to 1997.

Sources of Data

Outputs: The output data set contains district-wise data on 11 crops, namely, rice, wheat, Barley, sorghum, pearl millet, maize, small millets, all pulses, all oilseeds, sugarcane and potato. These crops cover more than 90 percent gross cropped area of the region. For each crop the data include area sown, production, farm harvest price, irrigated area, HYV area, etc. These data were compiled from various publications of the central and state governments (various issues of *Uttar Pradesh Ke Krishi Ankre*, Directorate of Agriculture, Govt. of Uttar Pradesh and *Farm Harvest Prices of Principal Crops in India*, Govt. of India).

Inputs: The input data set includes district-wise time-series data on human labour, animal labour, machine labour, farmyard manure, fertilizer, irrigation cost and rental value of land. These data are not readily available and therefore, were derived from district-level data on related variables.

Human Labour: Human labour includes cultivators and agricultural labourers. Total cultivators are the number of rural households whose primary job classification is cultivator and agricultural labour is the number of rural males whose primary job classification is agricultural labour. Total agricultural labourers is the sum of total cultivators and agricultural male labourers which was multiplied by 0.40 because it was presumed that 60 percent of labour force is either engaged in non-agricultural activities or migrated to other regions. Various farm management surveys indicated that farm workers work for about 180 days (Evenson *et al.,* 1999) and therefore, this variable is designated as quantity of labour, which is a flow of labour in a particular year. Finally, quantity of labour was multiplied by wage in the district. The data on cultivators and agricultural workers were obtained from population census (various issues of *Census of India*, Govt. of India and Agricultural Census, *Crop and Season Report*, Govt. of Uttar Pradesh, Statistical Abstract, State Planning Institute, Lucknow) and wage rate were taken from agricultural wages published by the government (various issues of Agricultural Wages in India, Ministry of Agriculture, Govt. of India). Wherever possible, the wage of a ploughman was taken; if a district did not report such a wage rate, the wage of 'other agricultural labour' was selected. An average annual wage was constructed from the monthly wages. The data for a nearby district were taken where the wage data were not available for a district.

Animal Labour: Data set on animal labour includes male cattle and male buffalo workers. Price in 1999-2000 was adjusted by output price index for developing the annual price series since 1970-71. The value of draft livestock thus obtained was multiplied by 0.50 to get annual animal labour cost. The fraction 0.50 come from taking account of expenditure incurred on feeding, rearing, and necessary depreciation and rate of return on ownership (Evenson *et al.*, 1999). Data set on numbers of cattle male worker and buffalo male worker are available in quinquennial livestock census (various issues of *Livestock Census in India,* Govt. of India).

Machine Labour: Annual tractor cost was assumed as the proxy for machine labour cost. The number of tractors in a district for the year 1999-2000 was multiplied with actual price of 35-horse power tractor (TAFE-3510) and price series was extended back to 1970 on the basis of proportional changes in the price index for agricultural machinery and transport equipment. This tractor price series was multiplied by a factor 0.25 to derive an annual tractor cost variable. The fraction 0.25 represents both depreciation and debt service on the investment. It includes the rate of return required if tractors are to be bought in first place. Thus, the variable for the annual cost of tractors represents a sort of shadow rental cost of a tractor in an appropriate flow form. The source of data for number of tractors was also the quinquennial livestock census.

Organic Manure: Farmyard manure (FYM) was taken a proxy for organic manure. A quantity of FYM was calculated on the basis of number of total livestock units in a district. Total number of livestocks was multiplied with 2 (average annual production of dung per animal) and again multiplied with 0.30 (only 30 percent of dung is finally converted into FYM and the rest 70 percent used as fuel), to get net quantity of FYM. The price of FYM was calculated on the basis of nutrient availability (0.3 percent nitrogen (N), 0.15 percent phosphorus (P), 0.30 percent potash (K)). The price of N, P and K was calculated on the basis of price fixed by the government for fertilizers and adjusted for the proportion of the nutrient present in each fertiliser. Prices are not reported for all fertilisers for all years and therefore, prices for intervening years are estimated based on movements of wholesale price index of fertilizers. The source for data on fertiliser quantity and price is *'Fertiliser Statistics*, (FAI, 1970 to 1999).

Irrigation Cost: The annual cost variable of pumping sets assumed as proxy for irrigation cost. The total number of diesel and electric pumping sets of a district separately was multiplied with prices of the pumping sets in a particular year.

The price of a pumping set was calculated on the basis of proportional changes in the price index of agricultural machinery and transport equipment. This price series were multiplied by 0.25 to derive an annual pumping set cost variable. The fraction 0.25 represents both depreciation and debt service on the investment. It includes the rate of return required if pumping set is to be bought in first place. Thus, the variable for the annual cost of pumping set represents a sort of shadow rental cost of a pumping set in an appropriate flow form. Finally, annual cost of diesel and electrical pumping sets variable were summed up. The sources of data for number of pumping sets were the quinquennial livestock census conducted by the Ministry of Agriculture.

Rental Value of Land: Rental value of land was calculated considering existing land rent in the region, guidelines set by FAO (1962) and suggestion given by the Expert Committee on cost of production estimates (1980). The Committee suggested the uniform rental rates based on fixed proportion of output varying from 12.5 percent to 40 percent of the value of the produce. In the present study, 33 percent of the value of produce was taken as rental value of land.

4.2.1 Determinants of Total Factor Productivity

Following Herdt and Lynam (1992), it was proposed that the TFP is a proxy indicator for the sustainability of rice-wheat system and therefore, determinants of the TFP can be treated as the determinants of the sustainability of this system. In order to examine the determinants of TFP, the following regression model was used:

$$\ln(TFP) = \alpha + \beta_1 RCH + \beta_2 EXT + \beta_3 FYM + \beta_4 PUL + \beta_5 IRR + \beta_6 WHY + \beta_7 RHY + \beta_8 YRN + u \quad (2)$$

Where;

ln (TFP) = Natural log of TFP index;

RCH= Index of agriculture research stock in Rs/ha GCA;

EXT= Index of agriculture extension stock in Rs/ha GCA;

FYM = Index of percent of nutrients supplied through farmyard manure to nutrients supplied through chemical fertilizers;

PUL= Index of percent of total pulses area to the rice-wheat system area;

IRR= Index of irrigation intensity;

WHY= Index of percent area under HYVs of wheat crop;

RHY= Index of percent area under HYVs of rice crop; and

YRN= Index of annual rainfall in mm.

Sources of Data

Research: For construction of research stock for a district, research stock was constructed as proportion to the share of the gross cropped area of the state's research variable stock.

Evenson *et al.*, (1999) while constructing the research variable in Indian crop sector compared different time lags varying from 3 to 9 years. In present the study, 8,8,8 time lags, i.e. the first 8 denotes number of years between the first appearance of the result of a research and its full impact and this segment is sloping upward, the second 8 refers the number of years in which full impact is recorded and this segment slopes horizontally and the third 8 refers the years of decay in contribution of a research and the segment turned as downward sloping. Thus, whole time shape looks like "inverted V" This shape is arrived at by assigning zero weight to the year's t, t-1 and t-2, and then it raised linearly to 1 in the year t-7 and remain the same up to t-16, after that it declines to zero over subsequent eight years.

Extension programs also have a time lag but it differs considerably from the research lag. Extension programs have direct and relatively quick impacts and therefore, the time weights used for extension stock were 0.5 in t-1 and 0.25 in t-2 and in t-3.

The state level expenditure on research and extension were taken from Pal and Singh (1997), however, data before 1960 were computed through linear extrapolations and per hectare expenditure was calculated on the basis of gross cropped area in the district. The data on other variables were compiled from various governments publications.

4.2.2 Computation of Estimated Marginal Products and Internal Rate of Return

The estimated coefficients can be used to compute the marginal products of capital stocks and marginal rate of return to the investments in research and other variables. The marginal products are computed from the estimated research stock elasticity and the ratio of annual expenditures to value of output. The procedure suggested by Evenson and Mckinsey (1991) was used for estimating the IRR.

$$EVMP\ (RCH) = RCH_e * (V/RCH)$$

Where

EVMP is the estimated value of marginal product, RCH is the research stock; RCH_e is the TFP elasticity of research stock;

V is the value of production related to TFP.

The time weights followed in computation of research stock can be used for estimation of marginal products. The investment of one rupee in year t-i will generate a benefit equal to 0.2 EVMP in year t-i+3, 0.4 EVMP in year t-i+4 and so on, and it will be complete EVMP in year t-i +7 and next 8 years remains equal to 1 and decline to zero over the subsequent 8 years as same pattern followed in computation of research stock. This benefit stream is then discounted at the rate at which the present value of the benefit is equal to one and the discount rate can be considered to be marginal internal rate of return.

4.2.3 Estimation of the Model

The model for the determinants of TFP was estimated using a dummy variable approach for the pooled cross-section and time-series data set for the districts. The pooling of time-series and cross-section data provides adequate degrees of freedom, improves efficiency and enables the estimation of the effects associated with a particular dimension of the data set. At the same time, due to its own statistical problems such as serial correlation and heteroskedasticity, ordinary least square (OLS) method cannot be applied.

There are two estimation methods for the pooled data, namely, dummy variable model (DVM) and the error component model (ECM). The DVM is estimated by OLS using dummy variables for cross-section units (districts in present study), whereas generalised least squares (GLS) method is used for the ECM. The criteria for model selection are the relative size of N (cross section units) and T (time-series units) and possible relationship between immeasurable individual attributes and measurable time varying attributes (explanatory variables). The ECM can be used if the following condition is satisfied; otherwise the DVM should be used (Judge et al., 1988, 489-490).

$T \geq 3$; and $N\text{-}K \geq 9$

Where, T= Time series observation (Year);

N= Number of cross-section units (districts); and

K = Number of parameters to be estimated (excluding dummy variables).

In this study, T= 27, N= 15 and K= 8. The relative size of N and T does not satisfy the condition of applying the ECM, as N-K (15-8=7) is less than 9. We have therefore used the DVM. The dummy variable was used for each district taking Varanasi as a base.

Accounting of Share of the Determinants of TFP Growth

To estimate how much each of the determinants contributes to the growth of TFP, the growth accounting exercise (Alston *et al.*, 1995) can be used as follows:

$$Qt = \sum \alpha\, x_t + \sum \beta\, k_t$$

Where;

Qt is the rate of growth in TFP;

x_t and k_t are the rates of growth of the explanatory variables; and

α and β are the respective elasticities of TFP with respect to each of the positive and significant variables.

4.3 Diversification Index

The diversification of crops is a strategy to minimize risk. It has positive impact on sustainability of a system. There are various methods to compute diversification index, among them the Herfindahl index is the most commonly used. The same index was used in the present study, which was computed by taking sum of squares of proportion of value of each crop in the system; mathematically it is expressed as follows:

$$HI = \sum_{i=1}^{n} P_i^2 \qquad i = 1, 2, \ldots n.$$

Where

P_i is the proportion of value of i^{th} crop in the total system;

n is the number of crops in the system.

The Herfindahl index takes the values ranging from 0 to 1, where 0 indicates perfect diversification and 1 refers to perfect specialization; thus the index bears inverse relationship with diversification.

4.4 Characterisation of the Rice-Wheat System

A system is defined as an arrangement of components that are interrelated and interact among themselves according to some process and transform inputs into outputs. Cropping systems are commonly described simply by the dominant cropping patterns they include. A more complete description would indicate specific performance characteristics, qualities and quantities of resources on which systems are based, and the technologies that transform them into cropping patterns. A cropping system usually refers to a combination of crops in time and space and cropping system approach seeks to increase the benefits derived from crop production by efficient utilization of both natural (land, solar radiation, water and soil) and socio-economic (labour, credit, power sources, etc.) resources (Zandstra *et al.*, 1981).

Crop productivity of a specific region is a function of biophysical environment, socio-economic conditions and managerial skills including education of the farmers. For sustainable rice-wheat system appropriate production strategies have to be developed and adopted. For this purpose important elements of existing production environment of the system such as soil, water resources, climate, crop area and cropping systems dynamics, issues related to tillage, residue management and relationship of crop productivity and environmental parameters have been analysed. Socio-economic issues related to farmers conditions in the area and resource use pattern influencing the system are also analysed.

4.5 Estimation of Yield Gaps and Prioritisation of the Constraints

4.5.1 Estimation of Yield Gap

Crop production loss is always estimated relative to a reference yield, which should be clearly determined. Production losses caused by one yield-limiting factor are a measure of improvement in yield and production, which could be obtained if this factor was removed, for example, through agricultural research. Knowledge of yield-limiting factors and their influence on yields and production may be very useful guide in establishing research priorities for a given system. Removal of factors, which cause large production losses, will naturally have a greater value than the removal of those causing smaller production losses. The analysis of yield gap provides a useful way of assessing extent and causes of production losses. In this study, the concept of yield gap proposed by Zandstra *et al.*, (1981) was used. The total yield gap can be defined as the difference between potential yield, which is maximum attainable yield at research station under optimal conditions and actual yield obtained by farmers. This total yield gap can be decomposed into two parts, viz.; Yield gap I and Yield gap II.

Yield Gap I: This gap refers to the difference between research station yields and potential farm yields obtained at demonstration plots in a particular region. This gap is caused by differences in climatic, soil and other physical-environmental factors, which cannot be managed or eliminated in farmers' fields.

Yield Gap II: This gap reflects a series of biophysical and socio-economic constraints and it is the difference between yield obtained at the nearest demonstration plot and average yield obtained at farmers' fields in a particular region. This gap is of prime concern in the present study. The yield gaps were estimated as follows:

Yield Gap I= $\{(Y_R - Y_D)/ Y_R\}*100.$

Yield Gap II= $\{(Y_D - Y_F)/Y_D\}*100.$

Where

Y_R is the research station yield;

Y_D is the demonstration plot yield; and

Y_F is the actual farm yield.

4.5.2 Estimation of Production Losses due to Various Constraints

The severity of technical constraints was assessed through estimation of production losses. The proportion of area-affected, average yield loss and frequency of occurrences indicate severity of a constraint. The information on these aspects were collected from sample farmers based on their past experience and perceptions. The estimates were averaged for rice and wheat separately from each constraint. The productions losses are calculated on the basis of area affected and yield loss per hectare due to a particular constraint in the region. The production losses were multiplied by the procurement price to get the value of production foregone due to various constraints. Finally, the total value of production losses due to various technical constraints was subtracted from the total value loss to get the losses attributable to socio-economic constraints. All technical constraints were ranked on the basis of the value of production loss.

The socio-economic constraints were not quantified as such with the help of methodology used for technical constraints. By and large, socio-economic constraints are not related with only-one individual crop but these are concerned with all crops as well as farming system. All the socio-economic constraints were ranked on the basis of percent of sample farmers reporting a particular constraint.

The productions constraints could be translated into priority research areas (PRAs). There is hierarchy in the steps, such as prioritise the constraints; translate constraints into research objectives; translate research objectives into research themes and activities, and finally, priority research area for the concerned system (Bradford, 1998).

Source of Data: For characterization of the rice-wheat system primary data collected from sample farmers were used. For identification of production constraints primary as well as secondary data were used. In first step, the information available in secondary sources was reviewed. In the second step, production constraints were elicited from scientists, extension personnel and other government officials at various levels. In third step, data were collected from farmers practicing the rice-wheat system. For selection of sample farmers 7 districts were selected with higher proportion of rice-wheat system. From each district, two blocks were selected randomly and from each block, one village was selected randomly. For the selection of sample farmers, all farmers in a village were grouped into three categories on the basis of size of holdings. A total of 10 farmers from each village were selected using proportionate random sampling method. Thus, a total of 140 farmers were selected for the detailed farm survey.

CHAPTER V

RESULTS AND DISCUSSION

In this chapter, results of this study are presented and discussed. For sake of convenience, the results are organised into the following sections:

5.1 Temporal Changes in Agriculture;

5.2 Trends and Determinants of Productivity of the Rice-Wheat System;

5.3 Sustainability Indicators (SIs) for Rice-Wheat System;

5.4 Characterization of the Rice-Wheat System; and

5.5 Estimation of Yield Gap and Prioritisation of Production Constraints.

5.1 Temporal Changes in Agriculture

5.1.1 Land Utilization Pattern

Land utilization pattern is largely influenced by agro-climatic (temperature, relative humidity, topography and soil types), economic (incentives, infrastructure development and industrialization, etc.) and institutional (government, social structure, religion, etc.) factors. The study area is better endowed with natural resources. However, it lagged behind in terms of development of infrastructure, including irrigation. Therefore, these factors influenced changes in land use pattern. Table 5.1 shows that net sown area was about 65 percent of the total area reported for land utilization and remained constant overtime. The gross cropped area showed however, a moderate growth. The area under desirable and undesirable ecological sector declined significantly, because of significant increase in the area under non-agricultural uses and fallow land in agricultural sector.

Table 5.1 Changes in land use pattern in eastern Uttar Pradesh, 1950 -96.

Particular	Area ('000 ha)			Compound growth rate (Percent per annum)		
	1950	1969	1996	1950-69	1969-96	1950-96
Reported area for land utilization	8503	8759	8661	-0.005	-0.002	0.002
Desirable ecological sector[b]	1549	1562	1179	-0.182*	-0.116**	-0.087***
	(18.21)	(17.83)	(13.52)			
Undesirable ecological sector[c]	412	294	186	-0.231**	-0.332***	-0.255***
	(4.84)	(3.36)	(2.12)			
Non- agricultural sector[d]	702	734	924	0.066***	0.155***	0.112***
	(8.26)	(8.38)	(10.60)			
Agricultural sector[e]	5838	6166	6391	0.034***	0.010***	0.017***
	(68.6)	(70.40)	(73.29)			
Net area sown	5421	5749	5662	0.036***	-0.014***	0.001
	(63.76)	(65.65)	(65.38)			
Gross cropped area	7024	7739	8652	0.050***	0.059***	0.050***
Kharif area of gross cropped area (%)	57.21	56.08	50.60	0.061***	-0.002	0.017***
Rabi area of gross cropped area (%)	45.25	43.51	47.21	0.049	0.119***	0.087***
Zaid area of gross cropped area (%)	0.54	0.41	2.00	-0.277	2.087***	1.171***
Cropping intensity (%)	130	135	153	0.028*	0.131***	0.089***

Notes: a) Figures in parenthesis indicate the percentage of respective column of reported area for land Utilization.
b) Desirable ecological sector include, area under forests, permanent pastures, other miscellaneous trees, and culturable wasteland.
c) Undesirable ecological sector includes area under barren lands.
d) Non-agricultural sector includes area under non-agricultural use.
e) Agricultural sector include, area under net area sown, current fallow, and other fallow.
f) *** Significant at 1% level. ** Significant at 5% level.
* Significant at 10% level.

Uttar Pradesh Ke Krishi Ankre (various issues), Directorate of Agriculture, Government of Uttar Pradesh, Lucknow.

5.1.2 Livestock Population

Livestock population in the region increased significantly because of increase in the number of milch animals. However, the growth in the number of milch animals as comparatively higher in 1980s. On the other hand, the number of draft animals showed a negative growth. The decrease in the number of draft animals clearly indicates increase in mechanization of agriculture in the region. This trend is similar to that observed in the north-west region of the country.

5.1.3 Agrarian Structure

Small and marginal farmers dominated the agrarian structure in eastern Uttar Pradesh. The marginal and smallholdings accounted for 94 percent of the total number of holdings and 66 percent of the area in the year 1991. The average size of holdings in the region also declined from 0.90 ha in 1971 to 0.67 ha in 1991 (Table 5.3). The number of marginal and smallholdings showed an increasing trend since 1971. It implies that fragmentation of landholding is reducing holding size. Therefore, agricultural development programs should be oriented to marginal and small farmers.

5.1.4 Irrigation Development

This region has significantly benefited from expansion of canal as well as tubewell irrigation. The net irrigated area increased at a compound growth rate of 0.20 per cent per annum. Now 56 percent of the net sown area and 63 percent of the gross cropped area is irrigated. The irrigation intensity measured as ratio of gross to net irrigated area, increased from 102 to 136 per cent during the period of 1950 to 1996. It is observed that groundwater use has increased significantly during the study period and now more than 70 percent of the gross cropped area is irrigated by tubewells and other wells (Table 5.4). It means that the minor irrigation expanded more rapidly than the canal irrigation. Eventually,

Table 5.2 Growth in livestock population, 1971-92.

Particular	Number of animals ('000)			Compound growth rate percent per annum			Number of animals per ha of GCA		
	1971	1981	1992	1971-80	1981-92	1971-92	1971	1981	1992
Eastern Uttar Pradesh									
Milch animals:									
Cow	2284	2579	4452	0.108	0.525**	0.199**	0.30	0.31	0.52
Buffalo	1687	2247	4024	0.295**	0.558**	0.325***	0.22	0.27	0.47
Draft animals:									
Bullock	6081	5523	4481	-0.106***	-0.160**	-0.124***	0.79	0.66	0.53
Buffalo	146	139	131	-0.100***	-0.110***	-0.104***	0.02	0.02	0.02
Total livestock	14288	16061	21771	0.130***	0.222*	0.114**	1.85	1.91	2.56

Note: *** significant at 1% level; ** Significant at 5% level; and * Significant at 10% level.
Source: *Livestock Census* (various issues), Directorate of Economics & Statistics, Ministry of Agriculture, Government of India, New Delhi.

Table 5.3 Distribution of operational holdings by farm size in eastern Uttar Pradesh, 1971-91.

Particulars	Numbers of holding ('000)			Area ('000 ha)			Average size of holding (ha)		
	1971	1981	1991	1971	1981	1991	1971	1981	1991
Marginal (< 1 ha)	5081 (75.4)	6126 (79.6)	7083 (82.3)	1655 (27.7)	2065 (35.2)	2509 (43.4)	0.33	0.34	0.35
Small (1.0 to 2.0 ha)	935 (13.9)	956 (12.4)	997 (11.6)	1299 (21.8)	1370 (23.4)	1376 (23.8)	1.39	1.43	1.38
Semi Medium (2.0 to 4.0 ha)	498 (7.4)	445 (5.8)	397 (4.6)	1354 (22.7)	1233 (21.0)	1068 (18.5)	2.72	2.77	2.69
Medium (4.0 to 10.0 ha)	196 (2.9)	154 (2.0)	116 (1.4)	1118 (18.7)	890 (15.2)	643 (11.1)	5.72	5.78	5.53
Large (≥10.0 ha)	32 (0.5)	19 (0.3)	11 (0.1)	545 (9.1)	311 (5.3)	187 (3.2)	16.81	16.16	16.69
All Holdings	6743 (100.0)	7701 (100.0)	8605 (100.0)	5971 (100.0)	5869 (100.0)	5782 (100.0)	0.89	0.76	0.67

Note: Figures in parentheses indicate percentage share in the total holdings.
Source: *Statistical Abstract*, (various issues) Department of Economics and Statistics, State Planning Institute, Uttar Pradesh, Lucknow.

Table 5.4 Irrigation development in eastern Uttar Pradesh, 1950-96.

Particulars	Area in ('000 ha)			Compound growth rate (percent per annum)		
	1950	1970	1996	1950-69	1970-96	1950-96
Area irrigated:						
Net irrigated area	1880	2346	3565	0.10**	0.22***	0.20***
Gross irrigated area	1922	2493	4834	0.12***	0.34***	0.27***
Percentage area irrigated:						
Net irrigated area	27	32	56	0.14	0.60***	0.40***
Gross irrigated area.	35	41	63	0.12*	0.48***	0.41***
Irrigation intensity	102	106	136	0.04**	0.21***	0.12***
Source of irrigation:						
Canal irrigation	93 (5)	400 (17)	899 (25)	1.51***	0.54***	0.96***
Tube wells	8 (0.4)	749 (32)	2502 (70)	5.59***	0.65***	2.23***
Other wells	1195 (64)	760 (32)	33 (0.7)	-0.25***	-2.51***	-1.52***
Tanks	331 (18)	250 (11)	73 (2)	-0.31**	-1.47***	-0.99***
Others	254 (14)	187 (8)	53 (1)	-0.76**	-1.10***	-0.75***
Total	1880 (100)	2346 (100)	3565 (100)	0.10**	0.22***	0.20***

Note : Figures in parentheses indicate percentage of the total in respective column.
*** Significant at 1% level; ** Significant at 5% level; and * Significant at 10% level.

Source: *Uttar Pradesh Ke Krishi Ankre* (various issues), Directorate of Agriculture, Government of Uttar Pradesh, Lucknow.

it helps to crop diversification and to sustain the rice-wheat system in the region.

Table 5.5 shows that in 1982, there were 3 districts utilizing less than 20 percent of their groundwater potential but only one district remained in this range of groundwater use in 1997. There was significant increase in the number of districts as well as area utilizing groundwater in the range of 21 to 30 percent. Thus, in spite of substantial increase in area irrigated by tubewell, the level of groundwater utilization remained within permissible limits (Table 5.5). This is in contrast to northwest region of the country where a large proportion of area is said to be over exploiting its groundwater.

Table 5.5 Groundwater utilization in eastern Uttar Pradesh, 1982-97.

Level of groundwater utilization (%)	No. of districts			Area ('000 ha)		
	1982	1992	1997	1982	1992	1997
<20	3	1	1	885 (16)	368 (7)	374 (7)
21-30	1	2	4	292 (5)	926 (17)	1444 (26)
31-40	6	7	6	2471 (44)	2454 (44)	2192 (39)
>40	5	5	4	1974 (35)	1822 (33)	1571 (28)
Total	15	15	15	5622 (100)	5570 (100)	5581 (100)

Source: *Statistical Diary* (various Issues), State Planning Institute, U.P,Lucknow.

5.1.5 Cropping Pattern

As seen from Table 5.6 rice and wheat crops dominated the cropping pattern in the region. These two crops together occupied 43 per cent of the gross cropped area during the early 1950s. Their share increased to 70 percent in the triennium 1997-99. This impressive area expansion under rice and wheat was influenced by the Green Revolution, expansion of irrigation facilities and

Table 5.6 Cropping pattern changes in eastern Uttar Pradesh, 1950-99.
(Area in '000 ha)

Crop	1950-52	1966-68	1977-79	1987-89	1997-99
Rice	2237	2434	2590	2800	2892
	(31.9)	(32.6)	(33.2)	(33.6)	(33.5)
Wheat	743	1036	2010	2926	3182
	(10.6)	(13.9)	(25.8)	(35.1)	(36.9)
Sorghum	109	107	76	81	72
	(1.5)	(1.4)	(1.0)	(1.0)	(0.8)
Pearl millet	103	146	152	146	123
	(1.5)	(2.0)	(2.0)	(1.8)	(1.4)
Maize	365	303	424	353	371
	(5.2)	(4.1)	(5.4)	(4.2)	(4.3)
Barley	926	832	451	149	91
	(13.2)	(11.2)	(5.8)	(1.8)	(1.1)
Small millets	445	513	315	111	42
	(6.3)	(6.9)	(4.0)	(1.3)	(0.5)
Total cereals	4929	5371	6019	6565	6773
	(70.2)	(72.0)	(77.1)	(78.7)	(78.5)
Total pulses	1348	1260	947	893	776
	(19.2)	(16.9)	(12.1)	(10.7)	(9.0)
Total food grains	6277	6621	6959	7458	7586
	(89.4)	(88.8)	(89.2)	(89.4)	(87.9)
Total oilseeds	56	88	117	126	143
	(0.8)	(1.2)	(1.5)	(1.5)	(1.7)
Potato	33	51	71	100	123
	(0.5)	(0.7)	(0.9)	(1.2)	(1.4)
Sugarcane	273	305	307	303	327
	(3.9)	(4.1)	(3.9)	(3.6)	(3.8)
Non food crops	747	836	844	884	1040
	(10.6)	(11.2)	(10.8)	(10.6)	(12.1)
Kharif	4032	4292	4303	4293	4389
	(57.4)	(57.2)	(54.7)	(50.7)	(50.4)
Rabi	2956	3173	3504	4001	4135
	(42.1)	(42.3)	(44.5)	(47.3)	(47.5)
Zaid	38	32	60	166	181
	(0.54)	(0.43)	(0.76)	(1.96)	(2.08)
Gross cropped area	7026	7497	7867	8460	8705
	(100.0)	(100.0)	(100.0)	(100.0)	(100.0)

Note: Figures are triennium averages and figures in parentheses denote percentage of gross cropped area in respective column.
Source: *Uttar Pradesh Ke Krishi Ankre* (various issues), Directorate of Agriculture, Government of Uttar Pradesh, Lucknow.

maize declined drastically in *Kharif* season. Similarly, in Rabi season, the area declined under barley and pulse crops. Total area under cereals increased from 70 percent in 1950-52 to 79 per cent during 1997-99, but the area under pulses decreased from 19 per cent to 9 per cent in the same period. The area under sugarcane, the main cash crop of the region, remained stagnant. The area under maize declined from 5.2 per cent to 4.3 per cent of the gross cropped area. Here it may be noted that the area under *Kharif* maize declined but area under *Rabi* maize increased continuously, particularly in the Northeastern zone, which is substituting wheat crop in *Rabi* season.

5.1.6 Cropping Pattern Changes: Substitution and Expansion Effects

Changes in cropping pattern in terms of 'expansion' and 'substitution' effects were measured by crop area-gross cropped area elasticity, i.e. by comparing the area growth rate of individual crops with the growth rate of the gross cropped area. Table 5.7 presents the elasticities for various crops during the four specified sub-periods. On the basis of these elasticities, different crops have been classified into three groups, viz. crops having elasticities more than or equal to one (group I), crops having elasticities less than one but greater than zero (group II) and crops having the negative elasticities (group III). The elasticity was greater than one for wheat and potato during the entire period, indicating that area increased under these two crops because of substitution and expansion effects. A similar effect was also observed for rice and oilseeds up to 1970s. Change in cropping pattern can also be examined in terms of the substitution and expansion effects. The substitution effect is the decline in area under some crops and corresponding increase in the area under other crops without any change in gross cropped area. The expansion effect is the result of increase in gross cropped area. The substitution effect can take place as a result

Table 5.7 Crop area-gross cropped area elasticity in different periods for various crops in eastern Uttar Pradesh, 1950-99.

Crop	1950-68	1969-79	1980-89	1990-99
Rice	1.19	3.07	0.43	-1.66
Wheat	6.70	23.60	4.38	4.05
Sorghum	-1.07	-1.60	3.98	10.59
Pearl millet	3.88	- 1.26	1.03	-2.02
Maize	-1.49	-1.90	-1.68	1.22
Barley	-1.46	-20.13	-16.81	-15.10
Small millets	1.48	-14.30	-17.69	-55.51
Total pulses	-0.93	-8.21	-1.65	2.06
Total oilseeds	8.44	3.73	1.38	0.02
Potato	8.07	14.69	5.48	4.23
Sugarcane	1.29	-2.50	0.14	-3.31
Non food crops	1.75	0.01	-1.33	11.78
Gross cropped area	1.00	1.00	1.00	1.00

Table 5.8 shows that during the pre-Green Revolution period, the expansion effect was more dominating, contributing to 71 percent to the total change in cropping pattern, while the substitution effect contributed only 29 percent. But during the Green Revolution period and the post Green Revolution period I, the substitution effect was much stronger, contributing 75 per cent or more to the total change. Finally, during the post-Green Revolution period II, the share of substitution and expansion effect was almost equal. Thus, much of the change in the cropping pattern happened during the Green Revolution period, and therefore, the Green Revolution crops (rice and wheat) gains are significantly at the cost of coarse cereals and pulses (Fig. 5.1 to 5.3).

5.1.7 Growth in Area, Production and Productivity of Crops

This section deals with growth in area, yield and production of various crops grown in the eastern Uttar Pradesh during 1950 - 1999. The entire period was divided into following four sub-periods:

i) Pre-Green Revolution Period (1950-68);

ii) Green Revolution Period (1969-79);

iii) Post-Green Revolution Period I (1980-89); and

Table 5.8 Relative contributions of substitution and expansion effect on cropping pattern in eastern Uttar Pradesh, 1950-99.
(Area in '000 ha)

Crop	1950-68	1969-79	1980-89	1990-99
Substitution effect	230	831	253	150
	(29)	(80)	(75)	(45)
Expansion effect	566	213	86	180
	(71)	(20)	(25)	(55)
Total effect	797	1044	339	330
	(100)	(100)	(100)	(100)

Note: Figures in parentheses indicates percentage share of total in respective column.

iv) Post-Green Revolution Period II (1990-99).

Table 5.9 gives the growth in the production of the various crops in the four sub-periods. During the Pre-Green Revolution period, production of wheat and potato increased significantly, mainly because of growth in area and yield. During the Green Revolution period, wheat and potato production increased significantly due to increase in area, whereas production of barley, small millets and total pulses decreased significantly. During the Post-Green Revolution Period I, production of maize, rice and wheat increased significantly. On the other hand, the production of barley and small millets decreased significantly due to negative growth in their area. During the Post-Green Revolution Period II, the production of wheat and rice increased significantly. The growth in wheat was led by both area and yield growth, whereas yield growth contributed to growth in the production of rice. Thus, it can be said that impressive growth in area under rice was observed during the pre- and Green Revolution periods, whereas wheat area continued to increase in all the sub-periods. The yields of rice and wheat stagnated in the pre- and Green Revolution periods but their yield registered appreciable growth during the post-Green Revolution period (Fig. 5.4). Thus, the process of the Green Revolution in this region was delayed by more than a decade.

5.1.8 Instability in Yield of Rice and Wheat

Sustainability can be achieved only through a step-by-step process of increasing and stabilising productivity. In other words, sustainability is a continuous process of increasing productivity in steps - before going to the next level of productivity, stabilise it at the first level and then increase productivity and stabilise it at the next level, and so on. In this way increasing productivity during one period would provide options for building for resource base, to some extent, which can be used to increase productivity to the next level, and so on.

Figure 5.1: Trends in area under rice and wheat in eastern Uttar Pradesh, 1950-99.

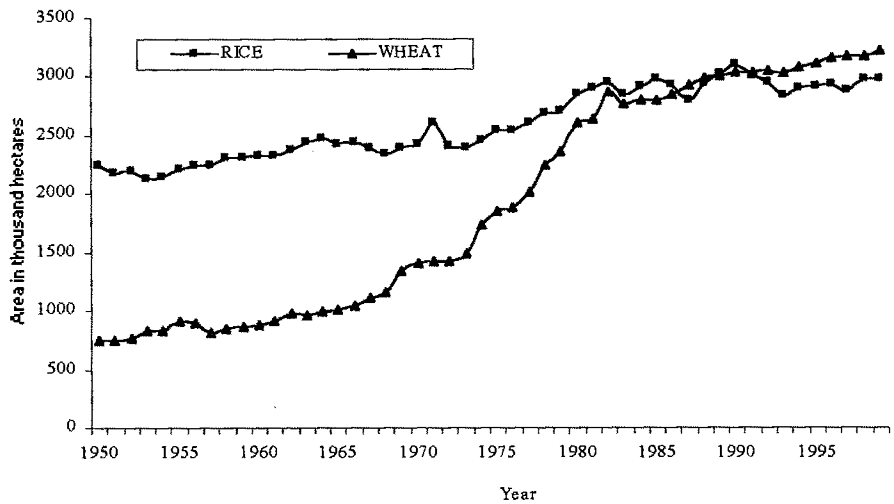


Figure 5.2: Trends in adoption of HYVs of rice and wheat in Eastern Uttar Pradesh, 1970-97.

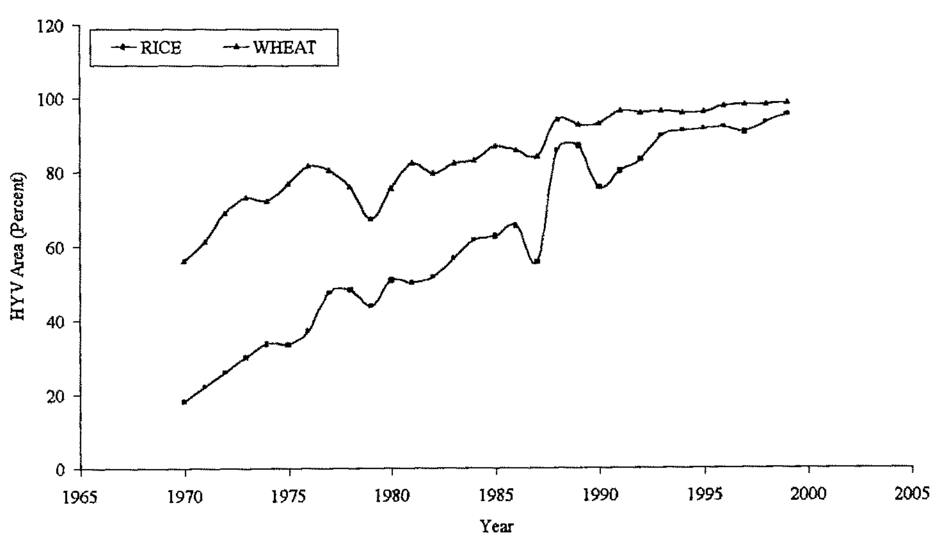


Figure 5.3: Trends in irrigated area under rice and wheat in eastern Uttar Pradesh, 1950-97.

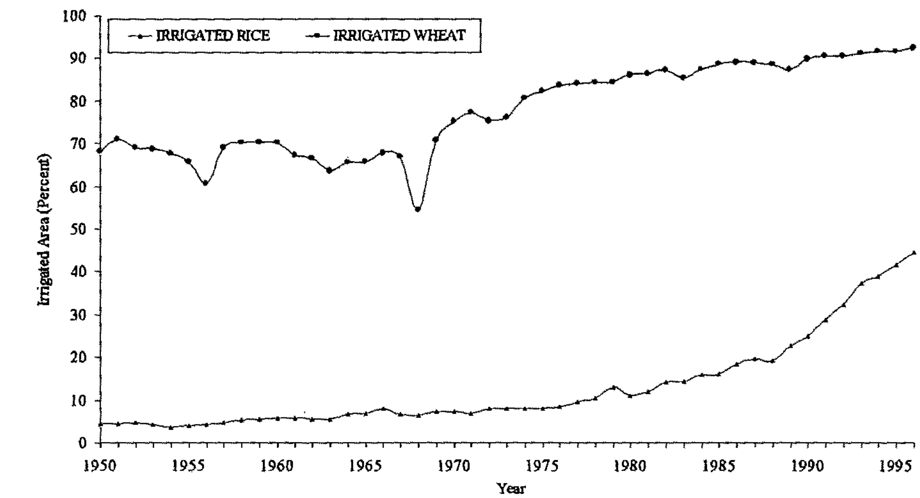


Figure 5.4: Trends in yield of rice and wheat in eastern Uttar Pradesh, 1950-99.

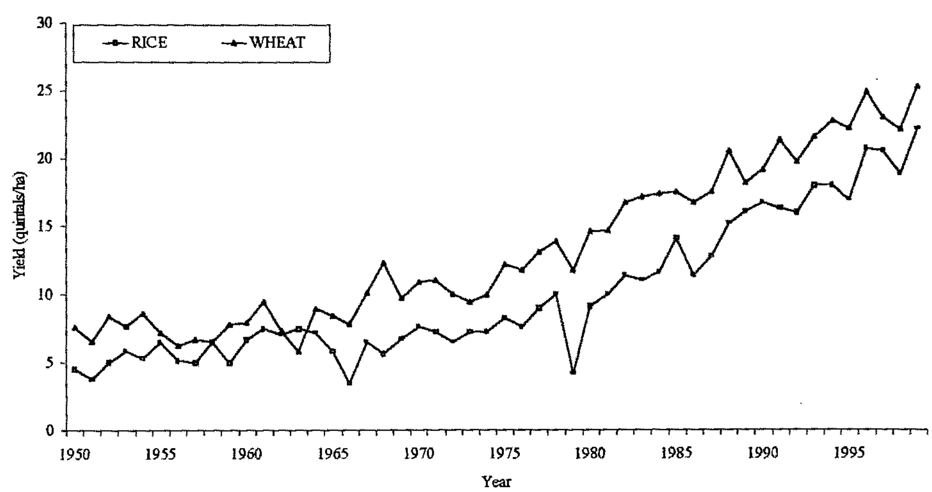


Table 5.9 Direction of growth in area, yield and production of various crops in eastern Uttar Pradesh, 1950-99.

Particulars	Direction	1950-68	1969-79	1980-89	1990-99
Area					
	Positive	Rice***, Wheat***, Pearl millet***, Small millets, Total oilseeds**, Potato***	Rice*, Wheat***, Sorghum, Total oilseeds, Potato**, Sugarcane	Rice, Wheat**, Sorghum, Pearl millet, Total oilseeds, Potato**, Sugarcane	Wheat***, Sorghum, Maize, Total pulses, Potato, Sugarcane
	Negative	Sorghum, Maize, Barley**, Total pulses, Sugarcane	Pearl millet, Maize, Barley***, Small millets**, Total pulses***	Maize, Barley***, Small millets***, Total pulses	Rice, Pearl millet, Barley**, Small millets***, Total oilseeds
Yield					
	Positive	Rice, Wheat, Maize, Barley, Small millets*, Total pulses, Potato, Sugarcane**	Wheat, Maize, Barley, Potato**	Rice**, Wheat*, Sorghum, Pearl millet, Maize**, Barley, Total pulses, Total oilseeds, Potato, Sugarcane	Rice**, Wheat**, Pearl millet, Small millets**, Total pulses, Total oilseeds, Potato
	Negative	Sorghum, Pearl millet, Total oilseeds	Rice, Sorghum, Pearl millet, Small millets, Total pulses, Total oilseeds, Sugarcane	Small millets	Sorghum, Maize, Barley, Sugarcane
Production					
	Positive	Rice, Wheat**, Pearl millet, Maize, Small millets**, Total oilseeds, Potato*, Sugarcane**	Rice, Wheat***, Maize, Potato**	Rice**, Wheat**, Sorghum, Pearl millet, Maize***, Total pulses, Total oilseeds, Potato, Sugarcane	Rice*, Wheat**, Sorghum, Pearl millet, Maize, Total pulses, Total oilseeds, Potato
	Negative	Sorghum, Barley, Total pulses	Sorghum, Pearl millet, Barley**, Small millets*, Total pulses*, Total oilseeds, Sugarcane	Barley***, Small millets**	Barley, Small millets*, Sugarcane

***Significant at 1% level; ** Significant at 5% level; * Significant at 10% level.

Though this is a time consuming process in areas with fragile environment and poor socio-economic conditions, this process alone can help the farmers who always try to minimise risk in farm output.

Table 5.10 Yield instability index of rice and wheat in eastern Uttar Pradesh, 1950-99.

Crop/ Period	Compound growth rate of yield (%)	Mean yield (kg/ha)	Annual increase in yield (kg/ha)	Instability index (%)
		Rice		
1950-68	1.42	440	8	19.78
1969-79	-0.31	670	4	21.21
1980-89	5.58	910	67	8.61
1990-99	3.1	1680	57	7.36
		Wheat		
1950-68	1.56	750	14	17.24
1969-79	2.81	970	32	9.41
1980-89	2.75	1460	46	5.97
1990-99	2.38	1920	52	5.45

For sustainability of a system the most desirable combination would be high yield growth with low instability. This trend was observed in the yield of both rice and wheat crops. As seen from Table 5.10, rice yield showed a sharp decline in its instability in 1980s, but the instability of wheat decreased drastically in 1970s. The instability remained low during 1990s in both the crops. This sharp decline in the yield instability can be attributed to expansion of tubewell irrigation and other yield increasing factors. It may also be noted here that absolute annual increase in yield is higher in rice, but it showed some tendency to decelerate.

5.1.9 Area under Rice-Wheat Sequence

State-Level Estimation

For the state-level estimation, triennium average of area under rice and wheat for recent available years i.e. 1996-98 was taken. Table 5.11 gives the area under rice-wheat sequence in India during the triennium 1996-98. The estimated area using Woodhead (1994) methodology was to the order of 10.75

million hectares (m ha). The sequence was adopted extensively in Uttar Pradesh (4.67 m ha), Punjab (1.97 m ha), Bihar (1.79 m ha), Madhya Pradesh (1.01 m ha), Haryana (0.80 m ha), West Bengal (0.31 m ha) and Jammu and Kashmir (0.20 m ha). In Uttar Pradesh, Punjab, Haryana and Jammu & Kashmir, the area under rice-wheat system ranged from 74 to 85 percent of rice area while for India as a whole it was 42 percent. In the states of West Bengal, Bihar, and Jammu & Kashmir the rice-wheat area was 85 percent of wheat area. The corresponding figure for India as a whole was 49 percent. The share of rice-wheat sequence area to the net-cropped area also showed wide variations across the states. In Punjab, the share of rice-wheat area was the highest (48 percent), followed by Jammu & Kashmir (28 percent), Uttar Pradesh (27 percent), Bihar (24 percent), Haryana (22 percent) and Madhya Pradesh (19 percent). For the country as a whole, 19 per cent of the net sown area was under the rice-wheat system.

District-Level Estimation

District wise rice-wheat area was estimated with slight modification in the methodology. The area under deep-water rice was deducted from the total rice area, and then, the multiplication factor was applied. As shown in Table 5.12, rice-wheat area showed considerable variations across states. The instability of the system varied from 31 % (of net sown area) in Gonda districts to 56 % in Faizabad district.

Using actual plot-wise information from the farm survey data, we also estimated the area to be was 59 percent of the net-cropped area. This is substantially higher than that obtained by the Woodhead methodology (41 percent). It may be noted here that our farm survey was conducted in the area intensively practicing rice-wheat system, and thereby giving higher estimates.

Table 5.11 Estimates of area under Rice-Wheat system in various states of India, 1996-98.

(Area in million hectares)

State	Total rice area	Deep water rice area [c] (>100 cm)	Total wheat area	Area under R-W system	R-W system area as % of total rice area	R-W system area as % of total wheat area	R-W system area as % of net cropped area	R-W system area as % of total R-W system area in India
Uttar Pradesh	5.71	0.22	9.30	4.67	82	50	27	43
Punjab	2.32	0	3.29	1.97	85	50	48	18
Bihar	5.09	0.46	2.10	1.79	35	85	24	17
Madhya Pradesh[d]	5.34	0	4.48	1.01	19	26	19	9
Haryana	0.94	0	2.09	0.80	85	38	22	7
West Bengal	5.87	0.25	0.36	0.31	5	85	6	3
Jammu & Kashmir	0.28	0	0.24	0.20	74	85	28	2
Total	25.55	0.93	21.86	10.75	42	49	19	100

Source: a) Based on data in *Agricultural Statistics at a Glance* (various issues): Directorate of Economics & Statistics, Ministry of Agriculture, Government of India, New Delhi.

b) Based on data for net cropped area for the year 1995-96, in *Centre for Monitoring Indian Economy* (September, 1999), Mumbai.

c) *Rice area by type of culture, 1997. South, Southeast and East Asia, a revised and updated data base*, IRRI, Manila, Philippines.

d) Estimation based on methodology proposed by Woodhead et al. 1994, *Rice-Wheat Atlas in India* for state of Madhya Pradesh as rice-wheat system area could be a fraction of 19 percent of rice and 26 percent of wheat area, which is lesser due to not congruence of rice and wheat area in state.

Table 5.12 Estimate of area under Rice-Wheat system in various districts of eastern Uttar Pradesh, 1997-99.

(Area in '000 ha)

District	Total[a] rice area	Deep water[d] rice area (>100 cm)	Total[b] wheat area	Rice-Wheat system area	Rice-Wheat system area as % of total rice area	Rice-Wheat system area as % of total wheat area	Rice-Wheat[c] system area as % of net cropped area
Allahabad	179.04	0	249.54	152.19	85	61	32
Azamgarh	281.91	17.00	292.87	225.17	80	77	52
Bahraich	197.84	21.00	204.14	150.32	76	74	33
Basti	385.89	45.00	316.49	269.01	70	85	47
Ballia	116.12	15.00	131.66	85.95	75	66	39
Deoria	229.39	32.00	240.73	167.78	73	70	39
Faizabad	200.95	6.00	199.58	165.71	82	83	56
Ghazipur	129.93	6.00	153.37	105.34	81	69	40
Gonda	197.50	23.00	240.69	148.32	75	62	31
Gorakhpur	315.02	23.00	307.36	248.22	79	81	53
Jaunpur	119.82	4.00	185.77	98.45	82	53	37
Mirzapur	170.95	0	195.78	145.30	85	74	38
Pratapgarh	113.18	0	139.63	96.21	85	69	44
Sultanpur	161.29	3.00	170.16	134.55	83	79	47
Varanasi	159.68	8.00	175.98	128.93	81	73	34
Eastern U. P.	2958.51	203.00	3203.77	2322.00	78	72	41
U.P.	5710.00	218.00	9364.00	4670.00	82	50	27

Source:a) Based on data in *Kharif Utpadan Karyakram* (1999-2000): Dept. of Agriculture, Government of Uttar Pradesh, Lucknow.

b) Based on data in *Rabi Utpadan Karyakram* (1999-2000): Dept. of Agriculture, Government of Uttar Pradesh, Lucknow.

c) Based on data for net cropped area for the year 1995-96, in *Uttar Pradesh Ke Krishi Ankre* (1995-96): Directorate of Agriculture, Government of Uttar Pradesh, Lucknow.

d) *Rice area by type of culture, 1997. South, Southeast and East Asia, a revised and updated data base*, IRRI, Manila, Philippines.

5.2 Trends and Determinants of Productivity in the Rice-Wheat System

In this section, trends and determinants of crop productivity in the rice-wheat system are analysed through partial and total factor productivity measures. Total factor productivity index also indicates sustainability of a system in the long term.

5.2.1 Partial Factor Productivity

A perusal of Table 5.13 gives trends in the partial factor productivity (PFP) of major inputs in the rice-wheat system in the study area. The productivity of human and animal labour increased significantly, while the reverse holds true for the productivity of machine labour, fertiliser and irrigation. The major reason for decrease in the productivity of these inputs could be under utilization of inputs, such as machine, imbalanced use of inputs, such as fertilizer or attainment of a stage where average productivity starts declining. As noted earlier, land productivity of the main crops i.e. rice and wheat showed a continuous upward trend.

Table 5.13 Trends in indices of partial factor productivity of major inputs used in Rice-Wheat system in eastern Uttar Pradesh, 1950-97.

Particular	70-72	80-82	90-92	95-97	Compound growth rate percent per annum
Human labour	0.918	1.204	1.462	1.520	2.35***
Animal labour	0.936	1.512	2.509	3.040	5.078***
Machine labour	0.561	0.051	0.032	0.031	-8.800***
Farmyard manure	0.917	1.236	1.536	1.345	2.266***
Fertilizer	0.887	0.450	0.403	0.376	-3.36***
Irrigation	0.679	0.106	0.047	0.029	-11.07***
Rental value of land	1.036	1.099	1.120	1.204	0.387***

***significant at 1% level; ** significant at 5% level; and *significant at 10% level.

Table 5.14 Changes in the share of output & input in the Rice-Wheat system in eastern Uttar Pradesh, 1970-97.

Particular	1970-72	1980-82	1990-92	1995-97
Output share				
Rice	0.256	0.269	0.352	0.389
Wheat	0.229	0.359	0.350	0.370
Barley	0.075	0.019	0.006	0.005
Sorghum	0.005	0.005	0.003	0.003
Pearl millet	0.012	0.010	0.006	0.005
Maize	0.031	0.017	0.017	0.016
Small millets	0.023	0.009	0.002	0.001
Total pulses	0.151	0.131	0.088	0.068
Total oilseeds	0.010	0.011	0.009	0.008
Sugarcane	0.189	0.142	0.111	0.090
Potato	0.036	0.048	0.051	0.045
Input share				
Human labour	0.266	0.256	0.317	0.363
Animal labour	0.110	0.114	0.059	0.051
Machine labour	0.004	0.044	0.068	0.066
Farmyard manure	0.045	0.031	0.021	0.025
Fertilizer	0.073	0.136	0.118	0.119
Irrigation	0.017	0.044	0.047	0.055
Rental value of land	0.485	0.376	0.370	0.321

5.2.2 TFP of the Rice-Wheat System

As shown in Table 5.14 and 5.15, all important crops of the region were included in the analysis, covering more than 90 percent of the gross cropped area. As seen from these tables the share of rice and wheat in the value of total output increased, while the share of barley, sorghum, pearl millet, maize, small millets, total pulses, total oilseeds, sugarcane and potato declined over time. This is consistent with the earlier observation that rice and wheat substituted other crops during the study period. The share of rice in the total output increased from 26 percent in 1970-72 to 39 percent in 1995-97, while that of wheat increased from 23 percent to 37 percent during the corresponding period. Seven inputs were considered for the estimation of TFP. It is observed that the share of human labour, machine labour, fertiliser and irrigation cost in value of total inputs increased over time while the share of other inputs such as animal labour, farmyard manure and rental value of land declined.

Table 5.15 Compound growth rates in the shares of outputs and inputs in Rice-Wheat system in eastern Uttar Pradesh, 1970-97.

(Percent per annum)

Particular	1970-80	1981-90	1991-97	1970-97
Output				
Rice	-1.09	3.46**	2.35***	1.92***
Wheat	5.40**	-0.41	0.67	1.72***
Barley	-11.64***	-10.37***	1.51	-10.98***
Sorghum	-1.55	-5.30	-3.76	-3.81**
Pearl millet	-3.62	-4.89	-3.56	-4.24***
Maize	1.37	-0.10	-6.76	-2.57*
Small millets	-7.20**	-12.94***	-13.55**	-12.76***
Total pulses	-0.15	-3.91	-3.80	-3.05***
Total oilseeds	-1.54	-1.78	-3.13*	-1.42*
Sugarcane	-3.44	-3.26*	-5.80**	-3.05***
Potato	4.77*	0.89	-3.32*	-1.42*
Input				
Human labour	0.17	2.97	2.51**	1.50***
Animal labour	2.21	-7.21***	-3.85**	-4.02***
Machine labour	32.99***	2.61*	-0.47	9.13***
Farmyard manure	-5.61	-6.49**	-2.17	-2.96***
Fertilizer	5.50*	-1.82	0.31	1.47
Irrigation	12.68***	0.10	2.88***	3.64***
Rental value of land	-3.08*	0.28	-2.46	-1.31***

*** significant at 1% level; **significant at 5% level; and * significant at 10% level

It implies that the use of modern inputs such as fertilisers, machine labour and irrigation increased which might have increased use of human labour though increase in the production. The share of traditional inputs such as human labour might has increased due to increased wages overtime. Human labour and land accounted for lion's share (68 percent) of the total cost in the triennium ending 1997.

Indices of Output, Input and TFP

To estimate the TFP in the rice-wheat system, 1970 was taken as the base year because the Green Revolution was observed in the study area after 1970 only. The entire period was further subdivided into following three sub-periods based on input use pattern and adoption of technologies.

i) Green-Revolution Period (1970-80);

Table 5.16, showed that in 30 percent of the area of eastern Uttar Pradesh a steady increase in the growth of TFP and in (70 percent) of the area the TFP growth decelerated. Nevertheless in about one half of these areas the TFP growth was more than one percent in 1990s. On an average, the growth in index of output was increasing during the entire period but growth in index of input was increasing with a decreasing rate.

On the other hand, districts falling under the decreasing trend group show that the rate of output growth was higher in the first two sub-periods and very low in the third sub-period. The growth of input indices also showed similar trend. The districts falling under the decreasing trend are those areas where the Green Revolution took off early and started reaping benefits from the first sub-period itself. Table 5.17 shows the compound growth of output, input and TFP by agro-climatic zones. The TFP growth was highest in the North-Eastern Plain Zone followed by the Eastern Plain Zone and the Vindhyan Zone during entire period. Further, the TFP growth showed diverse pattern across the zones. The TFP growth increased markedly during 1980s in the Northeastern and Eastern Plain Zones, while in the Vindhyan zone it increased markedly in 1990s. In 1990s, the TFP growth decreased in the Eastern Plain Zone, as well as in the North- Eastern Plain Zone but the decline was sharp in the former. For the eastern Uttar Pradesh as a whole, the growth in output and input indices was 4.08 and 2.29 percent, respectively, giving a TFP growth of 1.79 percent during 1971-97.

Table 5.17 further shows that the growth of input index was declining over time in all the zones. In fact, a decrease in the growth rate of inputs led to increase in TFP growth in the eastern plain zone. But it was growth in output, which contributed largely to the TFP growth in the North Eastern Plain Zone and Vindhya zone. During 1990s, deceleration in the growth of output was major cause of deceleration in the TFP growth in the North Eastern Plain Zone and Eastern Plain Zone. This conclusion is supported by several other studies. Fan (1991) observed that in China the TFP growth for wheat producing provinces was 2.8 percent annually during 1965-85, and more than 90 percent of this growth was attributed to institutional change (i.e. market reforms and

Table 5.16 District-wise compound growth rates in output, input and TFP in Rice-Wheat system in eastern Uttar Pradesh, 1970-97.

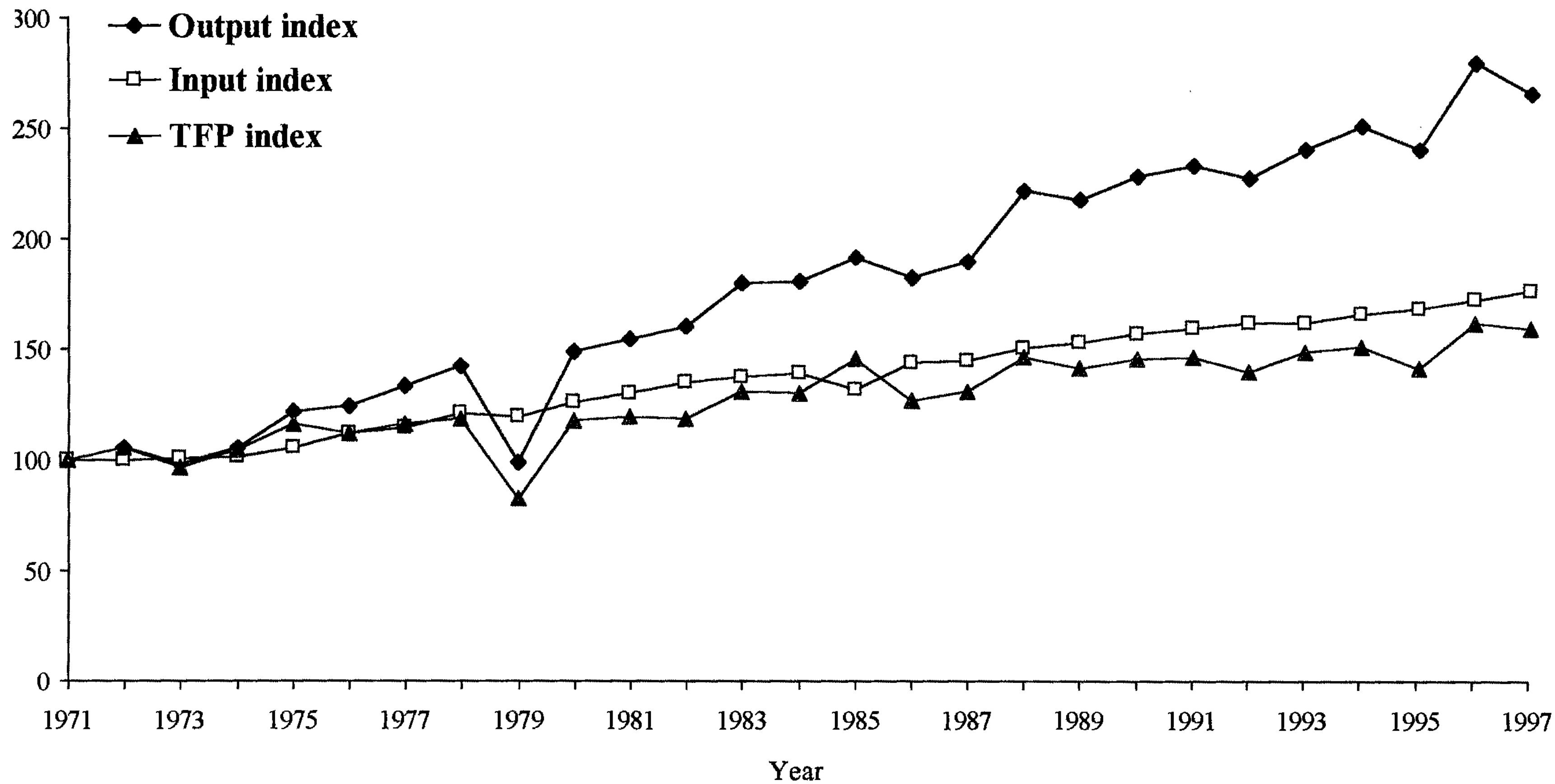
(Percent per annum)

District (Net sown area in '000 ha)		Output			Input			TFP			1971-97		
		71-80	81-90	91-97	71-80	81-90	91-97	71-80	81-90	91-97	Output	Input	TFP
Increasing trend													
Ballia	220 (3.9)	3.97	2.87	3.42	3.72	1.80	1.31	0.25	1.07	2.11	3.73	2.21	1.52***
Basti	578 (10.26)	0.42	5.02	5.38	1.51	1.83	1.05	-1.09	3.19***	4.33***	4.03	1.98	2.06***
Gonda	484 (8.59)	2.37	3.62	4.57	2.18	1.05	1.65	0.19	2.57***	2.92***	3.83	1.61	2.22***
Mirzapur	385 (6.83)	1.36	2.51	6.36	3.72	2.11	2.90	-2.36	0.39	3.46*	3.86	2.55	1.31***
Decreasing trend													
Allahabad	473 (8.39)	4.04	1.73	0.07	2.13	2.50	2.19	1.91	-0.77	-2.12*	3.18	2.46	0.71**
Azamgarh	436 (7.74)	2.94	6.17	1.70	3.63	2.64	1.90	-0.69	3.53***	-0.20	4.41	2.62	1.78***
Bahraich	459 (8.15)	3.65	6.19	4.29	2.89	1.69	1.38	0.75	4.50***	2.91*	4.77	2.21	2.56***
Deoria	427 (7.58)	6.00	3.75	1.24	2.95	1.90	0.59	3.05***	1.85***	0.65	3.97	2.00	1.96***
Faizabad	298 (5.29)	3.81	4.17	4.00	3.64	2.12	2.07	0.17	2.05***	1.93	4.37	2.79	1.58***
Ghazipur	263 (4.67)	2.14	4.90	0.051	4.38	2.37	1.95	-2.24	2.53***	-1.90	3.89	3.08	0.81**
Gorakhpur	469 (8.33)	3.41	4.09	2.31	2.89	1.71	2.32	0.52	2.38***	-0.01	4.02	2.25	1.76***
Jaunpur	263 (4.67)	6.62	2.98	0.61	3.74	2.23	0.69	2.88**	0.75	-0.08	3.92	2.43	1.49***
Pratapgarh	218 (3.87)	4.27	2.60	2.99	2.50	1.10	1.72	1.77*	1.50**	1.27*	4.20	2.10	2.10***
Sultanpur	285 (5.06)	0.80	3.99	3.93	2.52	1.68	1.63	-1.72	2.31**	2.23*	3.79	2.17	1.62***
Varanasi	375 (6.66)	3.65	4.11	3.87	2.71	2.38	2.45	0.94	1.73**	1.42	4.28	2.51	1.77***

*** Significant at 1% level; **significant at 5% level; and * significant at 10% level.

Figures in parentheses indicate percent area to the net sown area of eastern Uttar Pradesh for the year 1995-96.

ure 5.5: Growth in input, output and TFP indices in the rice-wheat system in eastern Uttar Pradesh,1971-97.



household production responsibility system) in the Post-Mao era. Technical change contributed only about 10 percent to the productivity growth. Sidhu and Byerlee (1992) stated that further productivity gains in wheat would depend on even more efficient use of inputs, increasing access to information and improving the management skills of farmers. Ali and Velasco (1993) found that TFP indices declined during 1970s and 1980s, with faster rate of deterioration (more than 2 per cent per year). Cassman and Pingali (1995) also calculated declining productivity indices for the rice component of the rice-wheat systems of Ludhiana district of the Indian Punjab. Their results indicate that TFP steadily increased during 1970s and levelled of for a while before slowly dropping. Both studies attributed the decline in TFP to deterioration of agricultural resources, especially soil. Murgai (1997) also argued in favour of greater efficiency in input use for productivity growth in future.

Table 5.17 Compound growth rates in output, input and total factor productivity in Rice-Wheat system in eastern Uttar Pradesh, 1970-97.

(Percent per annum)

Agro-climatic zone	Output	Input	TFP
North Eastern Plain zone			
1971-80	3.37	2.65	0.72
1981-90	4.53	1.91	2.62***
1991-97	3.22	1.62	1.60**
1971-97	4.12	2.26	1.86***
Eastern Plain zone			
1971-80	3.72	3.31	0.40
1981-90	3.73	2.28	1.45***
1991-97	2.21	1.92	0.29
1971-97	3.99	2.62	1.37***
Vindhyan zone			
1971-80	1.38	3.81	-2.43
1981-90	2.52	2.15	0.37
1991-97	6.36	2.90	3.46*
1971-97	3.87	2.61	1.26***
Eastern Uttar Pradesh			
1971-80	3.48	2.87	0.61
1981-90	4.09	1.96	2.13***
1991-97	2.81	1.70	1.11
1971-97	4.08	2.29	1.79***

*** Significant at 1% level; **significant at 5% level; and * significant at 10% level.

Note: Northen Eastern Plain includes districts of Bahraich, Basti, Deoria, Gonda & Gorakhpur.

Eastern Plain Zone includes districts of Allahabad, Azamgarh, Ballia, Faizabad, Ghazipur, Jaunpur, Pratapgarh, Sultanpur & Varanasi.

Decomposition of Sources of Growth in TFP

There are a number of studies analysing sources of growth in TFP. Evenson (1993) reviewed more than 78 such studies and concluded that the TFP cannot be simply considered a result of technical or technological change. It is produced by changes in technology, infrastructure including hard and soft infrastructure, institutions and agro-climatic conditions. The source wise decomposition of TFP growth depends on availability of data relating to changes in the quantity and quality of these variables.

The district-wise TFP index was regressed on indices of investments in crop research, agricultural extension, percentage share of nutrients supplied through farmyard manure, percentage of pulses area to the rice-wheat area, irrigation intensity, regulated market, percentage area under high yielding varieties of rice and wheat and annual rainfall for the period of 1970- 97. The other variables such as rural credit, rural literacy, rural electrification and rural road were initially included in the model but due to multicollinearity these variables were excluded at the later stage. The estimation was made using dummy variables model for the pooled cross-section time-series data set for 15 districts of the region. The total number of observations in the data set is 405 (15 districts □ 27 years). The equation was specified in semi-log form, that is, the index of TFP was used in log form and actual indices of all independent variables were used in the model. A summary of the variables used in the decomposition analysis is given in Table 5.18.

Table 5.19 provides the estimated parameters of the model. There are three major features of the results, viz. statistical properties of the results, signs of the estimated coefficients and relative importance of various determinants of TFP. The model explained 79.4 percent variation in the TFP. Only 3 out of the 8 determinants of TFP were found to be positive and statistically significant and these variables are research, HYVs of wheat and annual rainfall. All the variables have positive and significant effect on the TFP.

Table 5.18 Summary of variables used in the decomposition analysis of total factor productivity in Rice-Wheat system in eastern Uttar Pradesh, 1970-97.

Variable	Definition	Mean	Compound growth rate	Standard deviation
Dependent variable				
T F P	Total Factor Productivity Index	127.85	1.79***	19.86
Independent variables				
RCH	R-W system public research stock in rupees per ha GCA.	69.14	8.68***	44.57
EXT	Agriculture extension stock in rupees per ha.GCA	3.02	30.36***	4.60
FYM	Percent of nutrients supplied through farmyard manure to nutrients supplied through chemical fertilizers.	20.20	-5.25***	11.90
PUL	Percent of total pulses area to rice- wheat system area.	47.58	-3.62***	18.24
WHY	Percent of HYV area under wheat	84.17	1.53***	10.68
RHY	Percent of HYV area under rice	52.10	5.18***	23.09
IRR	Irrigation intensity (irrigated area / sown area)	37.70	0.95***	3.33
YRN	Annual rainfall in mm.	1132	-0.36	609
P1970-80	Dummy variable, 1 for 1970-80, 0 otherwise			
P1991-97	Dummy variable, 1 for 1991-97, 0 otherwise			

Table 5.19 Total factor productivity decomposition for the Rice-Wheat system in eastern Uttar Pradesh, 1970-97: estimated parameters with lag structure (8,8,8).

Variable	Parameter estimate	t-ratio	Standardized regression coefficients
INTERCEPT	4.54700***	56.152	
RCH	0.00058***	2.726	0.538
WHY	0.00111***	5.135	0.307
YRN	0.00038***	3.799	0.103
EXT	0.00001	0.326	0.043
FYM	0.00073	0.547	0.091
IRRIGATION	-0.00022	-0.586	-0.031
PUL	-0.00191	-1.418	-0.157
RHY	-0.00005	-0.562	-0.033
R^2= 0.794			
Adjusted R^2= 0.780			
F value 56.177			

Notes: i) The dependent variable is the log of total factor productivity index of the rice-wheat system and independent variables are in index form.
ii) The lag structure reflects lags between the times when expenditures on research are made and when they have their full economic impact. As conceived here, the lag has three segments. The first segment comes between the first appearances of the research result and its full effect. The second refers to the number of years during which the research contributes at full strength. The third represents the sort of decay in the research contribution, due perhaps to biological changes or its replacement by later, superior discoveries.
The numbers used here (8,8,8) refer to the number of years in each segment.
iii) *** significant at 1 percent ** significant at 5 percent
* significant at 10 percent.

The contribution of agricultural research and extension and HYVs of wheat to the growth in TFP is undisputed. Public sector investment in applied agricultural research has been vital to agricultural development. Growth is not produced by the passive "let the market work" policies that do not include critical public investment such as public research and extension. The estimated effect of agricultural research on TFP was particularly high. Similarly, the contribution of HYVs especially in wheat was also remarkable. The use of farmyard manure improves the soil heath and influences the TFP growth positively. The annual rainfall also influences the TFP growth positively because in abnormal years TFP declined drastically.

The impact of irrigation on TFP growth was negative but non-significant, which could be because of non-efficient use of canal irrigation, which is presently contributing more than 25 percent area of the total irrigated area. The impact of HYVs of rice was also negative but non-significant, which may be due to lower adoption and non-availability of suitable varieties of rice for various rice ecologies.

Growth Accounting

The contribution of determinants to growth in TFP can be calculated through a growth-accounting exercise that relates growth in TFP to the growth in explanatory variables. The growth-accounting exercise combines the parameters estimated for the sources of growth in the TFP decomposition equations with the rate of growth of those sources. Table 5.20 shows that research alone contributed 76 percent to the growth in TFP followed by HYVs of wheat (24 percent). The estimated marginal rate of return to the public research stock was 139 percent.

Table 5.20 Sources of growth in total factor productivity in Rice-Wheat system in eastern Uttar Pradesh, 1970-97.

Determinants	Annual growth in determinants (percent)	Elasticity of total factor productivity	Share in Total factor productivity growth (percent)
RCH	8.68	0.0162	76
WHY	1.53	0.0297	24
Total			100
Measured TFP growth			1.79

5.3 Sustainability Indicators (SIs) for Rice-Wheat System

Indicators can be used in number of ways such as simple measures of performance, an index derived from computed formulae and as a system of response. With the help of indicators rice-wheat system can be evaluated more easily. Various SIs are used by FAO, World Resource Institute (WRI) and UNDP to measure the sustainability of agricultural system. An economic indicator for measuring sustainability of the farming system is TFP. However, TFP alone is not a complete measure as all resources used in production are not included in estimation of TFP, particularly non-marketable natural resources. Some important universally accepted SIs are used to evaluate rice-wheat system in Table 5.21. For a system's sustainability increase in its productivity is a necessary condition. The productivity of rice and wheat increased about two to three times during the last three decades. However, growth rate in 1990s in comparison to 1980s showed a decelerating trend, which is not desirable for a sustainable system. In fact, crop yield is incomplete as a measure of economic efficiency because it does not consider the use of inputs other than land. The TFP of the system is decelerating which indicates that system is moving towards un-sustainability. A decline in the B:C ratio also indicates un-sustainable dimension of the system. The diversification of a system is also important for risk aversion and various other reasons, which influence the system's sustainability. The Herfindahl index indicates that the system is moving towards specialisation. In summary, it can be generalised that the system is moving towards un-sustainability, which can be reversed through arresting the possible causes of un-sustainability of the system.

Table 5.21 Sustainability indicators for Rice-Wheat system in eastern Uttar Pradesh, 1970-97.

Indicator	1970-71	1981-82	1997-98	Trend	Impact on sustainability
Productivity					
Rice productivity (kg/ha)	757	912	2049	Acceleration	Positive
Wheat productivity (kg/ha)	1093	1462	2299	Acceleration	Positive
Compound growth in rice productivity[a]	-0.31	5.58	3.1	Deceleration	Negative
Compound growth in wheat productivity[a]	2.81	2.75	2.38	Deceleration	Negative
Efficiency					
Growth in total factor productivity index (%)[a]	0.61	2.13	1.11	Deceleration	Negative
Profitability					
Benefit-cost ratio of R-W system	1.40	1.25	1.19	Deceleration	Negative
Variability					
Instability index of rice[a]	21.21	8.61	7.36	Deceleration	Positive
Instability index of wheat[a]	9.41	5.97	5.45	Deceleration	Positive
Equity					
Share of marginal and small farmers in total holdings (%)	89.3	92	93.9	Acceleration	Negative
Diversity					
Diversification index (Herfindahl index)[a]	0.18	0.26	0.31	Acceleration	Negative
Resource Utilization					
Land under desirable ecological sector (% of reported area)[b]	17.66	15.04	13.0	Deceleration	Negative
Land under undesirable ecological sector (% of reported area)[b]	3.30	2.74	1.92	Deceleration	Positive
Land under agricultural sector (% of reported area)[b]	70.59	72.70	74.07	Acceleration	Negative
Land under non-agricultural sector (% of reported area)[b]	8.41	9.49	10.98	Acceleration	Negative
Average size of land holdings (ha)	0.89	0.76	0.67	Deceleration	Negative
Net irrigated area (%)	32	32.4	56	Acceleration	Positive
Irrigated area under rice crop (%)	7.04	10.85	24.59	Acceleration	Positive
Irrigated area under wheat crop (%)	75.01	86.05	90.41	Acceleration	Positive
Numbers of livestock / ha[c]	1.85	1.91	2.56	Acceleration	Positive
Share of pulses area to R-W system (%)	15	11	9	Deceleration	Negative
Share of FYM use to total nutrients supply (%)	42	18	13	Deceleration	Negative
Groundwater utilization of available potential (%)	29	32	36	Acceleration	Positive
NPK use (kg/ ha)	2	54	142	Acceleration	Negative
NPK Ratio	5:1:1	9:2:1	24:6:1	Acceleration	Negative
Pesticides use (kg / ha)	0.001	0.066	0.13	Acceleration	Negative

Note: 'a' denotes periods of 1969-79, 1980-89 and 1990-99; 'b' refers to the years 1970, 1981 and 1996; and 'c' denotes to the years 1971, 1981 and 1992

5.4 Characterization of the Rice-Wheat System and Resource use Pattern in the Context of Sustainability

Broadly speaking, eastern Uttar Pradesh can be defined as irrigated ecosystem with irrigated area of 56 percent in 1997. Considering agro-ecological characteristics of the region, NBSSLUP, (1992 & 1999) has categorised it as high potential region. We further categorised the rice-wheat system based on resources and farmers' practices using the primary data collected for this purpose. The main characteristics are further used to assess the sustainability of the system.

5.4.1 Farmers Resources

Table 5.22 shows that among sample farmers, land distribution was highly skewed and fragmented. On an average, farmers possessed four separate land parcels, in some cases separated by long distances. For efficient water management, these parcels were often further sub-divided into small individual plots. Family size in the study area was fairly large, with approximately nine persons per family, including male, female and children. Interviews with sample farmers revealed scarcity of labour during the peak season (rice transplanting and harvesting of rice and wheat) due to migration of labour to Punjab and Haryana. Almost all the farmers owned cow or buffaloes.

Table 5.22 Resources of the sample farmers under Rice-Wheat system in eastern Uttar Pradesh, 1999-2000.

Particular	Small farmers	Medium farmers	Large farmers	All farmers
Number of farmers	64	44	32	140
Average size of holdings (ha)	0.86	2.8	6.5	2.8
Average number of land parcels	3	4	5	4
Average irrigated area (%)	60	83	75	71
Average family size	7	11	9	9
Average number of bullocks	1	2	0	1
Average number of buffaloes	1	1	2	1
Average number of cow	1	1	1	1

5.4.2 Crop Management Practices Followed by Sample Farmers

The rice-wheat system was practised on 59 percent of the area; other prominent cropping systems followed in the region were rice-mustard+ sugarcane, sugarcane (ratoon)-wheat, etc. The share of pulses based cropping systems was less than ten percent (Table 5.23). Almost all the area under rice-wheat system followed the transplanting of rice crop. About 68 percent of rice area was timely transplanted, while 20 percent of rice area was early transplanted. The remaining 12 percent of the area was late transplanted, delaying the sowing of wheat.

Table 5.23 Major crop rotation practices followed by sample farmers in eastern Uttar Pradesh, 1999-2000.

(Percent of net cropped area)

Crop rotation	Average
Rice-Wheat	57
Rice-Wheat- Green gram	2
Rice-Mustard + Sugarcane	6
Rice- Lentil	2
Rice + Pigeonpea + Sorghum	2
Rice-Barley	2
Rice-Fallow	2
Rice-Gram	2
Maize-Potato	3
Pearl millet-Wheat	2
Sugarcane (Ratoon)-Wheat	5
Sorghum (fodder)-Potato-onion	2
Sorghum (fodder)- Berseem	2
Others	11

In case of wheat crop, more than 45 percent area was late sown, and therefore, suffered from hot winds at the time of grain ripening resulting in significant decline in yield (Table 5.24). It is also observed that wheat planting was often delayed because of long turnaround time between rice harvesting and wheat planting, scarcity of draft power for field operations and non-availability of inputs in time. Experiments have shown that there will be one percent loss in wheat yield for each day of delayed planting beyond the last week of November (Monasterio *et al.* 1994). Another important implication of this delayed planting is that a short duration pulse crop can't be taken up in the summer season. Inclusion of pulses was also restricted because of inadequate time between rice and wheat crops, non-availability of resources in time, etc.

Table 5.24 Crop calendar practices followed by sample farmers in Rice-Wheat system in eastern Uttar Pradesh, 1999-2000.

(Area in hectares)

Particular	Percent of total R-W system
Rice	
Nursery Sowing (20th May to 25 th June)	100
Transplanting	
Early (up to 30th June)	20.32
Timely (1st July to 31st July)	68.25
Late (after 1st August onwards)	11.43
Harvesting (Oct. end to November)	100.00
Wheat	
Early (up to 15th October)	1.48
Timely (16th October to 30th November)	52.93
Late (after 1st December onwards)	45.59
Harvesting (end March to mid May)	100.00

Table 5.25 shows the use of the agro-chemicals in rice and wheat crops. In case of rice crop, NPK consumption was 150 kg/ha, which was less than recommended level of 210 kg/ha for the eastern Uttar Pradesh. These were given in the form of DAP and urea as basal fertilisers and urea as top dressing. Further, NPK ratio was badly distorted; it was 29:7:1 in rice and 60:8:1 in wheat against a recommended ratio of 4:2:1. FYM was applied at the rate of 4 tonnes/ha against a recommended level of 10-12 tonnes/ha. It implies that the system suffered from distorted C:N ratio due to low application of FYM. This is a serious limitation as organic matter plays vital role for micronutrients, exchange capacity of soil, microorganisms activity, water holding capacity, improve the soil tilth (Tisdale *et al.*, 1990).

Table 5.26 shows that more than 85 percent of rice area was under HYVs and rest of the area was under local varieties. Farmers reported that local varieties were suitable for stress conditions such as deep-water lands and lack of suitable modern varieties forced them to use local varieties to minimise risk. In case of wheat, almost all area was under HYVs. It may also be noted here that

25% of the seed of modern varieties should be replaced every year, but farmers replaced only less than 2 percent of the seed. Sarju-52 and Saket-4 varieties of rice were widely adopted in irrigated and un-irrigated conditions, respectively, due to higher yield and resistant to various stresses. In wheat, HD-2329 suitable for irrigated conditions and HD-2285 suitable for both irrigated and un-irrigated conditions, especially for late sowing, were widely adopted (Table 5.26).

Table 5.25 Agro-chemicals use in rice and wheat crops of Rice-Wheat system in eastern Uttar Pradesh, 1999-2000.

Particular	Average (kg/ha)
Rice	
Average fertiliser (NPK) use	150
Basal nitrogen use	62
Top-dress nitrogen use	54
Total nitrogen use	116
Phosphorus use	31
Potash use	3
Average FYM use	3000
Average zinc sulphate use	4
Average other micronutrients use	1
Average pesticide use	2
Wheat	
Average fertiliser (NPK) use	156
Basal nitrogen use	77
Top-dress nitrogen use	44
Total nitrogen use	120
Phosphorus use	33
Potash use	2
Average FYM use	1000
Average pesticide use	2

For selection of rice varieties, farmers' preferences are for grain yield, early maturity and sale price among other characteristics, and in case of wheat the preferences are for grain yield and suitability for late sown condition (Table 5.27).

Table 5.28 shows that sugarcane crop is more beneficial than the rice-wheat system as the B:C ratio of sugarcane crop was much higher than the rice-wheat system. This implies that the rice-wheat system can diversify to

Table 5.26 Major varieties of rice and wheat crops on sample farmers' fields in eastern Uttar Pradesh, 1999-2000.

Ecological Condition	Soil type	Rice HYVs	Local varieties	Average area under HYVs (%)	Average area under ecology (%)	Wheat HYVs	Local	Area under HYVs (%)	Average area under ecology (%)	Average seed replacement rate (%)
Un-irrigated (other than area under deep water)	Sandy loam and calcareous	Saket-4, Narendra -97, Narendra-118, Govind	Sarya, Kachni, Parag China-4,	87	48	K. 8027, K.8962, Gomti, HD-2285	Nil	100	29	0.5
Irrigated	Loam and sandy loam	Sarju-52, Pant Dhan-12, Jaya, PNR-381, Mahsuri, Pusa Basmati-1, Basmati-370, Ushar Dhan-1, Hybrid-2		100	45	HD-2329, HD-2285, UP-2003, Vaishali, Malviya-206, Malviya-234, HD-2643, UP-2382, Maghar, Triveni	Nil	100	71	1.9
Deep water	Clay loam	Jal Magn, Madhukar, Chakia-59, Jal Lahri, Barh Awrodhi	Sengar, Jaisuria	35	7	Nil	Nil	Nil	Nil	0.5

Table 5.27 Criteria for selection of rice and wheat varieties by sample farmers in eastern Uttar Pradesh, 1999-2000.

Characteristics	Preference of characteristics (% to total)
Rice	
Grain yield	32
Early maturity	26
Sale price	12
Flood tolerance	10
Resistance to drought	8
Resistance to pest & diseases	4
Volume expansion	4
Other characteristics	4
Wheat	
Grain yield	25
Suitable for late sowing	25
Bread quality	20
Sale price	10
Resistance to diseases	10
Other characteristics	10

5.5 Identification of Production Constraints in the Rice-Wheat System

As seen from Table 5.29, Fig. 5.6 and 5.7, the estimated yield gap I was 174 kg/ha (5 %) and yield gap II was 1455 kg/ha (42%) in case of un-irrigated rice. In irrigated rice, yield gap I was 631 kg/ha (12 %), while yield gap II was 2030 kg/ha (45 %). In wheat crop, yield gap I was 1636 kg/ha (29 %) and yield gap II was 1519 kg/ha (38 %).

The concern of present study is to minimize yield gap II through suitable research and policy options. The identified production constraints are shown in Fig 5.8 and Tables 5.30 to 5.34. It can be seen that, in case of un-irrigated rice, the share of technical and socio-economic constraints was 54 and 46 percent, respectively. Within the technical constraints, soil related constraints were dominant followed by the constraints related to weeds, climate, insect pests and diseases. Among all the individual constraints, drought ranked first, followed by flood, nitrogen deficiency, and weeds (*Cynadon dactylon*, and *Cyprus*

Table 5.28 Cost per hectare and resource use for rice, wheat and sugarcane crops in Rice-Wheat system in eastern Uttar Pradesh, 1999-2000.

Particular	Average cost (Rs/ha)		
	Rice	Wheat	Sugarcane
Family labour	2277 (17.90)	1490 (11.75)	3993 (14.32)
Hired labour	1143 (8.98)	613 (4.83)	3551 (12.73)
Total human labour	3420 (26.88)	2103 (16.59)	7544 (27.05)
Bullock labour	300 (2.36)	569 (4.49)	905 (3.25)
Machine labour	1227 (9.64)	1667 (13.15)	1687 (6.05)
Irrigation	441 (3.47)	482 (3.80)	3818 (13.69)
Seed	387 (3.04)	940 (7.41)	1219 (4.37)
FYM	625 (4.91)	142 (1.12)	1464 (5.25)
Fertiliser	2217 (17.43)	2733 (21.55)	2892 (10.37)
Plant protection	303 (2.38)	329 (2.59)	564 (2.02)
Interest on working capital	802 (6.30)	715 (5.64)	1796 (6.44)
Rental value of land	3000 (23.58)	3000 (23.66)	6000 (21.51)
Total cost	12722 (100)	12680 (100)	27889 (100)
Yield Quintals / ha.	27	29	500
Gross Returns	15230	18850	44500
Net profit	2508	6170	16611
B:C ratio	1.20	1.49	1.60

rotendus). The maximum percent of area was affected by *Cynadon dactylon, Selaria glauca, Cyprus spp.* among weeds; false smut and brown spot among diseases; armyworm, brown planthopper among insect pests; waterlogging, nitrogen and phosporus deficieny among soil related constraints; and flood and drought among the climate related constraints.

Table 5.29 Estimated yield gaps in Rice-Wheat system at Faizabad centre in eastern Uttar Pradesh, 1999-2000.

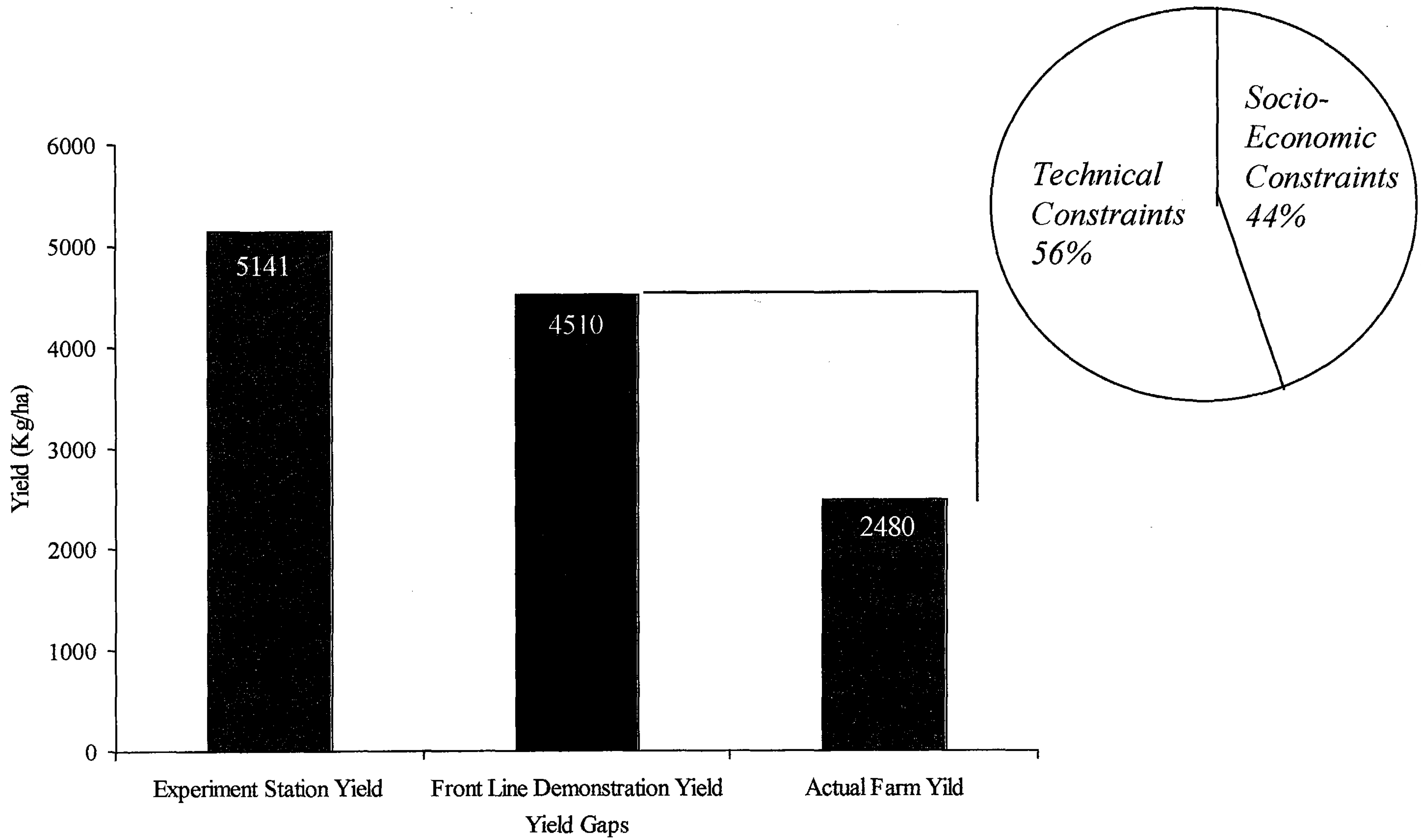
(kg/ha)

Particular	Rice		Wheat
	Un-irrigated	Irrigated	Irrigated
Average experiment station yield	3629[a]	5141[a]	5675[b]
Average front line demonstration yield	3455[c]	4510[c]	4039[d]
Average actual farm yield	2000[e]	2480[e]	2520[e]
Yield gap I	174	631	1636
	(5)	(12)	(29)
Yield gap II	1455	2030	1519
	(42)	(45)	(38)
Total yield gap	1629	2661	3155
	(47)	(57)	(67)

Source:. Experimental and demonstration yield data were taken from reports of `the coordinated projects and frontline demonstrations respectively.

In case of irrigated rice, the share of technical and socio-economic constraints was 56 and 44 percent, respectively. Within the technical constraints, soil related constraints ranked first followed by insect pests, disease pests, weed and climatic stress. Among the individual constraints, zinc deficiency ranked first; followed by nitrogen deficiency, stem borer, phosphorus deficiency, drought and *Cynadon dactylon*. The maximum percent of area was affected by *Selaria glauca, D. aegypsium* among weeds; false smut and brown spot among diseases; brown planthopper and stem borer among insect pests; waterlogging, and nitrogen and phosphorus deficiency among soil related constraints. It is worth noting that climate related factors had relatively lesser impact on the system because of good irrigation facilities.

ure 5.6: Yield gaps of irrigated rice in eastern Uttar Pradesh, 1999-2000.



In case of irrigated wheat, the share of technological and socio-economic constraints was 52 and 48 percent, respectively. Weeds-related constraints were dominant, followed by soil, diseases and climate related constraints. Among the individual constraints, *Phalaris minor* weed ranked first followed by nitrogen deficiency, phosphorus deficiency, *Averna spp.*, *Chenopodium album* and late season moisture constraints. *Phalaris minor, Avena spp.* among weeds; foliar blight and karnal bunt among diseases affected the maximum percent of area; nitrogen, phosphorus deficiency and late season moisture stress among soil related constraints; and hailstorm among climate related constraints. Nematode also effects the substantial portion of wheat crop of the system. It is important to note that climate-related factors have relatively less impact on the system because of good irrigation facilities. This was also supported by the fact that instability in crop yields has decreased over time.

Considering rice and wheat together for the rice-wheat system, the share of technical and socio- economic constraints was 54 and 46 percent, respectively. Soil-related constraints were most important among group constraints followed by weed-related constraints, insect pests-related constraints and climate-related constraints. Among the individual constraints, zinc deficiency, nitrogen deficiency, *Phalaris minor and* phosphorus deficiency were important in that order. It may be noted here that for the rice-wheat system constraints relating to irrigated rice and wheat were considered. These constraints were prioritised based on the value of production losses (Table 5.34). The production loss due to socio-economic constraints is difficult to estimate and therefore, these constraints were prioritised based on the perceptions of the farmers (Table 5.35). Most of the farmers have poor knowledge about new technologies due to poor outreach of extension services, experienced irregular electricity supply and lack of adequate infrastructure facilities.

Figure 5.7:Yield gaps of irrigated wheat in eastern Uttar Pradesh, 1999-2000.

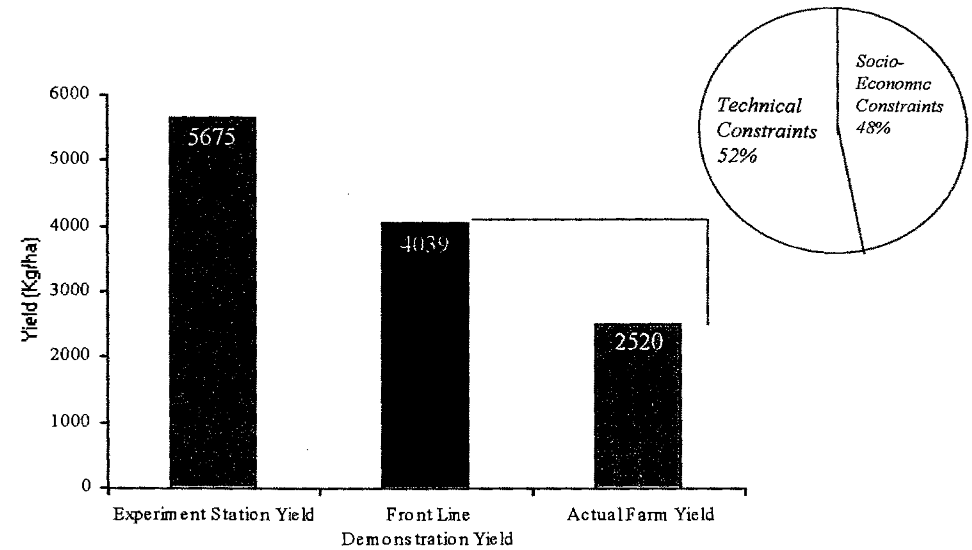
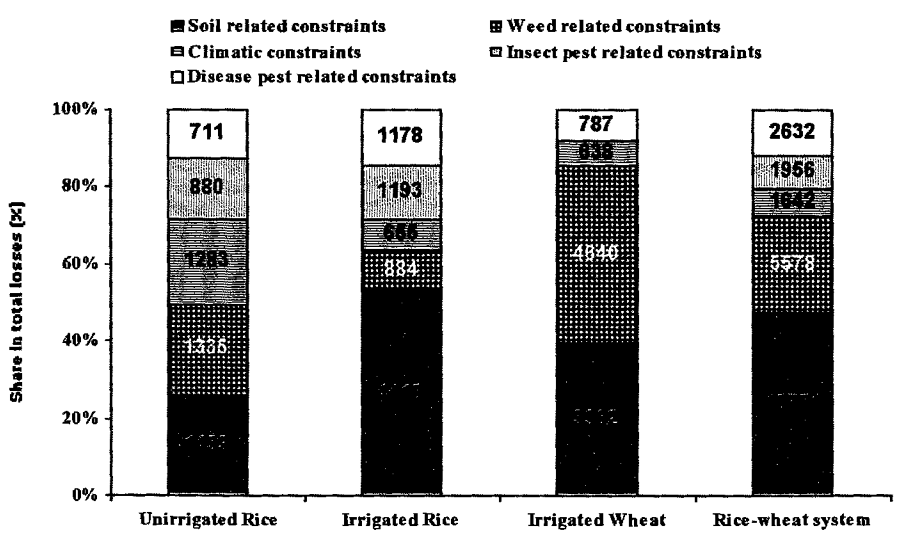


Figure 5.8:Crop production losses due to various technical constraints in eastern Uttar Pradesh, 1999 - 2000.



Note: Figure in bars are value of production loss in million rupees.

Table 5.30 Estimates of yield losses due to major constraints in un-irrigated rice crop in Rice-Wheat system in eastern Uttar Pradesh, 1999-2000.

Particular	Percent of area reported from constraints	Probability of occurrence of constraints	Actual yield losses reported in affected area (kg/ha)	Average estimated yield losses (kg/ha)	Percent of yield gap II	Estimated value of yield losses (Rs. Million)
Technical constraints						
Abiotic constraints						
Climate related constraints						
Drought	15	0.66	960	95	12	697
Flooding	20	0.33	1212	80	10	587
Sub-total Climate related constraints				**175**	**22**	**1283**
Soil related constraints						
Alkaline and saline soil	1	1	200	2	0	15
Nitrogen deficiency	20	0.5	730	73	9	535
Phosphorus deficiency	30	1	147	44	6	323
Potash deficiency	10	0.33	455	15	2	110
Zinc deficiency	10	1	150	15	2	110
Sulphur deficiency	5	1	140	7	1	51
Iron deficiency	2	1	300	6	1	44
Water logging	30	0.5	147	22	3	161
Late season moisture stress	12	0.5	250	15	2	110
Sub-total Soil related constraints				**199**	**25**	**1459**
Biotic constraints						
Insect pests						
Stem borer	8	0.5	900	36	5	264
Whitebacked planthopper	5	1	580	29	4	213
Leaf folder	24	0.33	278	22	3	161
Brown planthopper	27	0.3	185	15	2	110
Gundhi bug	21	1	52	11	1	81
Armyworm	30	0.1	233	7	1	51
Sub-total Insect pests				**120**	**15**	**880**
Diseases						
False smut	34	0.5	171	29	4	213
Sheath rot	15	0.5	333	25	3	183
Brown spot	20	0.33	318	21	3	154
Sheath blight	10	0.5	300	15	2	110
Bacterial blast	10	1	70	7	1	51
Sub-total Diseases				**97**	**12**	**711**
Weeds						
Cynodon dactilon	76	0.7	137	73	9	535
Cyprus spp.	52	0.8	156	65	8	477
Selaria glauca	70	1	41	29	4	213
Echinochloa colonum	23	0.66	99	15	2	110
Sub-total Weeds				**182**	**23**	**1335**
Rodents	8	1	50	4	1	29
Birds	30	0.1	33	1	0	7
Wild cow	10	1	70	7	1	51
Sub-total Others				**12**	**2**	**88**
Technical constraints				**785**	**54**	**5756**
Socio-economic constraints				**670**	**46**	**4903**
Total				**1455**	**100**	**10659**

Table 5.31 Estimates of yield losses due to major constraints in irrigated rice crop in Rice-Wheat system in eastern Uttar Pradesh, 1999-2000.

Particular	Percent of area reported from constraints	Probability of occurrence of constraints	Actual yield losses reported in affected area (kg/ha)	Average estimated yield losses (kg/ ha)	Percent of yield gap II	Estimated value of yield losses (Rs. Million)
Technical constraints						
Abiotic constraints						
Climate related constraints						
Drought	8	0.66	1098	58	5	427
Flooding	10	0.33	939	31	3	228
Sub-total Climate related constraints				**89**	**8**	**655**
Soil related constraints						
Alkaline and saline soil	1	1	200	2	0	15
Nitrogen deficiency	30	1	293	88	8	648
Phosphorus deficiency	30	1	193	58	5	427
Potash deficiency	20	0.5	300	30	3	221
Zinc deficiency	38	1	768	292	26	2150
Sulphur deficiency	5	1	880	44	4	324
Iron deficiency	2	1	700	14	1	103
Water logging	35	0.66	182	42	4	309
Late season moisture stress	10	0.5	600	30	3	221
Sub-total Soil related constraints				**600**	**53**	**4418**
Biotic constraints						
Insect pests						
Stem borer	23	0.5	678	78	7	574
Whitebacked planthopper	15	0.5	400	30	3	221
Leaf folder	10	1	220	22	2	162
Brown planthopper	25	0.5	112	14	1	103
Gundhi bug	10	1	120	12	1	88
Armyworm	5	0.16	1000	8	1	59
Sub-total Insect pests				**164**	**14**	**1208**
Diseases						
False smut	35	0.5	251	44	4	324
Sheath rot	2	0.66	288	38	3	280
Brown spot	25	0.3	453	34	3	250
Sheath blight	15	0.5	400	30	3	221
Bacterial blast	15	0.66	141	14	1	103
Sub-total Diseases				**164**	**14**	**1208**
Weeds						
Cynodon dactilon	20	0.5	440	44	4	324
Cyprus spp.	17	0.66	267	30	3	221
Selaria glauca	75	1	29	22	2	162
Echinochloa colonum	35	0.33	121	14	1	103
Dactyloctenium aegyptium	45	0.66	40	12	1	88
Sub-total Weeds				**122**	**11**	**884**
Technical constraints				**1135**	**56**	**8315**
Socio-economic constraints				**895**	**44**	**6556**
Total				**2030**	**100**	**14871**

Table 5.32 Estimates of yield losses due to major constraints in irrigated wheat crop in Rice-Wheat system in eastern Uttar Pradesh, 1999-2000.

Particular	Percent of area reported from constraints	Probability of occurrence of constraints	Actual yield losses reported in affected area (kg/ha)	Average estimated yield losses (kg/ha)	Percent of yield gap II	Estimated value of yield losses (Rs. Million)
Technical constraints						
Abiotic constraints						
Climate related constraints						
Flooding	8	0.15	250	3	0	41
Hailstorm	20	0.33	667	44	6	597
Sub-total Climate related constraints				**47**		**638**
Soil related constraints						
Alkaline and saline soil	1	1	100	1	0	14
Nitrogen deficiency	30	1	387	116	15	1574
Phosphorus deficiency	40	1	183	73	9	990
Potash deficiency	25	1	116	29	4	393
Zinc deficiency	21	0.66	209	29	4	393
Sulphur deficiency	21	1	33	7	1	95
Late season moisture stress	25	1	148	37	5	502
Sub-total Soil related constraints				**292**	**37**	**3962**
Biotic constraints						
Diseases						
Foliar blight	30	0.33	222	22	3	298
Loose smut	15	0.66	152	15	2	204
Karnal bunt	25	0.4	110	11	1	149
Powdery mildew	15	0.33	141	7	1	95
Leaf rust	12	0.66	51	4	1	54
Sub-total Diseases				**59**	**7**	**787**
Nematodes	**32**	**0.8**	**113**	**29**	**4**	**393**
Weeds						
Cynodon dactilon	56	0.5	54	15	2	204
Phalaris minor	85	1	172	146	19	1981
Avena spp.	72	1	101	73	9	990
Chenopodium album	45	1	98	44	6	597
Melilotus alba	38	1	95	36	5	488
Fumeria parvi	3	1	97	29	4	393
Sub-total Weeds				**342**	**44**	**4640**
Rodents	1	1	70	7	1	95
Wild cow	24	1	46	11	1	149
Sub-total Others				**18**	**2**	**244**
Technical constraints				**788**	**52**	**10664**

Table 5.33 Estimates of yield losses due to major constraints in Rice-Wheat system in eastern Uttar Pradesh, 1999-2000.

Particular	Average estimated yield losses (Kg/ha)	Percent of yield gap II	Estimated value of yield losses (Rs. Million)
Technical constraints			
Abiotic constraints			
Climate related constraints			
Drought	58	3	700
Flooding	34	2	411
Hailstorm	44	2	531
Sub-total Climate related constraints	**136**	**7**	**1642**
Soil related constraints			
Alkaline and saline soil	3	0	36
Nitrogen deficiency	204	11	2463
Phosphorus deficiency	131	7	1582
Potash deficiency	59	3	712
Zinc deficiency	321	17	3876
Sulphur deficiency	51	3	616
Iron deficiency	14	1	169
Water logging	42	2	507
Late season moisture stress	67	3	809
Sub-total Soil related constraints	**892**	**47**	**10771**
Biotic constraints			
Insect pests			
Stem borer	78	4	942
Whitebacked planthopper	30	2	362
Leaf folder	22	1	266
Brown planthopper	14	1	169
Gundhi bug	12	1	145
Armyworm	8	0	97
Sub-total Insect pests	**164**	**8**	**1956**
Diseases			
False smut	44	2	531
Sheath rot	38	2	459
Brown spot	34	2	411
Sheath blight	30	2	362
Bacterial blast	14	1	169
Foliar blight	22	1	266
Loose smut	15	1	181
Karnal bunt	11	1	133
Powdery mildew	7	0	85
Leaf rust	4	0	48
Sub-total Diseases	**219**	**11**	**2632**
Nematodes	**29**	**2**	**350**
Weeds			
Cynodon dactilon	59	3	712
Cyprus spp.	30	2	362
Selaria glauca	22	1	266
Echinochloa colonum	14	1	169
Dactyloctenium aegyptium	12	1	145
Phalaris minor	146	8	1763
Avena spp.	73	4	881
Chenopodium album	44	2	531
Melilotus alba	36	2	435
Fumeria parvi	29	2	350
Sub-total Weeds	**465**	**24**	**5578**
Rodents	7	0	85
Wild cow	11	1	133
Sub-total Others	**18**	**1**	**217**
Technical constraints	**1916**	**54**	**23147**
	[illegible]	**46**	**19705**

Table 5.34 Priority ranking based on value of production losses in Rice-Wheat system in eastern Uttar Pradesh, 1999-2000.

Priority ranks	Rice		Wheat	Rice-Wheat System
	Un-irrigated	Irrigated	Irrigated	Irrigated
1	Drought	Zinc deficiency	*Phalaris minor*	Zinc deficiency
2	Flood	Nitrogen deficiency	Nitrogen deficiency	Nitrogen deficiency
3	Nitrogen deficiency	Stem borer	Phosphorus deficiency	*Phalaris minor*
4	*Cynodon dactilon*	Phosphorus deficiency	*Avena spp.*	Phosphorus deficiency
5	*Cyprus rotendus*	Drought	*Chenopodium album*	Stem borer
6	Phosphorus deficiency	*Cynodon dactilon*	Late season moisture stress	*Avena spp.*
7	Stem borer	False smut	Hailstorm	Late season moisture stress
8	White-backed planthopper	Water logging	*Melilotus alba*	Potash deficiency
9	False smut	Sulphur deficiency	Zinc deficiency	*Chenopodium album*
10	*Selaria glauca*	Sheath rot	Potash deficiency	*Cynodon dactilon*
11	Sheath rot	Brown spot	*Anguina tritici* (nematodes)	Drought
12	Water logging	Flood	*Fumeria parvi*	Sulphur deficiency
13	Leaf folder	*Cyprus rotendus*	Foliar blight	Hailstorm
14	Brown spot	White-backed planthopper	*Cynodon dactilon*	False smut
15	Potash deficiency	Potash deficiency	Loose smut	Stem borer
16	Zinc deficiency	Late season moisture stress	Wild cow	*Chenopodium album*
17	Late season moisture stress	Sheath blight	Karnal bunt	Water logging
18	Brown plant hopper	*Selaria glauca*	Sulphur deficiency	Sheath rot
19	Sheath blight	Leaf folder	Rodents	*Melilotus alba*

Table 5.35 Ranking of socio-economic constraints identified for the Rice-Wheat system in eastern Uttar Pradesh, 1999-2000.

Particular	Frequency of constraints reported by farmers	Rank
Lack of knowledge about IFM, IPM, use of low cost fertilizers technologies such as blue green algae, new varieties and improved technologies suitable for stress environment, zero tillage and crop residue management	29	1
Low share of nutrients supply through FYM in total nutrient supply, lion's share of animal dung used as fuel	23	2
Poor extension reach of extension agencies and lack of demonstration trials	17	3
Low irrigation facilities and erratic supply of electricity	15	4
Low pulses area related to rice-wheat system area and lack of suitable cropping sequence	14	5
Lack of output market infrastructure	11	6
Lack of proper developed road infrastructure	10	7
Small and fragmented holding and limited resource base of farmers	8	8
Lack of improved implements and supply of spurious agro-chemicals, substandard seed	7	9
Declining area under common property land	6	10

These findings indicate that there are serious constraints to enhance economic efficiency and sustainability of the rice-wheat system. The main research and policy options in this regard and other emerging issues are discussed in the next chapter.

CHAPTER VI

SUMMARY AND CONCLUSIONS

In first decade of the Green Revolution, foodgrains production in India registered impressive growth because of rapid increases in area as well as productivity. The impact of the Green Revolution, however, was not evenly spread among all crops and agro-ecological regions of the country. In particular, the production of rice and wheat grew rapidly, particularly in the north-west region of the country. Rice and wheat now occupy 55 percent of the total area under foodgrains and contribute 75 percent to the total production (Government of India, 2000). Much of the production of these two crops is contributed by the rice-wheat system practiced on about 11 million ha area in the country. The state of Uttar Pradesh, particularly its eastern part, accounts for major share of the rice-wheat area (43 percent) in the country.

In spite of intensification of production systems, crop yields are not showing desirable growth. This is particularly true for the Green Revolution regions. On the contrary, it is increasingly reported that the growth in total factor productivity in the Green Revolution regions is decelerating and rice-wheat system is no exception to this. The question now arises is that what is happening in the cropping systems or regions where growth started at a later stage? Is the sustainability in such systems under threat and if so, what are the underlying factors? The present study aims to fill this information gap. The specific objectives of the study are: (1) To study the temporal changes in agriculture; (2) to study trends and determinants of crop productivity in the rice-wheat system; (3) to characterize the rice-wheat system and resource use pattern in the context of long-term sustainability; (4) to identify the constraints to accelerate and sustain productivity of the rice-wheat system; and (5) to suggest priority research areas and policy measures to accelerate and sustain productivity of the rice-wheat system.

The study used both secondary and primary data to examine temporal changes in agriculture, trends and determinants of TFP and constraints to sustainability of the rice-wheat system in eastern Uttar Pradesh. The major analytical techniques used in the study are: (i) semi-log model to estimate growth rate in agriculture; (ii) Cuddy-Della Valle index to compute instability index; (iii) Tornqvist-Theil index to compute TFP; and (iv) yield gap and its main causes. The study covers the period of 1950 to 1999 which was further divided into four sub-periods as: (i) Pre-Green Revolution Period (1950-68); (ii) Green Revolution Period (1969-79); (iii) Post-Green Revolution Period I (1980-89); and (iv) Post- Green Revolution Period II (1990-99).

Agriculture in eastern Uttar Pradesh was dominated by marginal and small farmers. There was significant increase in the area irrigated by both canal and private tubewells. However, no significant change has occurred in groundwater utilization since 1982. The fertilizer consumption also showed an increasing trend but NPK consumption ratio distorted over time due to more than proportionate use of nitrogen. The region predominantly grew HYVs of rice and wheat. These two crops gained area considerably, primarily at the cost of loss in area under coarse cereals and pulses. Potato and sugarcane also gained area to some extent.

The analysis of changes in cropping pattern revealed that during the pre-Green Revolution period, the expansion effect was more dominant than the substitution effect. But during the Green Revolution period and the post-Green Revolution I, the substitution effect was stronger than the expansion effect.

Both the effects became almost equal during the post-Green Revolution period II.

The area under rice-wheat sequence in India was estimated to be about 10.75 million (m) ha in the triennium ending 1998-99. The sequence was practiced extensively in Uttar Pradesh (4.67 m ha), Punjab (1.97 m ha), Bihar (1.79 m ha), Madhya Pradesh (1.01 m ha), Haryana (0.80 m ha), West Bengal (0.31 m ha) and Jammu and Kashmir (0.20 m ha). District-wise area under the system showed wide variations. Out of the fifteen districts of eastern Uttar Pradesh, only seven districts, namely, Basti, Gorakhpur, Azamgarh, Deoria, Faizabad, Bahraich and Gonda occupied 59 percent of the total area under the system in eastern Uttar Pradesh or 10 percent of the total area in the country.

There was a steady decline in the instability index of crop yields since 1970s. It is observed that the efforts to increase productivity during the pre-Green Revolution period and the Green Revolution period have been widely consolidated and impact came in the later period. It is widely accepted that investment for agricultural development especially for development, refinement and transfer of technologies, paid rich dividends.

Human labour, animal labour, machine labour, farmyard manure, fertilizer, irrigation cost and rental value of land were considered as inputs and rice, wheat, barley, sorghum, pearl millet, maize, small millets, total pulses, total oilseeds, sugarcane and potato were taken as outputs to study the trends in partial and total factor productivity. This analysis was carried out for three sub-periods: (i) Green-Revolution Period (1970-80); (ii) Post-Green Revolution Period I (1981-90); and (iii) Post-Green Revolution Period II (1991-97).

Partial factor productivity (PFP) of machine labour, fertilizer and irrigation capital decreased significantly since 1970s, while PFP of human labour, animal labour, farmyard manure and rental value of land increased significantly. The share of rice and wheat in the total value of output increased at the rate of 1.92 and 1.72 percent per annum respectively, while the share of other crops decreased significantly. Among all the seven inputs, the cost shares of human labour, machine labour, and irrigation cost increased significantly, while the shares of animal labour, farmyard manure, rental value of land decreased significantly. The share of fertiliser remained constant during the entire period.

The growth in the input index showed a secular decline, whereas that of the output index was continuously increasing until 1980s and slowed down thereafter. The growth in the output and input indices was 4.08 and 2.29 percent, respectively, giving a TFP growth of 1.79 percent during the entire period. The results of regression analysis showed that rainfall, research stock, and HYVs of wheat have positive and significant impact on the growth of TFP. Adjusted R^2 value of the model was 0.78. The growth accounting analysis indicated that research contributed 70 percent to the growth in TFP followed by HYVs of wheat (30 percent). The estimated marginal internal rate of return to research investment was 139 percent.

The farm survey data showed that the rice-wheat system was practiced on 59 percent of the net sown area on sample farms. Other prominent systems followed by sample farmers were rice-mustard+sugarcane and sugarcane (ratoon)-wheat. The share of pulses in net sown area was less than ten percent. It was also found that approximately 87 percent of rice area was under HYVs. Farmers felt that local varieties are suitable for different stress conditions for which no suitable modern varieties are available to them. Hence use of local varieties minimises risk. Other criteria used by farmers for selection of rice varieties were grain yield, field adoption, early maturity, eating quality, grain under wheat was sown with HYVs. However, average seed replacement rate in both the crops was less than 2 percent, which is much below the required replacement rate of 25 percent.

More than 45 percent of wheat area was late sown and therefore suffered yield losses from hot winds at the time of ripening, especially at milking stage. The delay in sowing of wheat often results from a long turnaround time between rice harvesting and wheat planting, due to residue of rice crop, scarcity of draft power and non-availability of inputs such as quality seeds and fertilizers. An important implication of late sowing and harvesting of wheat crop is that it may not be possible to include pulse crop in summer season. The inclusion of pulse crop is also constrained by less moisture content and shortage of labour.

The yield gap analysis showed that there is tremendous potential to increase crop yields at farm level. The yield gap II in rice and wheat was 45 percent and 38 percent, respectively. The share of technical and socio-economic constraints in the yield gap (for the system as a whole) was 54 and 46 percent, respectively. Soil-related constraints ranked first followed by weeds-related constraints. Nitrogen deficiency, *Phalaris minor,* phosphorus and zinc deficiency were predominant. It is important that these constraints should be accorded high priority for research.

The socio-economic constraints were ranked on the basis of opinions and perceptions of the respondents. Among the socio-economic constraints, lack of knowledge about improved technologies ranked first, which could be addressed by strengthening extension service in the study area. A number of conclusions can be drawn from the findings of this study. A synthesis of these conclusions alongwith their implications for sustainability of the production system is presented in Table 6.1.

Table 6.1: Policy implications for sustainability of the Rice-Wheat system.

Result/ Constraints	Possible causes	Opportunity	Messages	
			Research theme	Policy tools
Cropping pattern change in favour of rice and wheat crop	Green Revolution strategy	To promote diversification	Development of suitable crop varieties and diagnosis of constraints to diversification	Fresh look to the strategies of crop production to overcome the problems with other substitutable crop and enterprises in the system.
Declining TFP	Falling efficiency of input use and research investment	Development and adoption of efficient technologies	Long term strategic research for diagnosis of technical and socio-economic constraints that limits sustainability of the R-W system	Selective investment in research, which promotes sustainability of the R-W system, investment in infrastructure development.
Soil-related constraints	Un-scientific crop rotation, imbalanced use of fertilizer, less use of FYM	Encourage diversification, adoption of integrated nutrient management and practice of zero tillage concept	Integrated nutrient management, diagnosis of the causes of late sowing of wheat, practice of zero tillage concept and identify the role of socio-economic constraints related to sustainability	Fertiliser policy should encourage balanced use of fertiliser and FYM. Application of zero tillage to be encouraged through suitable policy.
Weeds related constraints	Continuous growing of R-W crop rotation, spurious supply of weedicides besides decline in efficacy of existing weedicides	Follow suitable crop rotation, check the supply of spurious weedicides and promote integrated weed management	Development of efficient weedicides with minimum residual effect, role of cultural, mechanical methods, etc. in integrated weed management	Investment in bio-technology to develop genetically modified plant which resist the crop losses, development of efficient weedicides with minimum residual effect and check and monitoring of supply of spurious weedicides
Slow adoption of new technology and poor extension support system	Lack of knowledge about new technology and lack of adequate demonstrations	Impact of new technology should be demonstrated through efficient extension system	Development of location specific technology and its refinement through farmers' participation	Technology development based on local farmers' problems and refinement with farmers' participation, strengthen extension services

There is deceleration in the growth of TFP because of emergence of soil-related constraints and widening of gap in transfer of technologies. This trend could be arrested by improving resource use efficiency and bridging the yield gap through prioritisation and translation of production constraints into research objectives. This requires adequate investment in agricultural research and development and fostering linkages between research, extension and farmers. At the same time, development of infrastructure and rural institutions are essential to further accelerate and sustain the productivity growth.

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