TECHNICAL EFFICIENCY IN RICE CULTIVATION IN KURUNEGALA DISTRICT OF SRI LANKA

By

Aboodharda Ahamed Bishrul Hafi B.Sc. (Agric)

A dissertation submitted in partial fulfilment of the
requirement for the degree of Master of Agricultural Development
Economics at The Australian National University

July 1985

DECLARATION

Except where otherwise indicated
this thesis is my own work.

A.A.B.Hafi

July 1985

AKNOWLEDGEMENTS

I am grateful to my supervisor Dr. Ric Shand for his guidance, encouragement and generous allocation of time toward the development of this dissertation. His valuable criticism and suggestions contributed immensely to the present form of this dissertation. I am also grateful to Dr. Sisira Jayasuriya whose extensive experience on rice constituted an invaluable and often tapped resource. Dr. K.Kalirajan of the National University of Singapore unselfishly allocated his time and responded to my frequent requests for help in solving analytical problems. Dr. Dan Etherington helped to refine my economic thinking by raising thought provoking methodological questions. I also wish to thank Dr. Nimal Ranaweera, Deputy Director of Agriculture, Department of Agriculture, Sri Lanka for encouraging me to use data collected under the ANU-SRI LANKA Research Project on Transfer of Rice Technology and for his intense interest in my graduate experience at the ANU. I greatly benefited from the assistance of Mr. Gregg Corra of the Bureau of Agricultural Economics in computer programming. I wish to thank Mrs. Christine Donnely for her lavish allocation of time for my frequent requests for data of the ANU-SRI LANKA Project. Thanks are also due to Mr. Sean Foley and Mrs. Wendy Cosford for their extensive editorial assistance and help in proof reading. I also wish to thank Ms. Yvonne Pittelkow and Mr. Peter Oats who contributed to my computing skills. My special thanks are due to the ANU-SRI LANKA Project for providing me with the data used in this study.

I wish to express my deep sense of gratitude to the Australian Development Assistance Bureau for the generous Scholarship Award and the Department of Agriculture in Sri Lanka for the handsome allowance of study leave.

Last, but by no means least, I wish to thank my wife Inul for her encouragement and traditional uxorial services and to our little son Intisar for the healthy distraction from mind boggling research.

ABSTRACT

Sri Lanka has made impressive achievements in the development and spread of a HYV technology package for rice during the last two and a half decades. This enabled her to proudly claim to be at the brink of self sufficiency in rice. Nevertheless, farm level rice output was consistently found to be well below the experimental station levels and the levels that could be achieved on the farm with research level management. Farm level rice output from a given combination of inputs can be different from the best practice output in a domain due to pure statistical noise, technical inefficiency and allocative inefficiency. The objectives of this dissertation were first, to examine farm specific technical efficiency in rice cultivation in the Kurunegala district of Sri Lanka and second, to recognize factors causing differential levels of technical efficiency. Average production function analysis was performed to approximate the specification of the average rice cultivation technology practised in the area using data from a sample of 203 farmers. Average production function was specified as the relationship between farm paddy output and selected explanatory variables that included three essential quantity inputs: land area, seed quantity and land preparation labour; four non-essential quantity inputs: weeding labour, quantity of nitrogen used, herbicide cost and bullock power; and qualitative dummy variables: method of irrigation, method of crop establishment and soil fertility. A modified Cobb-Douglas functional form was selected with essential inputs entering in multiplicative form and non-essential inputs entering in exponential form. All the quantity inputs variables were found to be positively contributing to farm paddy output. Irrigation and method of establishment entered the production relationship as useful shifter variables and, in addition irrigation was found to interact with herbicide cost variable and soil fertility dummy. The effect of herbicide cost variable was found to be significantly different in irrigated and rainfed areas.

The specification found for the average technology was contained in the stochastic frontier production function which is an analogue of the best practice production function for the study area. Technical inefficiency was modelled in the stochastic frontier production function by including a disturbance term u_i which has a truncated normal distribution in addition to a normally distributed disturbance term v_i which absorbs the variance due to stochastic elements. Maximum likelihood method was used to estimate the parameters of the stochastic frontier production function. As was expected the stochastic frontier production function was found to lie significantly above the average production function with a higher value for the intercept term and Maximum Likelihood estimates of coefficients of explanatory variables were more or less equal to the estimates of average production function. The stochastic frontier production function took account of the variation in frontier output due to random elements. However, this variance component was found to be statistically insignificant in relation to the total variance observed in the frontier output. Technical efficiencies were measured in relation to the stochastic frontier production function. Mean technical efficiency for the study area was found to be 68 percent and farm specific technical efficiencies were measured using farm specific values of conditional mean of u_i disturbance term which were calculated using the concept of conditional probability of u_i given $v_i - u_i$. Paddy farms in the study area were found to be operating with a wide range (19 to 93 percent) of technical efficiency and the farm output can be increased by 47 percent from its present levels by upgrading individual farm performance to the best practice level. Farmers' technical knowledge and formal education were found to be significantly contributing to the variation in farm specific technical efficiency.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1 Agriculture in the Economy of Sri Lanka

Agriculture is the dominant sector in the economy of Sri Lanka. Its contributions to Gross Domestic Product[1] and to total export earnings in 1982 were 22 and 55 percent respectively (Central Bank of Ceylon, 1983). Nearly half of the gainfully employed people are in the agricultural sector (Department of Census and Statistics, 1982). The agricultural sector can be divided into two components, namely a plantation sector which engages in large scale estate type production methods; and a small scale subsistence sector. The plantation sector is export oriented, and produces tea, rubber and coconuts, while the subsistence sector produces mainly rice and other food crops for domestic consumption. The areas under major crops are presented in Appendix Table A-1.

The subsistence sector is distinct from the plantation sector, and the development problems of the two sectors are completely different. Rice based agriculture was the mainstay of the economy before the introduction of plantation agriculture in the early 19th century during colonial rule. Since then development of rice based farming systems has remained stagnant. Introduction of the plantation sector was seen as a major blow to the development of subsistence agriculture in Sri Lanka (Snodgrass, 1966). Rapid development of the plantation sector was of no help with the problems of the subsistence sector. The surplus generated in the plantation sector was either reinvested in itself or paid out as dividends to foreign investors.

---

[1] at constant (1970) factor cost prices

1.2 Development of Subsistence Agriculture

1.2.1 Development Problems

Policy makers in Sri Lanka are concerned about the rapid rate of increase in the already large rural population and the high concentration of their labour in the agricultural sector, coupled with widespread poverty in the subsistence sector. Solution of these three problems are sought in the development of the subsistence agricultural sector and improvements of the livelihood of the people involved. Development of the subsistence sector provides food, raw materials, capital and labour for other sectors, and these are essential contributions in the process of overall economic development (Kuznets, 1969). Hence the development of the subsistence agriculture sector plays a significant role in overall economic development (Hayami and Ruttan, 1971).

The population problem has three main facets, namely rate of growth, density and the magnitude of the base population. The basic population problem in Sri Lanka lies in the rapid rate of growth rather than the size of the population which is not considered excessive (I.L.O, 1971). Though the rate of growth in population has tended to decline in the recent past, it is still high (1.7 percent in 1977) and has led to large family sizes and a high dependency burden.

The high concentration of the increasing population in the rural areas exacerbates the problems of the subsistence sector. The proportion of the labour force in agriculture did not change during the period 1957 to 1977 from its already high level of 55 percent of the total work force. The agricultural labour force is predicted to fall only marginally to 50 percent by 1985, based on very optimistic assumptions about the level of industrialization (I.L.O, 1971).

Absolute and relative poverty are widespread in the subsistence sector.[2] An associated feature of the overall problem of poverty is the

---

[2] The extent of poverty is defined as a proportion of the population below a cut off point of income or poverty line. Constructing a poverty line can be based on a number of criteria. For a detailed account of poverty in Sri Lanka see Richards, P and W. Gooneratne, 1980, Basic Needs, Poverty and Government Policies in Sri Lanka, International Labour Office, Geneva, (pp. 53-72).

inequality of income distribution which is relatively high in Sri Lanka. In terms of the Gini concentration ratio it was estimated at 0.45 for the whole country and at 0.43 for the agricultural sector (Oshima, 1971).

1.2.2 Strategies of Development of the Subsistence Sector

The main constraint on agricultural development in Sri Lanka is the inelastic supply of cultivable land. This situation calls for seed-fertilizer technology, which helps to increase production per unit land area as an appropriate path for development of the subsistence sector. This is consistent with the high pay off input model emphasized by Schultz (1968). This model rests on three pillars, namely getting the prices right, a supply of high yielding inputs and development of sources of these high yielding or high pay off inputs. An efficient price environment is necessary for farmers to allocate existing resources among their alternative uses in an efficient manner. Once this is achieved, profitable improved technologies should be evolved to achieve even higher productivity levels.

Government policies toward the agricultural sector in Sri Lanka have been mainly oriented toward increasing food crop production in order to achieve self-sufficiency in basic food items, particularly rice, at the same time as increasing rural employment and improving general conditions in rural areas. However, there has not been a consensus on the most appropriate strategy for the subsistence sector, while achieving self-sufficiency can be identified as the main policy goal pursued by successive governments (Kappagoda, 1974).

There are arguments for and against self-sufficiency as an appropriate policy tool. Despite the strong argument against self-sufficiency based on comparative advantage, policy makers still pursue the goal. This is mainly because of external and internal conditions prevailing with respect to Sri Lanka. The external pressure is due to the uncertainty of availability of food items in the world market and escalating prices. Continuous dependence on food imports results in a heavy drain on scarce foreign exchange, which is presently hard-earned, owing to unfavourable prices prevailing in world markets for primary commodities like tea, rubber and coconut. There has been an internal stimulus with the operation of a food subsidy scheme. Under this scheme, persons not paying income tax were eligible to receive rice at a subsidized price (or a free quota of rice during 1965-70). The purpose of these schemes was to relieve consumers from paying high prices for rice and to achieve greater equality in income distribution. This scheme was substantially revised in 1978 as a part of the economic reforms of the present government, which came to power in 1977, replacing it with a food stamp scheme for families earning Rs. 3,600 or less per annum (Central Bank of Ceylon, 1979). Operation of this scheme involved substantial financial costs, mainly because rationed food items were largely imported. This acted as an internal stimulus for the government to concentrate on achieving self-sufficiency.

Due to an overemphasis given to plantation production, the rice sector has remained stagnant in terms of expansion of area under cultivation and the technology used, at least until 1940, though state sponsored development programmes were started in the 1930s. Development of subsistence agriculture since then can be viewed in three phases, the first between the 1930s and the 1950s characterized by an extension of the area under paddy cultivation. The second phase was the period from the 1950s which was characterized by the development of institutional support and irrigation technologies necessary for the rice revolution. The third phase was characterized by development of modern high yielding varieties and associated technologies started in 1958 (Abdul Hameed, 1977). Wartime food shortages and general dissatisfaction with the land use pattern, that of overemphasized plantations, resulted in urgency for increasing food production in the short run. Extensification was selected first as the quickest way of achieving this, since the land frontier had not been reached during the the first stage. After 1950, during the second phase, the government used a different approach, intensifying development by providing complementary services while continuing to expand the area under rice. The major institutional developments were land reform, organization of Multipurpose Cooperative Societies to provide farm inputs and credits, crop insurance and a guaranteed price scheme.

Introduction of the Paddy Land Act in 1958 enabled tenant farmers to overcome problems of insecurity of land tenure and fear of eviction by the landlords. It also sought to establish favourable terms for rent sharing between landlords and tenants, and made provisions regarding inheritance of tenant lands (Sanderatne, 1972).

Adoption of new technology required capital investment by subsistence farmers in purchased inputs such as improved seeds, fertilizer, agrochemicals etc. Due to the subsistence nature of farming, farmers possessed little or no savings to finance these. Therefore institutional credit facilities were made available, at first through MPCS. However, these schemes were not fully implemented and most of them ended up with high default rates. Until recently, credit from commercial banks was not forthcoming.

Introduction of a guaranteed price scheme for paddy dates back to 1948. The main objective of this scheme was to provide an incentive to producers, to ensure a regular flow of surplus from farms to the rice delivery system and to protect the producer from exploitation by the middleman. Earlier MPCS, bought rice from farmers at a set price. From 1952 to 1966 the guaranteed price was higher than the open market price. This resulted in government purchase of a larger proportion of output. However, since 1966 the open market price has been higher than the guaranteed price, resulting in the Paddy Marketing Board collecting less paddy. In 1981/82 the Paddy Marketing Board (PMB) purchased only 15 percent of paddy produced and the increased role of the private sector has also contributed to the low level of performance by the PMB. However, the bulk of the PMB's purchases were from dry zone surplus districts. This indicates that the PMB still plays an important role in maintaining the floor price in surplus areas, despite its low levels of procurement (Central Bank of Ceylon, 1983).

A crop insurance scheme was introduced in 1958. This was felt necessary since adoption of new technology involved an element of risk, and risk aversion was a bottleneck to the widespread adoption of technology. This scheme guaranteed farmers compensation for any loss arising from natural hazards.

Along with these institutional developments, development and spread of HYV technology provided the major recent impetus to the rice revolution in Sri Lanka.

1.3 Green Revolution

Evolution of high yielding varieties of rice and wheat in the 1960s at the international crop research institutes, especially IRRI and CYMMIT, enabled many developing countries to achieve a phenomenal increase in productivity. This increased productivity was expected to trigger off the mechanism of structural transformation in these countries. This process was metaphorically called the 'Green Revolution'. IRRI in 1968 released a so-called 'miracle seed' (IR-8) variety for cultivation, the result of genetic engineering efforts to give high yield potential, and many other desirable characteristics of *Japonica* rice of Japan and Taiwan, to seeds of *Indica* varieties from tropical Asia (Farmer, 1979). Dwarfness, high response to chemical fertilizer, and photoperiod insensitivity were among the other desirable features of *Japonicas*. Subsequently IR-8 spread rapidly throughout many areas in Asia; e.g. Pakistan, Philippines and Indian Punjab (Bachman and Paulino, 1979; Dalrymple, 1974). IR-8 was not photoperiod sensitive and with high yields and other desired features, it was thought suitable for a wide range of conditions. This fanned enthusiasm among a group of writers on the Green Revolution, even to the extent of viewing the Green Revolution as some form of solution to the Malthusian dilemma (Brown, 1968). This over-optimism was, however, shortlived since IR-8 failed to spread in many parts of the rice growing areas in Asia (Farmer, 1979).

In developing HYVs, IRRI scientists' attention was directed toward areas of rice cultivation with favourable soil, water and climatic conditions that offered the fastest way of increasing rice production in the short run (Hargrove, 1979). As a result HYVs were environmentally specific and demanding in terms of soil nutrients, moisture and favourable climatic conditions. But biophysical factors found in rice growing areas differ widely, and as a result, successes in adoption and achieving yield increases were not even. There were success areas and seasons identifiable in different countries (Farmer, 1979). Yields under irrigated conditions were higher than yields under rainfed conditions. Yields in South India, where 85 percent of the area was under irrigation, were almost double the yields realized in Eastern India, where only 30 percent of the area was under irrigation (Barker and Pal, 1979). Consequently adoption of HYVs and associated technologies was widespread in South India compared to the eastern part. Dry seasons in most rice growing countries produced better yields compared to the wet (monsoon) season; Navari (Dec/Jan - May) in Tamil Nadu in South India , Yala (May - June) in Sri Lanka and Rabi (Oct - March) in Bangladesh provide ample sunlight for high yields (Farmer, 1979).

As a result, environment specific HYVs could not spread to many rice growing areas, and were successful only under favourable conditions. Early HYVs released by IRRI embodied Japonica's feature of doing well with very long photoperiod conditions in temperate climates. As a result these varieties could not perform well under cloudy, monsoonal conditions prevailing in tropical Asia. Short duration varieties faced the problem of waterlogging, with the extended monsoonal condition found in some parts of South Asia. A variety with photoperiod sensitivity could have been ideal for the monsoonal period with long wet days. Incorporating photoperiod sensitivity back to HYVs would thus be an answer for such conditions, and development of deep water rice varieties will be necessary for extended monsoonal conditions.

As a result, research priorities at IRRI are now including development of suitable cultivars for rainfed conditions, incorporating photoperiod sensitivity with high yield and other desirable characteristics, and development of deepwater rice.

Much has been said about the production aspects of HYVs in developing countries, and most of the empirical work on the Green Revolution has been on the economic and social aspects, particularly on the distributional consequences of HYVs. Uneven adoption patterns of HYVs and related inputs in many rice growing areas aggravated economic and social disparities at the farm and regional levels (Singh and Day, 1975). Most of the empirical studies have concentrated on the issue of the distribution of increased income or output between different farm size and tenure categories and between regions (Pearce, 1977). The Green Revolution was said to be biased toward large farmers and landlords, and the access to new inputs was a function of the resources and power that an individual farmer possessed (Frankel, 1971). Some criticise the Green Revolution for being biased against labour by decreasing the value added for labour and increasing value added for capital (Srivastava and Heady, 1973 ; Frankel, 1971; Griffin, 1974). Byers (1972) viewed the changes brought about by the effect of HYVs on the social and economic fabric of the society as a dialectical process resulting in a qualitative change in the mode of production, from semi-feudal to capitalist agriculture. The Green Revolution has also resulted in widespread labour displacement in some parts of the world, for example in Indian Punjab (Singh and Day, 1975). Some researchers have presented evidence to the contrary, that adoption of HYVs increased labour utilization and wages (Johl, 1974). Many writers have attributed the adverse distributional and employment effect of HYV technology to the institutional structure in developing countries. Institutions have been blamed for being biased in favour of large farmers and landlords (Gotsch, 1972). Lipton (1978) pointed out that price incentives influencing adoption of HYVs appear to have favoured large farmers. Nicholson (1984) argued that the overall pattern of distribution of land, unsuitability of grain monoculture for small farms and general lack of credit were to blame, not the institutions. According to him institutions have been biased toward commercial and progressive agriculture, not toward landlords and large farmers.

Most empirical investigations of the economic aspects have been on the issue of equity and employment effects of the Green Revolution. Efficiency aspects in terms of allocation of resources have received scant attention (Lau and Yotopoulas, 1971). However, there have been attempts at relating productivity differences to land size (Bardhan, 1973).

Productivity differences due to technical aspects of the technology or technical efficiency have only recently received attention (Kalirajan and Flinn, 1983; Kalirajan and Shand, forthcoming). HYVs of rice have spread to over a quarter of the rice growing area in Asia, but by the mid 1970s, average yields obtained from HYVs, even under very good water control conditions, were well below the potential yield realized at research stations (Barker, 1979). In order to identify and quantify constraints on high yields in HYVs, a multidisciplinary research project involving biological scientists and economists at IRRI and other national research stations was started. Conceptually, the approach was to divide the yield gap into the 'whats', bio-physical constraints limiting yields and the 'whys', socio economic factors responsible for suboptimal input usage. As a result the methodology of this project involved research managed agronomic experiments with farm surveys (De Datta et al., 1978)

However, the results of country studies from this project were not as gloomy as was suggested by Barker's (1979) findings. Summarizing country results, Herdt (1979) concluded that available technology was generally exploited to its potential. Herdt and Mundac (1981) later subjected the information collected in the 'constraint' project in the Philippines study area to econometric analysis. This study revealed that farmers were generally allocatively efficient, but technical inefficiency could explain the yield gap to some extent. Technical inefficiency was found to be mainly related to size of the farm, with small farms as the more efficient.

However, a number of writers were sceptical about these findings, due to limitations in the methodology used in the constraints study. Most of the experimental sites selected were similar to research station conditions, and did not account for the wide range of conditions found in farming areas (Pal, 1978). The experiments were carried out only in irrigated areas, while suitable HYVs have spread to rainfed areas in many parts of the rice growing areas. In addition, even though the approach conceptually recognized identification and quantification of 'why' factors on yield constraints, these received less attention. As a result 'what' questions have been thoroughly identified and quantified but 'why' factors only to a lesser extent even for the irrigated areas (Flinn, 1980).

1.4 Rice Revolution in Sri Lanka

1.4.1 Development and Spread of High Yielding Varieties of Rice

In Sri Lanka the 'Green Revolution' can more appropriately be viewed as a 'rice revolution'. Development of HYVs in Sri Lanka is more a result of indigenous effort than a case of infusion of exogenous technology. There was little research prior to 1930 along the line of varietal improvement. However, the few efforts made in pure line selection during that period laid the foundation for the breeding of modern HYVs. Pure line selection was found to increase yield potential by 15 percent over that of unselected indigenous varieties (Senadhira et. al., 1980). This resulted in improved traditional varieties with a yield potential of 3.13 metric tons per hectare (Dias, 1977). In Sri Lanka, Pure line selection helped to increase yield potential further, to a limited extent. However, due to poor stability their introduction and subsequent spread were of limited success (Senadhira et.al., 1980). These initial efforts in varietal improvement in terms of pure line selection were certainly useful in cross breeding with foreign strains. This gave rise to the 'H' series of HYVs; H-4, H-7, H-8 and H-10 etc. These varieties are popularly called old improved varities (OIVs). H-4 which was released in 1958 proved to be an outstanding success. The improvement was seen in an increased yield potential, up to 5.20 metric tons per hectare, and stability due to blast resistance. H-4 also had the advantage of being a rugged plant type, ensuring the farmer a reasonably good yield even under adverse conditions. In 1968/69, 413,000 hectares were planted with old HYVs (Dalrymple, 1974). H-4 was, however, susceptible to lodging due to its tall stature.

The IRRI dwarf variety IR-8 was introduced in the 1960s, but had limited success. In the 1977/78 cultivation year less than 1,000 hectares was planted with IR-8 (Dalrymple, 1974). Susceptibility to pests and diseases was the reason for its limited success (Dias, 1977). A UNRISD (1977) study found that farmers in the Palannoruwa and Minipe areas had given up cultivating it due to pests and disease problems and the difficulty invoved in threshing harvested paddy (Amerasinghe, 1977; Selvadurai, 1977).

Then new HYVs were released, popularly called New Improved Varieties (NIV) or "BG" series in the early 1970s. BG varieties were the result of crossing old HYVs with dwarf varieties like IR-8 and TN-1. Old improved varieties dominated the rice growing areas of Sri Lanka until 1970/71. Release of BG varieties, with a yield potential of 4.68 to 7.80 metric tons per hectare in 1970/71, resulted in a dramatic change in the adoption pattern of HYVs (Dias, 1977). The area under BG varieties increased from 1,145 hectares in 1970/71 to 197,144 by 1972/73 (Dalrymple, 1974). As a result the area under old improved varieties started to decline. In the Monaragala and Hambantota districts of southeastern Sri Lanka, new improved varieties occupied 54 percent of the cultivated area by 1972/73, only two years after their release (Dias, 1977).

Since then the adoption of HYVs has continued to spread rapidly. District level information collected by the Department of Agriculture in Yala 1983 and Maha 1983/84 seasons on the adoption of different types of paddy varieties (NIV, OIV and traditional) under rainfed and irrigated conditions are presented in Appendix Tables A-2, A-3, A-4 and A-5. These tables indicate that the percentage of area and percentage of farmers adopting NIVs were higher under irrigated conditions than under rainfed conditions; these percentages were also higher in the drier Yala season than in the monsoonal Maha season. On the average, during Yala 1983 and under irrigated conditions, about 93 percent of farmers adopted NIVs on 97 percent of the total area planted to paddy on the island (Appendix Table A-2). Corresponding values for rainfed conditions for the same season were 84 and 85 percent respectively (Appendix Table A-4). Slightly lower values were reported in Maha 1983/84, while irrigated areas performed better (Appendix Tables A-3 and A-5). The better performance in Yala season was due to better environmental conditions prevailing for the adoption of NIVs with a drier season and high levels of solar radiation. Also the short maturing varieties were necessary to cope with inadequate water supply in the Yala season. Therefore the availability of a wide range of short maturity (3 and 3 1/2 months) varieties in the NIV group could have been the other reason for a higher level of adoption of NIV's in the Yala season. Monsoonal conditions prevailing in the Maha season were not as ideal for NIVs, whereas OIVs and traditional varieties are well adapted to monsoonal conditions.

1.4.2 Increase in Rice output and its Sources

Information on the area sown and production of rice over the period 1953/54 to 1983/84 are presented in Appendix Table A-6. Along with the spread of HYVs, the area under cultivation also recorded a marked increase over the period 1966 to 1978, from 654,608 to 875,746 hectares. Until 1965, yields were stagnant. However, from 1967, yields started to increase rapidly as a result of co-ordinated efforts of government in 1966 to increase productivity (Dias, 1977). The sources of increased rice output over the period 1961 - 76 were studied by Bachman and Paulino (1979) who concluded that, despite the widespread adoption of HYVs, the yield increase over this period was moderate, and the increase in total production was mainly due to the expansion of area, and especially due to increased cropping intensity.

The period selected by Bachman and Paulino coincided with a period of area expansion and stagnant per hectare yields (Appendix Table A-6). The impact of yield increases, due to the spread of NIVs, on output was especially apparent after 1975. Therefore, an alternative analysis was done utilizing information for the period from 1953/54 to 1983/84. In this analysis the entire period was divided in two, before and after the introduction of NIVs in 1972. Separate exponential growth curves were fitted to compute average growth rates in annual gross areas sown and total production for the two periods and for the entire period. The models used were:

$$\log Q_t = \beta_0 + \beta t + u_t^q \tag{1.1}$$

$$\log A_t = \alpha_0 + \alpha t + u_t^a \tag{1.2}$$

Where Q_t = total production of paddy in in year t

A_t = total gross extent sown to paddy in year t

t = time, representing in year number (t=1, 2, ..., n)

u_t^q and u_t^a = disturbance terms of production and gross extent sown trend equations respectively.

The values of β_0, β, α_0 and α were estimated using Ordinary Least Square (OLS) regression. The trend rates of growth in production and gross area sown are indicated by the estimated values of β and α respectively. The results of the OLS regression for the two periods before and after the introduction of NIVs in 1972, and for the entire period 1953/54 to 1983/84 are summarized in Table 1-1.

The level of influence of the trend variable time in the observed variation in total production and gross area sown was measured by the value of the coefficient of determination, R^2. High values for R^2 for

Table 1-1: Results of OLS Regression of Production and Extent Sown Trend Equations

	Pre NIV		Post NIV		1954-83	
	log Q	log A	log Q	log A	log Q	log A
Constant	17.1^*	13.9^*	17.8^*	14.1^*	17.2^*	14.0^*
	(.062)	(.023)	(.079)	(.156)	(.051)	(.021)
Time	$.0485^*$	$.0229^*$	$.0689^*$	$.0158^*$	$.0439^*$	$.0195^*$
	(.005)	(.002)	(.011)	(.006)	(.003)	(.001)
R^2	.82	.89	.79	.42	.89	.90
$\bar{R}^2$	.81	.88	.77	.35	.88	.90
F	79.1	137.1	34.5	6.5	232.3	282.1

Source: Regression Analysis

Notes: values given within parenthese are standard errors
* significant at 1 percent level

the production trend regression for all three periods indicate the importance of the trend variable. In the case of gross area sown the values of R^2 were very high for the period before the introduction of NIVs and for the entire period 1954-83; but it was only 0.42 for the period 1973-83. The estimated values for the coefficients β and α for all the periods were significantly different from zero at the 0.01 level.

The estimated trend relationships for the periods, before and after the introduction of NIVs, were tested to ascertain whether they were significantly different from each other, using an F test as suggested by Chow (1960). The null hypotheses were:

$$\beta_{\text{pre 1972}} = \beta_{\text{post 1972}}$$

and

$$\alpha_{\text{pre 1972}} = \alpha_{\text{post 1972}}.$$

i.e. that there were no differences in the coefficients obtained in two periods. The F values were calculated using the formula given below:

$$F_{(k+1),(n+m-2k-2)} = \frac{SSE - SSE_1 - SSE_2/\ (k+1)}{SSE_1 + SSE\text{-}(2)/\ (n+m-2k-2)}$$

where: SSE = sum of squared errors of the regression for 1954-83
SSE_1 = sum of squared errors of the regression for 1954-72
SSE_2 = sum of squared errors of the regression for 1973-83
k = number of regressors
n = number of observation of the first period
m = number of observation of the second period

The calculated F value, $F_{2,26}$ for the total production trend was 3.03, which was greater than the critical $F_{2,26}$ of 2.98 at the 95 percent level of significance. Thus the null hypothesis was rejected for the case of total production. However, for the gross area sown, the calculated F value was 1.65, which was smaller than the critical value. Therefore, there was not adequate evidence to reject the null hypothesis: and the area sown trend relationship was the same over the whole period studied.

Table 1-2: Sources of Growth in Increased Output during the Period 1953/54 -1983/84 (rate of growth in %)

	1954-72	1973-84	1954-84
Production	4.85	6.89	4.39
Extent Sown	2.29	1.58	1.95
Yields/ha	2.56	5.31	2.44

Source: Regression Analysis and Calculation

Sources of increased output before and after the introduction of NIV's and for the entire period from 1953/54 to 1983/84 are presented in Table 1-2. Production and area sown recorded average growth rates of 4.39 and 1.95 percent over the entire period studied. The contribution of yield increases, which is given by the difference of these two growth rates, was 2.44 percent, indicating the predominant role played by these. Increase in area sown made a moderate contribution to output increase. However, the two periods before and after the introduction of NIVs show marked differences in these growth rates. Yield increased at an annual growth rate of 5.31 percent after 1971/72, whereas area sown increased at a lower rate of 1.58 percent.

1.4.3 Socio-economic Consequences of HYVs

There is little evidence to suggest that adverse income distributional and employment consequences resulted from the introduction of HYVs on the scale of the Indian Punjab or elsewhere. However locality studies conducted in Minipe and Palamunai by the UNRISD study did reveal a worsening of income inequalities. Amarasinghe (1977) and Selvadurai (1977), respectively the authors of these locality studies, have attributed this to differences in resource endowments rather than to an institutional bias. However, in major irrigation schemes like Galoya and Udawalawe, researchers found other factors substantially contributing to inequality. Farmers cultivating in the head area of channel irrigation schemes were better off on a number of counts, with greater access to adequate water and also to other institutions, compared to those in tail areas. This has been noted to have serious implications in encouraging a form of capitalism in rural areas (Moore et.al., 1983). Incidence of landlessness increased in some areas after the introduction of HYVs. Farmers who owned land before 1960 were found to be landless in 1972 in Palannorua and Palamunai areas (Selvadurai, 1977; Selvanayagam, 1977).

Imports of tractors also appeared to have aggravated inequality in Sri Lanka, though tractorization in Sri lanka has happened quite independently of the Green Revolution, i.e. tractorization was not necessitated by the use of new technology, and vice versa (Abdul Hameed, 1977; Ahamed, 1973). Use of tractors in Sri Lanka appears to have started somewhere in 1950s, well before the introduction of HYVs. Ahamed (1973) has estimated that for every acre on which a tractor replaces the plough the labour requirement is reduced by 8 man-days. The distribution pattern of tractor ownership indicates that only a very few affluent farmers own them. Hence this has helped to increase inequalities in income distribution.

1.5 The Problem

As mentioned in section 1.4.1, the spread of HYVs has been dramatic, especially since the release of NIVs. Studies have showed that in the fairly short period of time since the introduction of NIVs, farmers have adopted other improved cultural practices such as use of chemical fertilizer, pest control and weed control with the improved seeds (Dias, 1977; Harris, 1977; Amarasinghe, 1977; and Selvadurai, 1977). However, farm level production with the new technology package has been well below the experimental levels, even under irrigated conditions, as has been noted for most of the rice growing areas of Asia .

In order to increase rice output rapidly research efforts were first concentrated on developing improved varieties suited to favourable conditions, e.g. irrigated areas. However, the rapid spread of such varieties throughout the country in a very short period suggests adoption of these varieties by farms with low levels of management, in combination with low levels of nutrients. Therefore, some writers have even argued that there was over adoption (Dias, 1977; Harris, 1977), in which case the observed yield-gap[3] would mainly be due to the environmental differences between research station and the average farm and non transferable components of the reserch station technology. However, Sri Lanka has produced a number of varieties suited to the wide range of conditions found in different regions. Suitable varieties for unfavourable conditions prevailing in rainfed areas have been bred. Even though the yield-gap due to the non-transferable nature of the technology has narrowed with the development of location specific varieties, wide variation in farm level productivity can still be seen in many farming areas.[4]

An IRRI research project on constraints to high rice yields covered three study areas in Sri Lanka, namely the Giritale major irrigation scheme in the dry zone and Mawathagama and Wariyapola areas in Kurunegala district. In the Giritale study area, an average yield-gap of 1.0 ton per hectare, between the potential and actual

---

[3] This was the yield gap I identified in the IRRI constraints projects and correspond to the difference between actual yield and maximum yield obtained at research station. This gap is mainly due to environmental differences between the research station and the average farm and some components of research station technology that can not be transferred to farmers' fields (De Datta et al, 1978)

[4] For instance, Gunasena et al. (1977, p. 161) found about 60 percent of farmers obtained yields varying from 2.5 to 3.0 tons per hectare and some obtained even 5.0 tons per hectare in the Giritale major irrigation scheme

yields in farmers environment was found (Gunasena et al., 1977, p. 166), whereas in Kurunegala district it was from 0.9 ton per hectare to 0.7 ton per hectare (Jogaratnam et al., 1979, p. 339). Fertilizer, insect control and weed control were found to explain a portion of the observed yield gap in Giritale. Application of fertilizers at levels well below recommendations explained most of the yield-gap in study areas in Kurunegala district. The unexplained portion of the yield gap ranged from 0.2 ton per hectare to 0.5 ton per hectare in Kurunegala. Jogaratnam et al. (1979) found that farmers did not possess adequate knowledge of chemical fertilizer use, and some farmers were not aware of the importance of applying split doses of fertilizer at different stages of growth. A considerable number of farmers applied more fertilizer than the recommended quantities and were not familiar with insect control and chemical weed control. The yield constraints studies, however, were not able to shed adequate light on socio-economic factors responsible for yield gaps. Some evidence of the relationship between socio-economic factors and productivity differences can be found in a few other studies. In the UNRISD study, lack of credit and poor institutional structures were found to be the main reasons for farmers not using recommended levels of fertilizer and other inputs (Abdul Hameed, 1977). In some areas owner cultivators' yields were found to be greater than those of tenants (Izumi and Ranatunga cited in Lipton, 1978).

Such socio-economic factors need to be studied in detail in order to discover which factors are responsible for variation in farm specific output. Once these are known policy prescriptions can be derived to help rectify such situations. Thus this study is designed to test the following hypothesis.

> Observed farm level productivity differences in utilising a given technology are mainly due to farms not adopting the technology to its best practice level and elimination of such productivity differences by upgrading individual farm performance to high level of achievement can make a significant contribution to the national rice output.

The specific objectives of the study are:

1. To analyse the observed differences in farm productivity in Kurunegala district in order to assess the level of

utilization of the existing technology relative to its potential.

2. To identify socio economic factors causing differences in farm level productivity in order to distil some policy implications.

1.6 Chapter Outline of the Thesis

The next chapter deals with the study area, sampling and data collection. Study area description includes general background information on Kurunegala district and on paddy cultivation activities in the 1983/84 Maha season. Chapter 3 is devoted to concepts and the analytical framework developed in pursuing the objectives of the study. Chapter 4 deals with the specific methodology employed in the study. Chapter 5 presents the results and a discussion. Chapter 6 presents a summary and the conclusion of the thesis.

CHAPTER 2

THE STUDY AREA

2.1 Introduction

Kurunegala district has the distinctive feature of representing three major agroecological zones: wet, dry and intermediate zones. Sampling and data collection procedures used in this study are outlined in section 2.3. General background information on demographic characteristics, climate and soil, water supply for agriculture and agricultural infrastructure will be dealt with in section 2.4. Some of the findings of the survey are presented in subsequent sections from 2.5 to 2.8. These are categorized into socioeconomic characteristics, availability of agricultural inputs, farmers' technical knowledge and rice cultivation.

2.2 Location

Kurunegala district is located in the western part of Sri Lanka. It is one of the 24 administrative districts in the island and covers approximately 4,775 square kilometres[1] (Department of Census and Statistics, 1982). The central town of the district, Kurunegala, is situated some 93 Km northeast of Colombo. Kurunegala town is the third largest city in the island. The district accounts for 7 percent of total area and 8 percent of the total population of the island (Department of Census and Statistics, 1982). The district is predominantly rural with 96 percent of its population living in rural areas against the national rate of 78 percent (Department of Census and Statistics, 1979).

---

[1] This area includes inland waters which account for 3 km^2

2.3 Sampling and Data Collection

Since one of the objectives of this study is to analyse comparative physical performance of HYV technology under different water control situations, farmers were selected from major irrigation, minor irrigation and rainfed paddy areas. A survey was conducted to collect base line information on the farmers and information pertaining to the Maha 1983/84 season.

2.3.1 Sampling Procedure

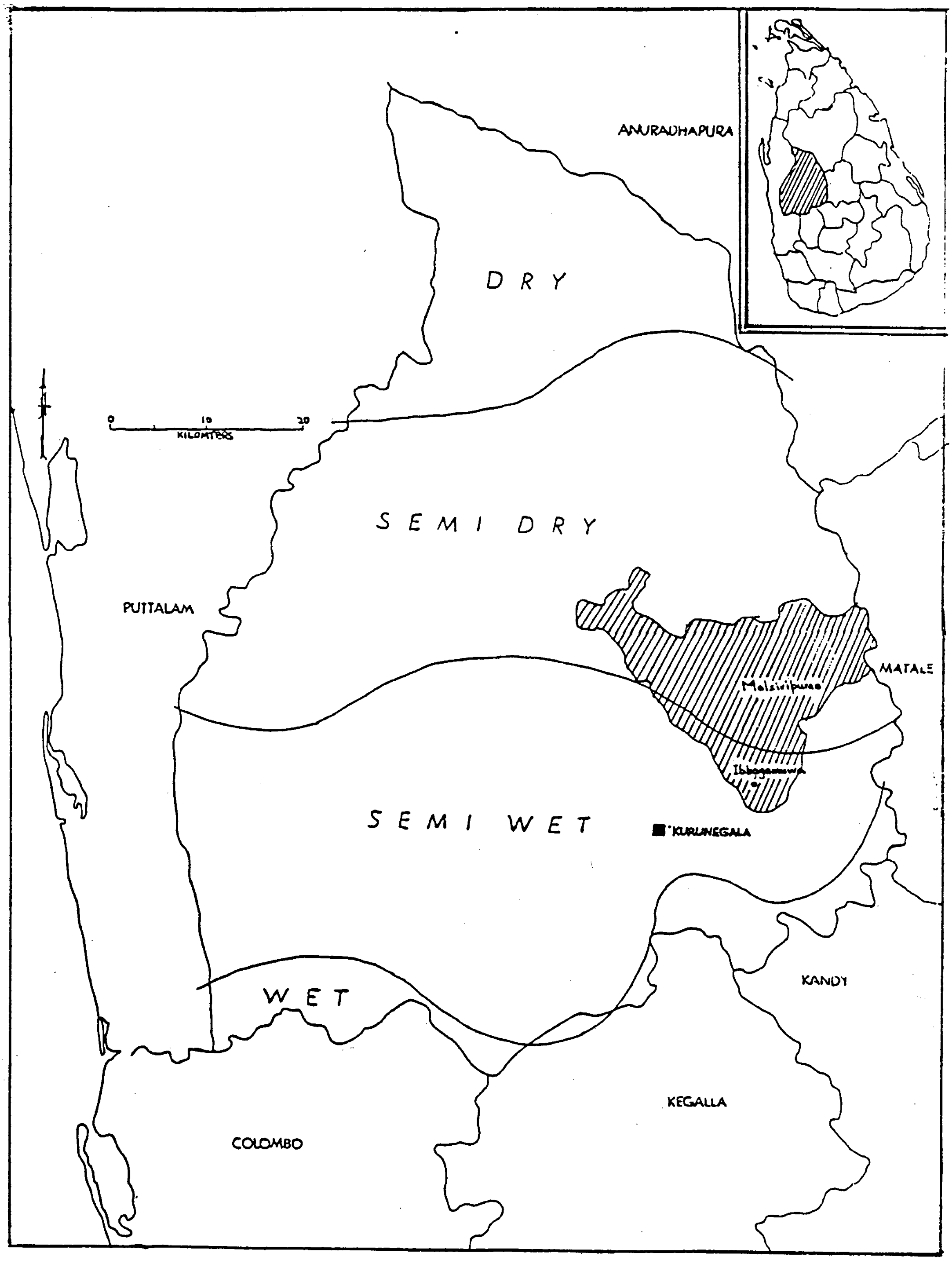
As will be explained in section 2.4.2 about 70 percent of the area in the district comes under the intermediate agroclimatic zone. Therefore. it was decided to base the study in this area. In the first stage, two Agrarian Services Areas, which adequately represent farms cultivating under three water control conditions in the intermediate zone, were purposively selected. Selection of ASC areas were based on the gross area sown to paddy under the three water control situations in Maha 1983/84. The number of farmers to be surveyed from an ASC area under a particular water control condition was arrived at by considering the total area sown to paddy under given water control conditions. The total sample size for the district, for a given water control situation, is thus proportionately divided between the two selected ASC areas based on the above criteria. The distribution of three samples between two selected ASC areas are presented in Table 2-1 and the study area is shown in Figure 2-1.

Table 2-1: Distribution of Sample By Agrarian Services Areas

ASC Area	Major Irrig.	Minor Irrig.	Rainfed	Total
Ibbagamuwa	69	22	40	131
Malsiripura	6	3	63	72
Total	75	25	103	203

In total, 75, 25, and 103 farmers respectively were selected from major irrigation, minor irrigation and rainfed areas. Farmer lists maintained at ASC centres provided information on the size of the farm

Figure 2-1: A Map Showing the Location of the Study Area in Kurunegala District



and method of water control. These lists were then used for the second stage as the sample frame for selecting farmers to be interviewed.[2]

An ASC area covers a number of small villages or hamlets. Thus the selected farmers from an ASC area could be grouped by villages. The distribution of the subsample in an ASC area between these villages is given in Appendix Tables B-1, B-2, B-3. The samples for major irrigation, minor irrigation and rainfed areas included farmers from 18, 5, and 10 villages, respectively.

All farmers selected had at least one lowland parcel and most had more than one. Distribution of lowland parcels between ASC areas and villages under different water control situations are also given in Table 2-1 and Appendix Tables B-1, B-2, and B-3. The total number of lowland parcels were thus 170, 48, 205 in major irrigation, minor irrigation and rainfed areas respectively.

2.3.2 Data Collection

The basic unit of investigation was the farm household. Three types of questionnaire were used to collect data. The first was designed to collect baseline information on farmers and the farm family. This survey was carried out immediately after sowing of the Maha 1983/84 crop. Along with this questionnaire another schedule, designed to collect information on the paddy crop, was used to enter data pertaining to paddy activities performed up to the date of interview. Separate questionnaires were used to record data for each paddy parcel operated by the farmers. The same farmers were interviewed a second time immediately after the paddy harvest to record the rest of the information pertaining to the outgoing season. The Maha season in the area occupies about 4-5 months in a year. Therefore measurement errors due to poor recall by farmers are likely to be minimal as farmers were interviewed at two points in time.

Five Economic Assistants of the Division of Agricultural Economics of the Department of Agriculture were used as enumerators. All of them

---

[2] The respective values for 'n' were arrived at by dividing total number of farmers in an ASC area under a given water control condition by the number of farmers to be selected. For instance, if four farmers were to be selected from a list of 20 farmers, the 5th, 10th, 15th and the 20th formed the sample.

were university graduates and had more than 15 years experience in field data collection. Data collection activities were closely supervised by the Agricultural Economist for the region.

2.4 General Characteristics

2.4.1 Demographic Characteristics

Kurunegala district had an estimated population of 1.20 million in 1981, accounting for 8 percent of the total population in the country (Dept. of Census and Statistics, 1982). The southeast corner of the district, which is in the wet zone, is more populous, with a density amounting to over 387 per square kilometre, while the northern dry zone, averaged less than 155 persons. Overall population density averaged 232 per square kilometre in the district (Dept. of Census and Statistics,1979). By all island standards, the population of the district was relatively young, with 49 percent of the population in the age group from 5 to 24 years, against the island average of 46 percent (Census of Population, 1971). The population of Kurunegala town is about 27,000, three and a half times larger than that of other towns in the district (Dept. of Census and Statistics, 1979).

2.4.2 Climate, Soil and Topography

The climate in the district is characterized by slight variations in temperature and highly fluctuating rainfall. On the basis of mean annual rainfall the district is classified into 3 agroclimatic zones: dry, wet and intermediate zones. Mean annual rainfall and the relative area covered by each of these three zones are given in Table 2-2.

The district receives rainfall from two monsoons. The Northeast monsoon brings rainfall to the whole district during October - December, while the Southwest monsoon brings rains, mostly to the southern wet zone, during March - June. The first monsoonal period is locally identified as 'Maha', or greater season, whereas the second period is locally called 'Yala', or lesser season.

The dominant soil group in the wet zone and semi wet intermediate zone of the district is the Red Yellow Podsolic. Reddish brown latasolic soils are found in part of the wet zone in the mid country. The dry zone part of the district and the northern semi-dry

Table 2-2: Agroclimatic Zones in Kurunegala District and Area Coverage

Agroclimatic Zone	Mean Annual Rainfall (inches)	Area Coverage %
Dry	< 60	20
Intermediate	60 - 75	70
--Semi-dry		
--Semi wet		
Wet	> 90	10

Source: ARTI, 1981, Kurunegala District Rural Development Project, An Analysis of the Pre-Project Siruation, Research Study No 45, Agrarian Research and Training Institute, Colombo, p.11

intermediate zone contain mainly reddish brown earths (Department of Agriculture, 1981)

The terrain ranges from flat to steeply dissected hills. Parts of the district in the midcountry have steeply dissected hilly, rolling and undulating terrain; whereas parts of the low country have rolling, undulating and flat terrain (Department of Agriculture, 1981).

2.4.3 Water and Irrigation for Agriculture

Favourable conditions exist in the district for water storage, due to relatively high rainfall and run-off. Storing run-off water in reservoirs has been practised from the earliest time. There are 9 major tanks with service areas ranging from 320 - 2000 hectares, and a total service area of 10,000 hectares. There are also 3,000 village or minor irrigation tanks and 600 village anicuts (small diversion schemes), with a total service area of 38,000 hectares (World Bank, 1979) However, many of these minor irrigation tanks are in poor condition due to lack of maintenance. Major and minor tanks are found in the dry and semi dry intermediate zone. Agriculture in the wet zone is predominantly rainfed. In the Maha 1983/84 season about 63,589 hectares were planted to rice. Of this total, areas under major irrigation and minor irrigation tanks were, respectively, 14.6 and 41.6 percent. The balance, 43.8 percent, was cultivated under rainfed conditions (Dept.

of Census and Statistics, 1984).[3] Nearly 97 percent of the rice area in the wet zone is rainfed, whereas 97 percent of rice area in the dry zone is irrigated (ARTI, 1981).

2.4.4 Agricultural Infrastructure

The Agrarian Services Centres (ASC) are widely utilized to render a multitude of services to farmers. There are 53 Agrarian Services Centres in the district (Department of Agriculture, 1984(a)). A branch of the Bank of Ceylon located in the centre extends agricultural credit and caters for other banking services. A section of the Agrarian Services Department provides farmers with agricultural inputs such as fertilizer, agrochemicals and seed. Agricultural extension activities in the designated ASC area are looked after by extension officers of the Department of Agriculture operating from the centre. There is also a separate unit for coconut development, represented by the officers of Coconut Cultivation Board.

In addition, 764 cooperatives, under 17 primary societies, are also involved in the supply of agricultural inputs and purchases of agricultural produce. There are 10 veterinary services centres in the district to cater to the needs of animal husbandry (Dept. of Agric., 1984). At district level, extension activities are coordinated by an Assistant Director of Agriculture assisted by five Agricultural Officers.

2.5 Socio-economic Characteristics

2.5.1 Family Composition and Age Structure

As indicated above the basic unit of investigation is the farm household. Average age of the farmers in the district was about 46 years. Although the average age of the farmers was not considerably different among three irrigation conditions, the proportion of farmers less than 40 years of age was found to be 44.6 percent in rainfed areas

---

[3] These proportions show a marked difference in the Yala season. For instance, in 1983 Yala season, out of a total of 34,737 hectares cultivated with rice, 23.8, 23.8 and 52.0 percent were, respectively, under major irrigation, minor irrigation and rainfed conditions (Dept. of Census and Statistics, 1983).

while the corresponding values for other areas were considerably lower (Appendix Table C-1). The average size of a farm household for the district was about 4.5 persons. However, the corresponding value in 1978/79 was 5.3 persons (ARTI, 1981). The variation in the mean farm household size among the three irrigation conditions was not significant. The reduction in the size of farm household may be due to a sharp reduction in birth rate or to an increase in emigration.

On average, 26 percent of the family members were less than 16 years of age. Corresponding values for major irrigation, minor irrigation and rainfed areas were, respectively, 23.6, 30.3, and 28.3 percent (Appendix Table C-2).

2.5.2 Education and Farming Experience

The high literacy rate, generally observable throughout Sri Lanka was also apparent in the three study areas. On average the district had an average literacy rate of about 94.6 percent among farmers; there was no significant difference in this ratio among the three study areas (Appendix Table C-3)

About 37 percent of the farmers in the district had received 5 years of education and another 33 percent had received 8 years of education. The proportion of farmers who had received education up to 5th year was 45.3 percent in the major irrigation areas, which was substantially higher than corresponding values for the other two areas. About 37.3 percent of farmers in rainfed areas were educated up to 8th year (Appendix Table C-3).

The average farmer in the district had about 25 years of farming experience. Nearly two thirds of the farming population in the major irrigation areas had more than 20 years of farming experience. Corresponding proportions for the other two areas were about half the farmers. (Appendix Table C-4).

2.5.3 Occupational Structure

Approximately 96 percent of the respondents were involved in farming activities (Appendix Table C-5). About 62 percent of the farmers in the district cultivated on a full time basis, whereas part time farmers accounted for 35 percent (Appendix Table C-5.) There was not much difference in the percentage values for full time farmers (about 63 percent) between major irrigation and rainfed areas. The corresponding value in the minor irrigation area was 44 percent (Appendix Table C-5).

In this rural setting, persons having a number of subsidiary occupations, in addition to their main occupation, were very common. This was reflected in the occupational pattern of farmers (Appendix Table C-6). Approximately 85 percent of farm respondents had some form of subsidiary occupation, on other farms, off-farm or both, in addition to their own farm activities. Farmers engaged in activities such as petty trade, supply of labour for other farms and off farm activities to supplement the meagre income derived from their relatively small land holdings. Some government servants in the area undertook part time farming activities. Some agricultural labourers work as tenant farmers, toddy tappers and brick makers.

Involvement of other family members in farming activities was frequently observed in the district. Participation in farming activities on their own farm or other farms by members of the age group less than 16 years was not common. However, family members in the age group over 16 years contributed substantially to farming activities. Approximately 80 percent of the people in this category contributed to farming activities irrespective of sex (Appendix Table C-7). Most of them worked on a part time basis. Approximately 16 percent worked on other farm activities on a part time basis. Nearly 79 percent of female members of this group contributed to their own farm on a part time basis.

2.5.4 Allocation of Farm Labour

It is clear from the preceding section that income generating activities on other farms and off farm occupy an important place in the occupational structure. Therefore, it was of interest to see how farmers allocated labour among alternative activities during the greater 'Maha' season.

Only 23 percent of respondents reported conflict in allocating farm labour between highland and paddy cultivation. The corresponding percentage for allocating labour between farm and nonfarm activities was 15.3 percent. There was not a great deal of difference between the figures for the three areas in allocating labour between highland and lowland paddy cultivation and between farm and nonfarm activities (Appendix Table C-8). Most of the farmers resorted to hired labour and exchange labour to meet excessive demands for labour. Conflict in labour allocation was found during the busy month of November, when farmers broadcast or transplanted paddy in the lowlands.

Labour allocation by the farm heads between different alternatives in the period starting from September 1983 and February 1984 (Appendix Table a C-8) shows that there was not much difference in labour allocation in terms of percent of respondents reporting and the average number of hours worked on highland activities. However, as expected, a marked variation in labour allocation was observed in paddy cultivation. November 1983 could be identified as the peak of the Maha season; approximately 90 percent of respondents reported working on lowland paddy cultivation. During this peak month, on average, about 86 hours of labour was spent on paddy cultivation.

Allocation of labour on other farm activities was also found to reach a peak in November 1983. This was because of the seasonal nature of the agricultural activities in the area.

2.5.5 Size, Distribution and Ownership of Land Holdings

According to the Census of Agriculture 1973 there were about 172,000 operational holdings in the district, including 300 estates with an area greater than 13.6 hectares (20 acres) (Appendix Table C-9). Average size of holdings was 1.61 hectares (4 acres), compared to the national average of 1.0 hectare (2.5 acres). Skewness in land distribution was lessened by the Land Reform Act 1972-75, which imposed a land ceiling of 20.2 hectares (50 acres) for highland and 10.1 hectares (25 acres) for lowlands. As shown in Table 2.0 about two thirds of the total number of holdings were within the size range of 0 - 1.21 hectares (0-3 acres).

Data collected for this study totally excluded estates. Therefore, the information on size of holdings and land distribution presented below should be identified with the three irrigation methods. There were two types of land operated by respondents, namely highland and lowland. All respondents reported both types of land.

2.5.5.1 Highland

On average, approximately 56 percent of highland holdings were less than 0.2 hectare. Nearly 75 percent of highland holdings were less than 0.4 hectare. Size distribution of highlands by irrigation methods did not show a great deal of difference (Appendix Table C-10), except in the case of minor irrigation areas where only 56 percent of holdings were less than 0.4 hectare.

2.5.5.2 Lowland

All the respondents had at least one parcel of lowland, and nearly 61 percent of respondents operated at least 2 parcels. The maximum number of parcels operated by a respondent was 3, and only 28 percent reported having 3 parcels. This pattern of distribution was not found to be greatly different among the three sub samples (Appendix Table C-11).

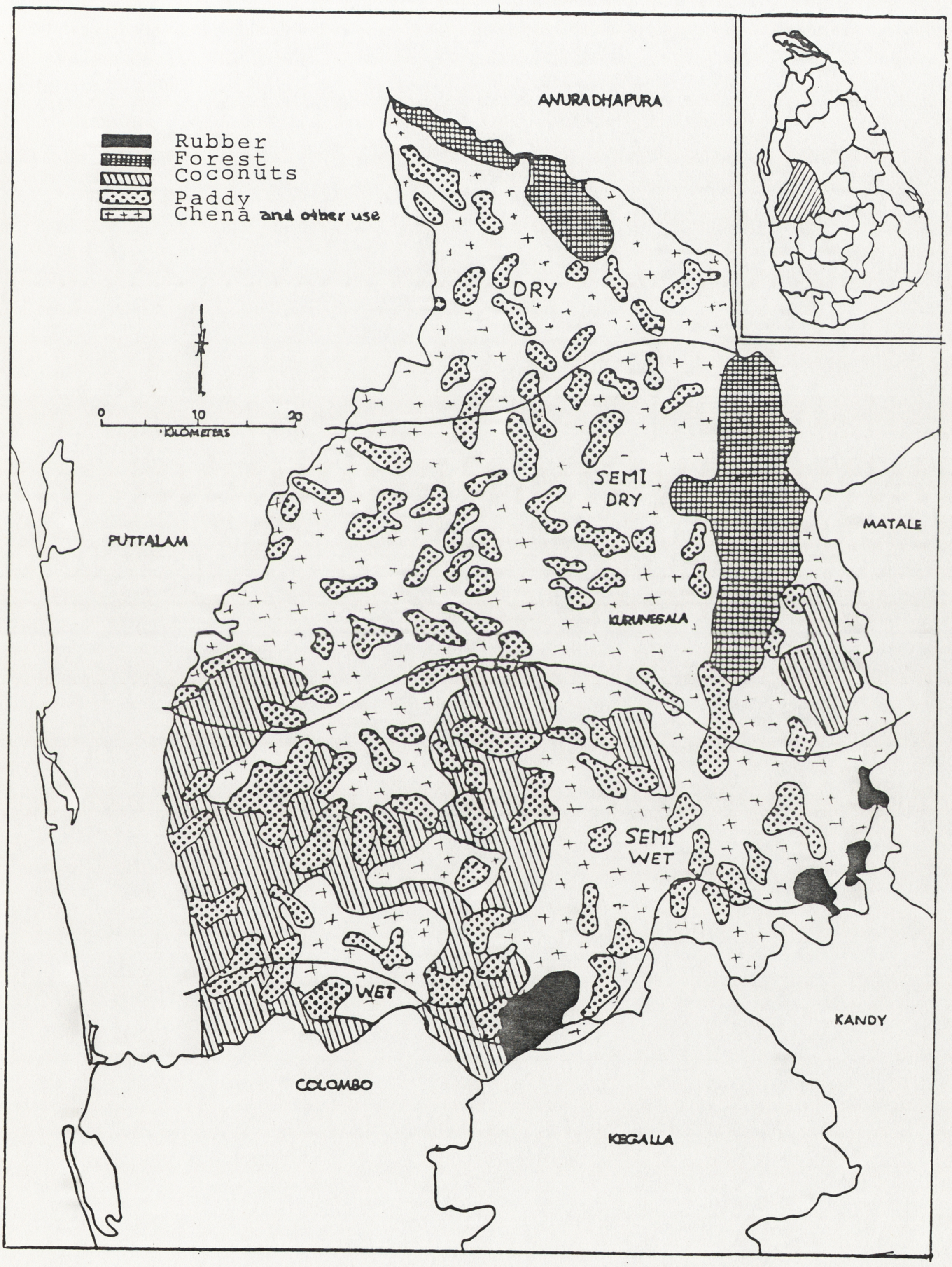
Average size of a lowland parcel was 0.29 hectare and on average nearly two thirds were less than 0.2 hectare. Nearly 92 percent of lowland parcels were less than 0.4 hectare. The overall size distribution pattern of lowland parcels was not different between the methods of irrigation (Appendix Table C-12). Average sizes of lowland parcels were 0.34 ha , 0.27 ha and 0.26 ha in major irrigation, minor irrigation and rainfed areas, respectively.

Approximately 50 percent of these parcels were self owned, slightly over one third were operated by tenant farmers and about 12 percent operated under joint ownership (Appendix Table C-13).

2.5.6 Crops and Land Utilization

According to the Census of Agriculture 1973 total land area in the district was 480,000 hectares. Out of this, 161,943 hectares were being used for shifting or Chena cultivation, the balance being utilized for other purposes. Coconuts and Paddy were the main crops cultivated, accounting for 153,846 and 96,186 hectares (35 percent and 11 percent of the national acreage), respectively (Dept. of Census and Statistics, 1982; 1983). Coconuts and Paddy are cultivated on highlands and lowlands, respectively. The geographical spread of these two crops is shown in Figure 2-2.

Figure 2-2: A Map Showing Geographical Spread of Paddy and Coconut Cultivation in Kurunegala District



Source: Adapted from The World Bank (1979)

2.5.6.1 Highland

Nearly two thirds of respondents reported having some highland crops. Of these, approximately 60 percent had coconuts; another 20 percent reported intercropping coconut with crops like banana, manioc etc. Homegarden type of agriculture, primarily based on coconut, occupies an important position in the district. This does not change very much if land utilization in the highlands is analysed according to different methods of irrigation. However, in minor irrigation areas highland cultivation was reported by nearly 75 percent of farms; about one third reporting intercropping coconut with other highland crops (Appendix Table C-14).

2.5.6.2 Lowland

All the lowland parcels surveyed in major irrigation and minor irrigation areas were planted with paddy. Though planting lowlands with other crops was virtually absent, one parcel in the minor irrigation area was found planted with red onion.

2.6 Availability of Agricultural Inputs

Institutional credit was available to nearly 83 percent of farmers interviewed but only 3.7 percent had used such credit. In the minor irrigation areas none of the farmers had used credit. The extent of credit availability, in terms of percent reporting was 72, 84, and 95 for major irrigation, minor irrigation, and rainfed areas, respectively. In answer to the question 'Why didn't they borrow when the credit was available to them ?', farmers most frequently responded red tape and other procedural difficulties and conditions of repayment that were too strict. Credit was not available to a few farmers who were defaulters or did not possess adequate collateral for security.

A few farmers did not answer the question on availability of other inputs namely fertilizer, pesticides, fungicides and herbicides. Therefore, frequencies were based on the total number of farmers who responded to relevant questions. More than 95 percent of farmers reported availability of chemical fertilizer, pesticides, fungicides and herbicides. Reported availability of these inputs was 100 percent in rainfed areas (Appendix Table D-1).

2.7 Farmers Technical Knowledge

Farmers were asked questions as to whether they knew the recommended quantity and timing for application of fertilizer, pesticides, fungicides and herbicides (Appendix Table D-2). Approximately one third of the farmers reported knowledge of recommended quantities and timing of chemical fertilizer applications. For fertilizer, being the most widely used purchased input, more farmers had a knowledge of recommended quantities and timings compared to other purchased inputs. Corresponding values for the recommended quantity and timing of pesticides were 62.0 and 59.8 percent respectively. Going from the most common input, fertilizer, to the least common input, fungicides, corresponding values become smaller (Appendix Table D-2). This pattern was observed in all three study areas.

An important observation can be made (Appendix Table D-2) regarding the level of technical knowledge between the three areas. More farmers in the major irrigation area had knowledge of recommended quantities and timing of inputs than farmers in minor irrigation and rainfed areas. Rainfed areas recorded the lowest frequencies. This may be due to a concentration of agricultural extension activities in high potential irrigated paddy areas.

2.8 Rice Cultivation

2.8.1 Varieties Cultivated

Ninety five percent of paddy parcels were planted with new improved varieties. Since cultivators of about 4 percent of parcels were unaware of the name of the variety, this percentage might actually be slightly higher. Regarding use, the type of the variety (Old Improved, New Improved or Traditional) there was not much difference between the three study areas. When we consider frequency values for specific varieties, BG 34-8 and BG 276-5 varieties were the most common being planted, respectively, in 38 and 29 percent of parcels. The relative importance of these two varieties does not change when we consider parcels by type of irrigation (Table 2-3) except in major irrigation areas where BG 400-1 was the most common.

Adoption of short aged varieties was very common in the district.

Table 2-3: High Yielding Rice Varieties Adopted (percent parcels reporting)

Variety	Major Irrig	Minor Irrig	Rainfed	District
BG 400-1	32.9	.0	.5	13.6
BG 34-8	24.7	37.5	50.3	38.1
BG 276-5	15.7	50.0	36.5	29.4
BG 379-2	8.5	7.5	1.7	5.2
BG 11-11	3.3	-	-	-
BG 90-2	3.3	2.2	1.9	2.7
BG 94-1	3.3	.0	.5	1.6
BG 94-2	.6	.0	1.1	.8
BG 34-6	1.9	.0	.5	1.0
Other NIVs	2.6	.0	1.1	
OIVs	.6	.0	.5	.5
Not Known	3.2	2.5	4.5	3.8

Source: Survey Data

Paddy varieties cultivated in the area can be divided into 4 age groups namely; 3 months, 3 1/2 months, 4 months and 4 1/2 months. The survey data revealed 42 percent and 36 percent of parcels planted with 3 and 3 1/2 month varieties respectively. However, this overall pattern for the district changes remarkably when we consider paddy parcels by method of irrigation. In minor irrigation and rainfed areas, nearly 94 percent of parcels were planted with shorter aged varieties (3 and 3 1/2 months categories). The corresponding proportion for major irrigation was only 56 percent (Table 2-4).

This marked difference was due to uncertainty about the availability of adequate water under minor irrigation and rainfed conditions. Assured water supply under major irrigation areas enabled the farmers to cultivate 4 and 4 1/2 months varieties, which have higher yield potential compared to their shorter aged counterparts. In general, long duration varieties consume more water to produce per gram of dry matter (Yamada, 1974). Therefore, they were well adapted to major irrigation conditions. This was reflected in the popularity of the 4 month BG 400-1 variety in that area. None of the parcels in minor irrigation areas, and only one parcel in rainfed areas, adopted this variety, whereas the majority of paddy parcels in major irrigation

Table 2-4: Distribution of Adopted Rice Varieties By Age Groups (percent parcels reporting)

Duration	Major Irrig	Minor Irrig	Rainfed	District
3 months	19.2	63.0	57.8	42.1
3 1/2 months	36.8	30.4	37.4	36.4
4 months	38.5	6.5	2.9	18.2
4 1/2 months	5.5	.0	.5	2.5

Source: Survey Data

areas used it. Both BG 34-8 and BG 276-5 varieties belong to the 3 months group and nearly 85 percent of the paddy parcels in minor irrigation and rainfed areas were planted to these two varieties.[4]

When asked why they chose a particular variety farmers answers showed that the most influential factors were high yields and desired age of the variety. More than 97 percent of parcels adopted the recommended variety.

2.8.2 Establishment of Rice

Rice was broadcast sown in about 56 percent of parcels and transplanted from nurseries in the other 43 percent. There were two methods of transplanting practised in the district namely random transplanting and row transplanting, the former being the most common. However, this picture varies markedly between the three types of irrigation. Broadcasting seed paddy was reported in 76 and 83 percent of parcels in minor irrigation and rainfed areas, respectively (Table 2-5). The corresponding value for the major irrigation area was 21 percent, and paddy was transplanted in 78 percent of parcels.

Most of the farmers in minor irrigation and rainfed areas broadcast because of the relative convenience of this method when faced

---

[4] Since some farmers were not aware of the name of the variety cultivated, varieties and their frequencies cannot be presented under relevant age groups in Table 2-3 itself. However, all the farmers knew what the age group of the variety was. Thus the frequency distribution by age group is presented in Table 2-4.

Table 2-5: Method of Establishment Adopted For Rice (percent reporting)

Method	Major Irrig	Minor Irrig	Rainfed	District
Broadcasting	20.9	76.1	83.0	56.5
Row T/P	26.9	6.5	2.4	13.2
Random T/P	51.1	17.4	13.6	29.8
Row Seeding	1.1	.0	.0	.4

Source: Survey Data

with insufficient time, farmers in this area are heavily dependent on natural rainfall and usually start paddy cultivation late after waiting for rains or for the tanks to fill. Farmers in major irrigation areas can transplant since they have an assured water supply and are less affected by rainfall. The main reason for most of the farmers in major irrigation areas adopting transplanting was the relative ease with which weeding can be practised.

Paddy was established in the field at more or less the same time in the three sample areas. The peak period was found to be November 1983 (Appendix Table D-3). Planting had to be done in time to realize the maximum potential of the variety cultivated. Timely planting was found in 84 and 79 percent of the parcels in major irrigation and rainfed areas, respectively. The proportion in minor irrigation areas was 63 percent, and 32 percent reported late planting (Appendix Table D-3). Time of water availability or onset of rains was given as the reason for establishment of paddy early or late; late availability of water or late arrival of rain resulted in late planting.

The amount of seed used per hectare varied markedly between the three irrigation areas; 122.0, 241.5, and 190.4 Kg per hectare respectively, in major irrigation, minor irrigation and rainfed areas. The majority of farmers in all three areas used paddy retained from the previous harvest for seed.

2.8.3 Water - Irrigation for Paddy Cultivation

Farmers in the district received the first rains for the 'Maha' 1983/84 season during October 1983 and the rains continued till November in some parts of the rainfed areas. Almost every paddy parcel reported having at least 15 rainy days during the season. The average number of rainy days reported was 24, and nearly two thirds of parcels experienced 21 to 30 rainy days. In this, there was not a great deal of variation between the three irrigation areas (Appendix Table D-4).

2.8.3.1 Irrigated Areas

In canal irrigated paddy areas, access to irrigation water can be unevenly distributed among parcels located along an irrigation canal. A paddy parcel located in head areas along an irrigation canal may receive more water than a parcel in the tail. In major irrigation areas 38 and 37 percent of the parcels were located in head and body areas, respectively. Corresponding values for minor irrigation area were 43 and 36 percent. Therefore less than one third of parcels were located in tail areas under the two types of irrigation (Table 2-6).

Table 2-6: Location of Paddy Parcel in Relation to the Irrigation outlet (percent reporting)

Location	Major Irrig	Minor Irrig	District
Head	38.9	43.5	39.1
Body	37.5	35.8	37.2
Tail	24.5	20.5	23.7

Source: Survey Data

At least one water issue was made available to 95 percent of the parcels in both types of irrigation areas, but the number of parcels that received a second issue was markedly different in two areas. About 91 percent of parcels in major irrigation areas received a second issue, compared with only 54 percent of parcels in minor irrigation areas. A similar difference was also observed for the third issue of water, the corresponding values being 85 percent and 26 percent. The maximum number of water issues received by a parcel was 7 in major irrigation areas and 4 in minor irrigation areas (Table 2-7).

Table 2-7: Water Issues from the Tank
(percent reporting)

No of Issues	Major Irrig	Minor Irrig	District
One Issue	96.6	95.6	96.4
Two Issues	91.8	54.3	84.9
Three Issues	85.2	26.1	74.4
Four Issues	28.6	6.5	24.3
Five Issues	2.7	.0	2.2
Six Issues	1.1	.0	.0
Seven Issues	1.1	.0	.0

Source: Survey Data

Approximately 30 percent of parcels received the first water issue in October and another 59 percent in November 1983. But corresponding values for minor irrigation areas for October 1983 and November 1983 were 6.8 and 61.3 percent respectively. A few parcels in minor irrigation areas received water even later in December 1983. This shows that water issue in minor irrigation areas was relatively late.

2.8.3.2 Water Stress

Lowland paddy requires standing water during the growth of the rice plant. The number of days the field was left without standing water can be taken as a measure of the extent of water stress. Water stress should always be identified with the stage of growth, as there exists a markedly different response pattern for water stress between different stages of growth. Murakami (1974) found drought treatment one month before and after booting stage caused substantial reduction in the percentage of fertile rice grains. Moisture stress during the period starting from the end of transplanting to 15 days before the booting stage results in a reduction in number of panicles per hill. Water stress in a particular stage of growth may be experienced more than once, due to inadequate water supply by irrigation or rainfall. As could be expected, survey data revealed more water stress under rainfed conditions. The first incidence of water stress was in the nursery stage and was experienced by 9.3 percent, 19.6 percent and 38.8 percent of paddy parcels, respectively, in major irrigation, minor irrigation and rainfed areas. For the tillering stage the corresponding figures for the first water stress were 6.6, 28.3 and 50.5 respectively. Prolonged water stress during the tillering stage was found in rainfed areas and another 34 percent of paddy parcels were affected by further water stress. On average, rainfed paddy parcels first experienced about 10 days of water stress and followed by another 8 days during the tillering stage (Table 2-8).

Table 2-8: Water Stress in Nursery, Tillering and Booting Stage (percent parcels reporting)

Stage	Major Irrig		Minor Irrig		Rainfed		District	
	% rep	Av days	% rep	Av days	% rep	Av days	% rep	Av days
Nurs(1)	9.3	1.7	19.6	11.8	38.8	18.2	24.4	15.1
Nurs(2)	1.6	3.6	4.3	7.0	5.8	6.8	3.9	6.2
Till(1)	6.6	8.5	28.3	7.0	50.5	10.4	29.7	9.8
Till(2)	1.1	4.5	13.0	8.2	34.0	8.8	17.9	8.6
Boot(1)	.0	0.0	.0	-	4.5	11.5	2.0	11.5
Boot(2)	.0	-	.0	-	2.9	7.0	1.3	7.0

Source: Survey Data
Notes: average number of days were calculated from the total number of parcels reported water stress at a particular stage

2.8.4 Usage of Purchased Inputs

2.8.4.1 Fertilizer

Fertilizer was used on nearly all parcels in major irrigation and minor irrigation areas, while in rainfed areas it was used only on 90 percent of parcels. Chemical fertilizer should be applied at different times in the growth of the rice plant. The number of applications, amounts and their timing depend on the age group of the variety and the method of establishment practised by the farmer. The recommendations prepared by the Department of Agriculture are given in Appendix E-1. If a 3 or 3 1/2 months variety was broadcast chemical fertilizer should be applied 4 times. If these varieties are transplanted, chemical fertilizer should be applied 3 times in the main field. For 4 and 4 1/2 month varieties, fertilizer should be applied 4 times, regardless of the method of establishment. The first fertilizer application for any of these is called the basal application and should be made at the time of levelling the field, after ploughing and before transplanting or sowing. The fertilizer mixture 'V' is recommended for basal application. It has a N:P:K ratio of 3:30:10.

All parcels in irrigated areas used some form of fertilizer as a basal application, but only 90 percent used it in the rainfed areas. However, on average, only 70 percent of parcels applied the correct type of fertilizer, 'V' mixture. Across irrigation types there was a marked difference in these values, 91, 78, and 40 percent for major irrigation, minor irrigation and rainfed areas, respectively (Table 2-9).

Table 2-9: Application of Different Kinds of Fertilizer (percent parcels reporting)

Item	% Rep	V Mixture	Urea	TDM
Maj Irrig				
1st Appn	100.0	91.2	8.8	-
2nd Appn	91.8	1.5	90.1	.2
3rd Appn	69.8	-	1.0	68.6
Min Irrig				
1st Appn	100.0	78.2	21.7	-
2nd Appn	95.7	2.1	65.2	28.2
3rd Appn	56.5	-	-	56.5
Rainfed				
1st Appn	89.9	40.8	29.7	19.4
2nd Appn	57.2	-	32.2	25.0
3rd Appn	30.8	-	-	30.8
District				
1st Appn	95.0	70.2	18.5	6.3
2nd App	75.0	.7	57.3	17.0
3rd Appn	48.6	-	0.7	47.9

Source: Survey Data
Notes: (a) Percent parcels reporting use of some form of fertlizer

The number of parcels on which a second dosage of fertilizer was applied was slightly smaller in the two types of irrigation area but there was a significant drop in the percentage of parcels which received a second dose in the rainfed areas (57 percent). Only about

70 percent of paddy parcels in major irrigation areas applied a third dosage of fertilizer. Corresponding values for minor irrigation and rainfed areas were 56.5 and 30.8 percent, respectively (Table 2-9). Again the prevalence of using an inappropriate type of fertilizer was apparent. No parcel applied fertilizer a fourth time.

It is important to compare the average amounts of different fertilizer applied per hectare with the recommended levels. Since the fertilizer recommendations (Appendix Table E-1) for different combinations of varietal age groups and methods of establishment vary, average quantities applied were calculated for these different situations in the sample. These quantities were compared with the recommended quantities by calculating percentage values of the recommended quantity applied (Table 2-10). Only information on the frequently reported combinations of varietal groups and methods of establishment is presented in this table.[5]

All lowland parcels that adopted any of the combinations of practices in the two irrigation areas in Table 2-10 reported application of some form of fertilizer. However, in rainfed areas, when the short aged 3 or 3 1/2 months varieties were broadcast, some parcels did not apply any form of fertilizer (Table 2-10). The completeness of adopting a recommended fertilizer package was very different between irrigated and rainfed areas. In rainfed areas, for instance, of those paddy parcels that were broadcast with 3 months varieties, slightly over one third applied the V fertilizer mixture. In terms of completeness major irrigation areas ranked first, followed by minor irrigation and rainfed areas.

Application of chemical fertilizer over and above the recommended quantities was frequent (Table 2-10). In comparing average the quantities applied of a particular type of fertilizer, overapplication was predominant in the case of TDM fertilizer mixture. This resulted in highly increased levels of potash (K_2O), one of the constituent

---

[5] For instance, in major irrigation areas seedlings of 4 - 4 1/2 months varieties were transplanted in 46 percent of parcels; another 31 percent of parcels transplanted with 3 1/2 months varieties and these two combinations together were reported in 77 percent of parcels (Table 2-10). There were other such combinations, but less frequently reported

Table 2-10: Quantities of Different Fertilizers Applied Per Hectare A Comparison with the Recommended Levels

	% rep (a)	V mixture		Urea		TDM		N	P	K
		% rep (b)	Av. amt Kg	% rep (b)	Av. amt Kg	% rep (b)	Av amt kg	Av amt Kg	Av amt Kg	Av amt Kg
Major										
4 months	46	97	199	97	133	90	165	116	60	53
var-T/P	[100]		(107)		(107)		(108)	(96)	(108)	(157)
3 1/2months	31	97	172	87	83	95	100	73	52	37
var-T/P	[100]		(92)		(49)		(87)		(94)	(200)
Minor										
3 months	57	74	124	89	143	89	143	112	37	41
var-B/C	[100]		(67)		(153)		(188)	(157)	(66)	(122)
3 1/2months	21	100	176	85	112	85	129	95	53	43
var-B/C	[100]		(95)		(120)		(169)	(133)	(95)	(127)
Rainfed										
3 months	53	38	68	59	100	68	130	87	20	24
var-B/C	[89]		(37)		(107)		(171)	(122)	(36)	(71)
3 1/2months	28	40	63	51	55	70	104	58	19	27
var-B/C	[91]		(34)		(59)		(136)	(81)	(34)	(80)

Source: Survey Data

Notes: Average amounts applied were given in the table in kilograms and they were compared with the recommended amounts by calculating percentage values of the recommended quantity applied. These values are given within parentheses.

(a) Percent parcels reporting the age group - method of of Establishment Combination. Figures given within square brackets are percent parcels used some form form of fertlizer

(b) Percent parcels of the group applied different types of fertilizer.

* Application of TDM was not recommended when 3 1/2 months varieties of paddy were transplanted.

nutrients in TDM (30:00:20) fertilizer mixture. As far as the V fertilizer mixture is concerned, quantities applied were close to recommended levels in major irrigation areas and in minor irrigation areas when 3 1/2 month varieties were planted. In rainfed areas quantities of V mixture applied were well below the recommended levels;

only 37 and 34 percent of the recommended quantity of this fertilizer was used in paddy parcels which adopted broadcasting with 3 and 3 1/2 months varieties, respectively. The incompleteness in the adopted fertilizer package in rainfed areas was reflected in these sub-recommended quantities of fertilizer used. Quantities of Urea applied showed much wider fluctuations around the recommended quantities. In major irrigation areas when 4 months varieties were transplanted Urea was used more or less at the recommended quantities whereas, when 3 1/2 months varieties were transplanted about half the recommended quantity was used. In minor irrigation areas overapplication of Urea was common and in rainfed areas its use was at recommended levels and 60 percent of the recommended levels respectively, for 3 months and 3 1/2 months varieties when they were broadcast.

In terms of different nutrients, N, P and K overapplication of N was common in minor irrigation areas and in rainfed areas when 3 months varieties were broadcst (Table 2-10). Average amounts of N applied ranged from 81 percent to 157 percent of recommended quantities. The nutrient P (P_2O_5) was applied at rates ranging from 34 to 108 percent of the recommended levels, whereas, as noted earlier, overapplication of potash was found to be common in irrigated areas and the average quantity applied ranged from 71 percent to 200 percent of the recommended level. In terms of supply of nitrogen, paddy parcels which adopted 3 1/2 months varieties in major irrigation and rainfed areas were not so affected by their low use of Urea. Paddy parcels in major irrigation areas seemed to be reasonably well nourished with nitrogen. This was because of the compensating effect of N added in the TDM fertilizer mixture. Urea should be applied at the early stages of growth of the rice plant (Appendix Table E-1) and TDM applied at a later stage. Therefore, although the compensatory N application of TDM supplemented the already low amount received through sub-recommended quantities of Urea, the additional N was received late. Application of nutrient P was well below the recommended quantity (nearly one third) in rainfed areas. This was mainly due to low amounts of basal fertilizer mixture (V) (3:30:0) used in rainfed areas as noted before. Even though the nutrient K was applied well above the recommended quantities in irrigated areas, its use in rainfed areas were at 71 and 80 percent of the recommended levels, respectively when 3 months and 3 3 1/2 months varieties were broadcast.

In general, there is no evidence of serious undernourishment (Table 2-10) in irrigated areas from the point of view of average amounts of nutrients applied relative to the recommended levels. What is evident is an imbalance in the quantities of different fertilizers applied. In rainfed areas the situation was not satisfactory in terms of nutrient supply, the reason being mainly the incompleteness in the fertilizer package adopted. Moreover, it is important to add these nutrients at the correct time to achieve maximum efficiency. Information on timing of fertilizer applications from farmers revealed that nearly half the farmers in rainfed areas did not apply fertilizer at the correct time. Corresponding values for major irrigation and minor irrigation areas were 78 and 72 percent respectively.

2.8.4.2 Pesticides

Few farmers reported pest attacks. Approximately one third of parcels in irrigated areas experienced pest attacks, while in rainfed areas incidence was less than half that experienced in irrigated areas i.e or only 10 percent of parcels. Most of the pest attacks were reported in December 1983, during tillering or booting stages. At least 7 insect pests caused damage to paddy crops. Leaf roller or Leaf folder (Cnaphalocrosis medinalis), Thrips (Thrips oryzae) and Brown Plant Hopper (Nilaparvata lugens) were the most common. However, most farmers who experienced pest attacks perceived them to be of moderate or slight severity. About 95 percent of parcels affected by pests were treated with some kind of pesticide. Approximately 90 percent of parcels were treated with liquid forms of pesticides. Application of pesticides in granular form was found to be less frequent. Lebaycid, Metacid and Parathion were the commonly used insecticides. The per hectare cost of pesticides was in the range 36.00 Rs to 84.00 Rs in the three study areas (Table 2-12).

2.8.4.3 Chemical Herbicides

In major irrigation areas chemical weed control was not common, and only 11 percent of parcels reported the use of herbicides. In rainfed areas, on the other hand, nearly 25 percent of parcels reported use of herbicides, and about 71 percent of parcels in minor irrigation areas applied herbicides to control weeds. All the chemicals applied were liquid, the popular trade names being, 3-4 DPA, Shell M 50 and MCPA. Per hectare herbicide costs varied from 57.00 Rs to 196.00 Rs (Table 2-12).

2.8.5 Use of Labour

The farmer and his family were the main source of labour used in paddy cultivation. However, in peak periods in lowland cultivation these sources were almost fully utilized, and for most of the farmers, were insufficient. In these circumstances farmers responded by exchanging or hiring labour. Transplanting, manual weeding and harvesting were the peak period activities for which farmers used outside help. Total labour used per hectare for different operations is presented in Table 2-11.

These average quantities are aggregates of labour from different origins: farmers, families, exchange and hired labour. In estimating female labour used for operations other than transplanting, a conversion factor of 0.75 was used and for children's labour one child day was considered equivalent to a half a manday. In calculating the total labour used per hectare only those operations reported for more than 25 percent of parcels were included. Information on the amount of labour for less frequently reported operations is presented in Table 2-11 in parentheses. Since there were two methods of establishing paddy, the average amount of labour used for the most frequent method was used in calculating the total amount of labour.

As Table 2-11 shows, about 25 - 36 percent of total labour was spent on land preparation activities. This involved clearing vegetative growth, cleaning bunds and plastering them, ploughing the field with a wooden plough, followed by harrowing, puddling and levelling. For ploughing and harrowing operations, water buffaloes or neat cattle were used as draft power. Total number of mandays of labour required for a hectare of paddy was highest in major irrigation areas. This was

Table 2-11: Use of Labour for Paddy Cultivation

Activity	Major Irrig		Minor Irrig		Rainfed	
	% rep.	MD/ha	% rep.	MD/ha	% rep.	MD/ha
Land Preparation	100	45.3	100	54.3	100	44.4
Transplanting	82	48.8	(18)	(89.5)	(15)	(49.7)
Broadcasting	(17)	(3.5)	82	12.6	85	6.5
Manual Weeding	72	24.1	52	21.1	30	7.8
Fertilizer Appn.	100	5.4	100	8.4	89	3.6
Pesticides Appn.	30	1.0	30	.6	(10)	(4.7)
Herbicides Appn	(11)	(.5)	71	1.5	25	.8
Bird Scaring	(5)	(1.0)	(24)	(14.9)	(7)	(2.5)
Irrign/Water Mgt.	48	2.07	(6)	(.15)	(1.4)	(1.1)
Harvesting	100	30.9	100	28.3	100	31.7
Threshing	100	13.7	100	14.8	100	10.9
Winnowing	100	6.6	100	5.4	100	8.0
Total		177.9		147.0		113.7

Source; Survey Data

because on about 82 percent of parcels paddy was transplanted, which requires a considerable amount of labour. The total number of mandays needed was less in minor irrigation and rainfed areas, since the majority of parcels were broadcast.

2.8.6 Farm Power

Use of tractor power for land preparation was not frequently observed. Water buffaloes and neat cattle were the main sources of draft power used in land preparation. In minor irrigation areas, only 22 percent of lowland parcels were ploughed with hired buffaloes. Threshing of paddy was mainly done with 4 wheel tractors in the district. Proportions of parcels reported threshing with 4 wheel tractors were 84, 87 and 74 percent in major irrigation, minor irrigation and rainfed areas, respectively. Farmers on average spent about 291 rupees to thresh a harvest from a 1 hectare paddy field.

2.8.7 Average Costs, Yields and Returns per Hectare

Cost of cultivation, yields and returns are given in in Table 2-12. In calculating total labour cost, an imputed cost for family labour is also included. Family, exchange and hired labour were costed at the average wage rate of 25 Rs per manday. Fertilizer and seed costs were calculated using per kilogram prices of 3.06 Rs. and 3.95 Rs., respectively.

Table 2-12: Average Per Hectare Costs and Returns From Paddy Cultivation

Item	Major Irrign.	Minor Irrign.	Rainfed
Cost of Cultivation Rs/ha			
Labour	4447.25	3743.00	3024.25
Fertilizer	1239.30	1863.08	865.41
Seeds	879.75	954.93	301.12
Pesticides	63.17	84.20	(36.35)
Herbicides	(75.37)	195.65	56.70
Bullock Power	679.30	679.30	576.10
Tractor Power	278.12	285.12	304.05
Total	7586.89	7810.28	5127.63
Yield MT/ha	3.53	4.39	2.65
Av. Price.Rs/MT	3089.55	3089.55	3089.55
Gross Return	10,906.11	13,563.12	8,187.30
Net Returns	3319.22	5752.84	3059.67

Source; Survey Data

The total cost per hectare was highest in minor irrigation areas, closely followed by major irrigation areas. However, total costs per hectare in rainfed areas was only 66 percent of the total cost incurred under irrigated conditions. Minor irrigation areas produced the highest yields, followed by major irrigation and rainfed areas. Gross returns were based on the open market price of paddy of 3089.55 Rs/MT. Average net returns in rainfed areas were only 260 Rs less per hectare than that for major irrigation areas, despite the high level of inputs and better yields reported in the latter areas. Differences in net returns between these two areas were small as rainfed areas reported reasonably good yields with relatively low costs. The minor irrigation areas reported the highest yields and net reuturns.

CHAPTER 3

ANALYTICAL FRAMEWORK

3.1 Introduction

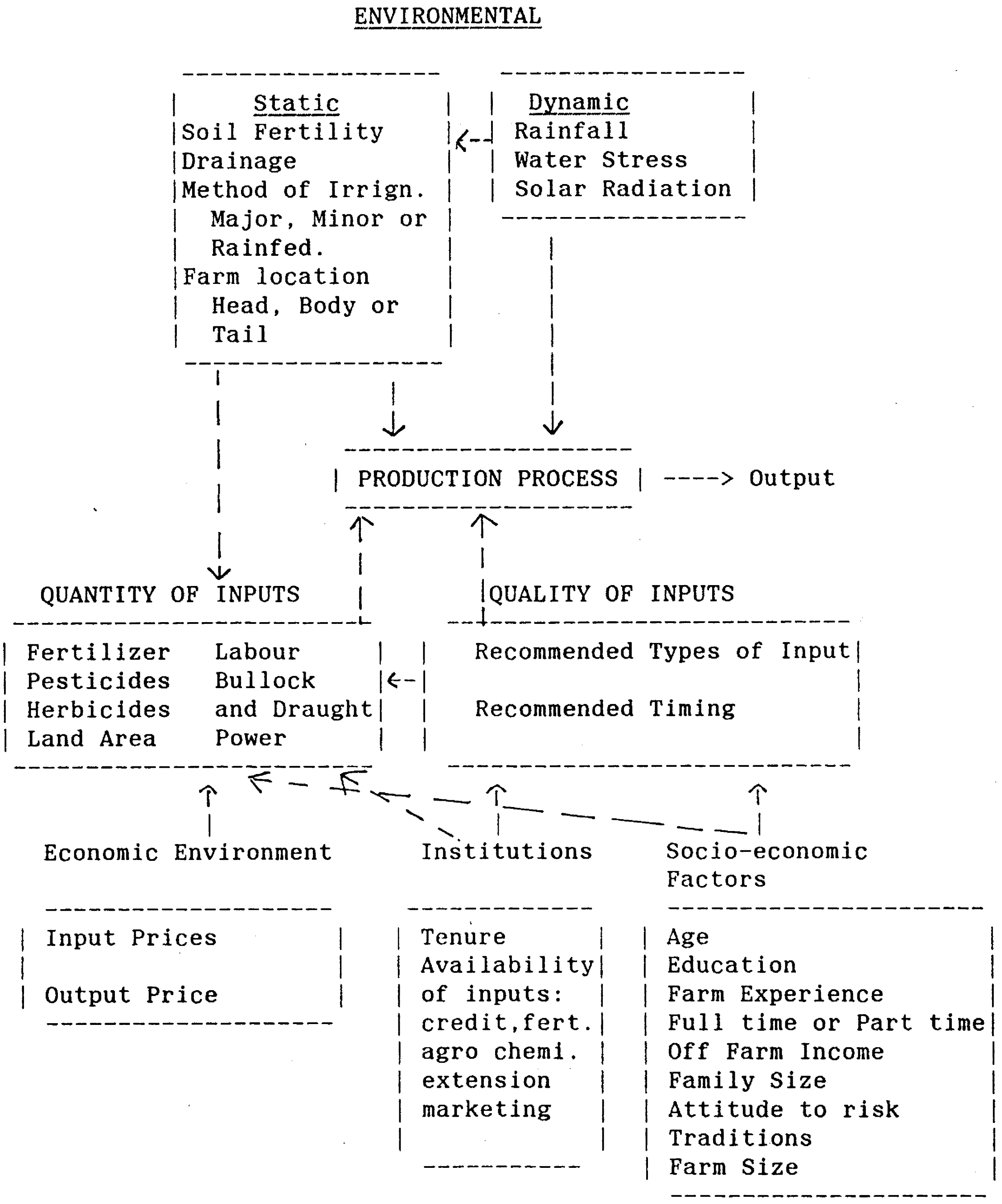
This chapter describes the analytical framework and the relevant concepts involved before progressing to the analytical techniques actually employed in the thesis. A conceptual model which hypothesizes factors and their interrelationships influencing paddy production in the study area is outlined in section 3.2. Section 3.3 develops a standard of best physical performance which can be estimated with the survey data, and elaborates on the concept of best practice technology. Technical and allocative efficiencies are defined in section 3.4., and the measurement of technical efficiency in relation to a frontier production function, is explained in section 3.5. In this last section, the stochastic frontier production function model is introduced together with the four stages involved in testing the conceptual model.

3.2 A Model of Paddy Production

A conceptual model of farm level rice production incorporating factors influencing production processes is presented in Figure 3-1. Production processes occur over time during which they are influenced by a number of direct and indirect factors. Three kinds of factors influence the production process directly. First, interaction between physical factors such as method of irrigation, soil fertility, drainage, location of a farm in relation to an irrigation outlet and climatic factors like rainfall set lower and upper bounds on yield and yield variability. Second, production behaves as a positive function of a range of quantities of input application. Third, quality of inputs, in terms of recommended input types (variety, kind of fertilizer, pesticide etc.), recommended timing of application also directly influence yields.

Farm level production is also influenced by a set of indirect factors. Institutional factors such as land tenure, availability of credit and other purchased inputs such as seeds, fertilizers, pesticides, herbicides and extension services influence the quantity of these inputs applied. Socio-economic characteristics of farmers such as age, education, family size, off-farm activities, part time or full time farming and custom also influence the quantity of inputs applied at the farm level. In addition, farmers' socio-economic characteristics also influence the quality of inputs. Finally the economic environment, represented by input and output prices, determines the ultimate profitability of alternative technologies and practices, thereby influencing the level of their adoption.

Figure 3-1: A Hypothetical Paddy Production Model at the Farm Level



3.3 The Concept of Best Practice Technology

Given the production model outlined above, a wide range of physical performances in paddy production can be expected in a farming community. There may be farmers who exploit the available technology to the maximum feasible level set by the interactions of the various forces in this model, and thus obtain the maximum feasible yield. These farmers can be characterized as employing the best practice technology.

The term 'best practice technology' was first used by Salter (1966). Varied performance by farmers in employing a given technology under a given set of conditions exists owing to the slow adjustment process which accompanies technical change. As Salter (1966) argues, 'in such circumstances the flow of new techniques outstrips the ability of the system to adjust, and a gap appears between potential technical change and actual technical change'. Salter (1966) identified (in manufacturing industries) the reason for slow adjustment as the presence of durable capital equipment. In small scale agriculture it may, more appropriately, be due to the institutional and socio-economic constraints on achieving high yields, or the 'why' factors identified in the IRRI constraints study.

The best practice technology applies not only to the peer group of farmers employing it; conceptually it holds for all the farmers in the domain: potentially, best practice production levels can be obtained by other farmers if they employ the best practice technology. The best practice technology could be represented in an input space as in Farrell's (1957) efficient isoquant or in input-output space as a frontier or industry production function (Aigner and Chu, 1968). This also corresponds to the theoretical notion of a production function. In theory, the production function is defined as the relationship that describes the greatest possible output for a given combination of inputs (Ferguson, 1966). Therefore, the best practice or the frontier technology can be considered as the observed standard with which performance of individual farms can be compared.

3.4 Technical and Allocative Efficiency

The performances of many constituent farms employing the same technology may lie below the best practice performance for a variety of reasons:

1. Observed differences in performance between farms may be due to pure random disturbances.
2. There can be differences between farms in the efficiency with which the available technology is being utilized. Heterogeneity of factors of production may not cause such differences as long as the heterogeneity is spread evenly. Differences in technical efficiency occur when there are differences between farms in the average quality of inputs

applied and level of management. If these differences in quality and management variables can be identified and quantified we will be in a position to find socio-economic and institutional answers to the 'why' questions.

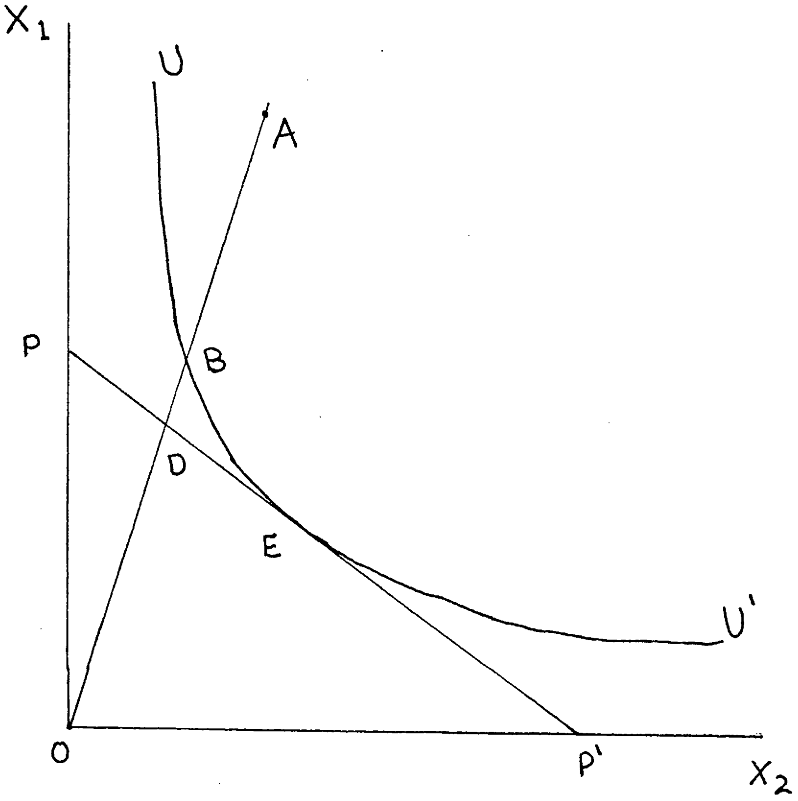
3. If the farmers' objective is to maximize profits, for a given market situation all the farmers should produce a certain level of output. Whenever there is a change in market prices of inputs and outputs farmers should be able to adjust, in order to continue producing a profit maximizing output. Farmers' success in producing this maximum output and adjusting when the market situation changes may differ, with many of them still producing low levels of output. This is due to differences in price or allocative efficiency

Forsand and Hjalmarsson (1974) defined efficiency as 'a statement about the performance of a process of transforming a set of inputs into a set of outputs'. Technical efficiency measures the realized output in relation to the greatest level achievable from the given set of inputs in a technical production function. Allocative or price efficiency compares the marginal value product with the opportunity cost. Farrell (1957) identified overall economic efficiency as being composed of technical and allocative efficiencies. This is illustrated both geometrically and algebraically using a hypothetical example following Farrell's exposition (Figure 3-2).

For a hypothetical farm producing a single output, Y, employing two factors, X_1 and X_2, this can be explained geometrically. UU' denotes the unit isoquant for the most efficient level of technology. Points to the southwest of UU' are infeasible, whereas points to the northeast are inefficient. Farrell assumed a linearly homogeneous production process where constant returns to scale prevail. Given an input combination such as A, where the same unit output is observed, Farrell defined the degree of A's technical efficiency (TE) as the ratio OB/OA. If we assume competitive markets for purchased inputs, relative factor costs are embodied in the iso-cost line PP'. The input combination corresponding to point E minimizes the cost of producing the unit product. Also assuming independence between technical and allocative efficiencies, Farrell defined the latter, in relation to point A, as OD/OB . Combining these two measures he produced an index of overall economic efficiency as OB/OA * OD/OB = OD/OA.

A situation of more than two factors is difficult to explain geometrically on a two dimensional plane. Algebraically we can consider

Figure 3-2: Farrell's Efficient Unit Isoquant



a situation where a farm is producing product Y, by combining factors, X_1, $X_2, \ldots, X_n$. The production function for this situation can be represented as given in equation (3.1)

$$Y_i = f(X_{1i}, X_{2i}, \ldots, X_{ni}) \tag{3.1}$$

From this function we can derive an expression depicting a unit isoquant under the assumption of linear homogeneity in the production process, as given in equation (3.2)

$$1 = f^0(X_{1i}, X_{2i}, \ldots, X_{ni}) \tag{3.2}$$

For the best practice production function which defines the set of maximum outputs obtainable from a given set of input levels in the domain, this unit isoquant can be considered as representing the minimal combination of inputs that can produce a unit of output. There can be farms combining various amounts of inputs X_1, X_2,......,X_n to produce the same unit of output. Farm i which combines X_{1i},X_{2i},..X_{ni} amounts of inputs to produce this unit output, is said to be technically efficient (inefficient) if this combination of inputs lies on (or above) the isoquant.

Price efficiency can be considered in a similar fashion, comparing the isocost plane representing the minimum cost of producing a unit of output with this isoquant.

All of Farrell's measures are made along a ray emanating from the origin through the inefficient input combination, and thus preserving the factor proportion employed by the inefficient farm. With the assumptions of continuity and strict monotonicity, measurements along such a ray ensure a distinction between technical and allocative efficiencies. In order to maintain this distinction Farrell derived his unit isoquant from a primal production function, rather than a dual cost function[1] explaining the relationship between units of physical inputs and physical outputs.

3.5 The Best Practice Production Function and Technical Efficiency

In accordance with the neoclassical theory of production, a production function explaining the maximum output for a given level of inputs can be written for such a domain as

$$Y_i = \text{Max} \ f_i(X_{1i}, X_{2i}, \ldots\ldots\ldots, X_{ni})T_i \tag{3.3}$$

where Y_i = output of ith farm

X_{1i}, X_{2i},...,X_{ni} = amounts of inputs for the ith farm.

---

[1] The distinction between technical efficiency and allocative efficiency cannot be maintained if one chooses the dual cost function. The cost function enables us to derive only overall economic efficiency.

T_i = the level of technology in terms of quality of inputs, management etc.

The maxima of the above equation correspond to the levels of production obtainable by employing the best practice production technology. This can be written as

$$Y = \text{Max } Y_i/T_i \tag{3.4}$$

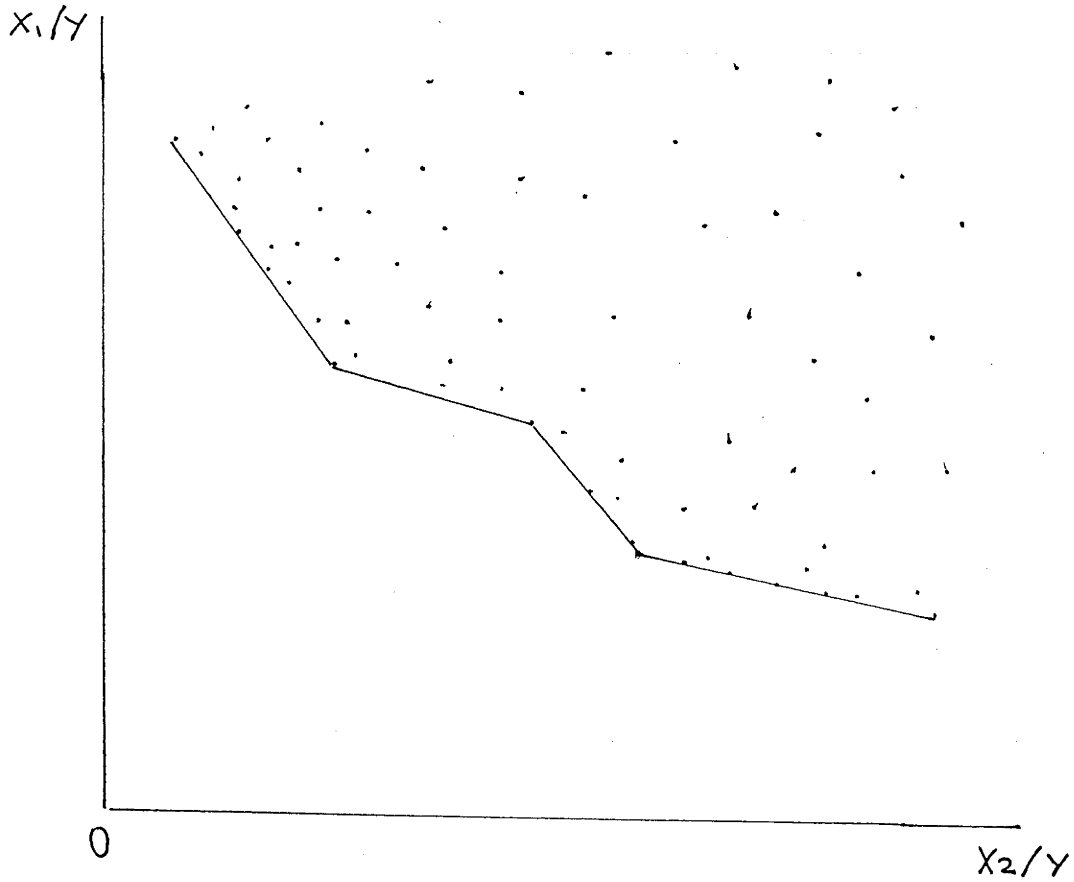
Farrell's efficient isoquant was the precursor of the frontier production functions. These functions can also serve as an efficiency standard and be used to explain best practice technology. However, Farrell's measures of technical efficiency are different from technical efficiency indices derived from a frontier production function. To illustrate briefly Farrell's approach involves construction of the frontier using the ratio of input to output (Farrell, 1957). For instance, for a two input and single output case this can be done as follows: assuming constant returns to scale, the input to output ratios for each input (X_{1i}/Y_i, X_{2i}/Y_i) for individual observations can be calculated and then plotted (Figure 3-3). A line can be drawn to join the lowest points (closest to the origin). This line connects all the points where unit output is obtained at minimum combinations of inputs. This curve can be used to calculate technical efficiency as illustrated in Section 3.2.

This approach is nonparametric and no functional form is imposed. The second feature is an advantage, while the restrictive assumption of constant returns to scale and the frontier's susceptibility to outliers and measurement errors are disadvantages.

Farrell himself suggested an approach for estimating technical efficiency related to a frontier production function, involving estimating a parametric frontier using the Cobb-Douglas form. Aigner and Chu (1968) followed this and derived a frontier using a homogeneous Cobb-Douglas specification. They showed how the estimates of parameters of the Cobb-Douglas production frontier could be derived using mathematical programming techniques; either Linear Programming or Quadratic Programming. Their model can be written as follows:

$$\ln y_i = \ln f(x_i) - u_i \tag{3.5}$$

Figure 3-3: Constructing Farrell's Efficient Isoquant



$$\ln y_i = \alpha_0 + \sum_{i=1}^{n} \alpha_i \ln x_i - u_i$$

where; y_i = output

x_i = inputs

$u_i \geq 0$, one-sided disturbance term

Because of the one sided error term, the observed value of Y should lie on or beneath the frontier production function. In other words $y \leq f(x)$. The elements of the parameter vector $\alpha = (\alpha_0, \alpha_1, \ldots\ldots \alpha_n)$ can be estimated using linear programming, even without specifying any probability density function for u_i. This can be written as an LP problem for minimizing the sum of the absolute values of the residual (objective function) subject to the constraint $u_i \geq 0$. Once the parameters of the function are found we are in a position to characterize the frontier technology in a simple mathematical form. This is certainly a better estimation procedure than Farrell's direct method. However, restrictive Cobb-Douglas specifications, problems of outliers and lack of any statistical properties are disadvantages.

To overcome the problem of outliers Timmer (1971) suggested a method of estimating a probabilistic frontier production function. As the term implies, this can be thought of as a highly probable frontier production function. In order to derive this, and retaining the procedure outlined by Aigner and Chu (1968), he introduced an externally specified probability, P, e.g P = 98% . The procedure involved discarding (100-P)% observations until the coefficients stabilized. While Timmer was thus able to overcome the problem of outliers, estimates of parameters derived this way still lack statistical properties. This was because neither Aigner and Chu nor Timmer specified the distribution or density function of the disturbance term. If this could be achieved parameters of the frontier production function with their statistical properties could be estimated by appropriate econometric techniques, obtaining a deterministic statistical frontier.

There are several important differences between Farrell's efficient isoquant and the frontier production function approach. Frontier production functions, as outlined above, assume a specific functional form and have a parametric production surface in the input-output space, whereas an efficient isoquant is only a series of connected hyperplanes convex to the origin in input space. Frontier production functions, by adopting a specific functional form, remove the assumption of linear homogeneity

However, both Farrell's efficiency isoquant and the frontier production functions discussed here are deterministic. In other words, we assume that all farms face the same set of frontier production, profit and cost functions. However, in the real world, owing to factors beyond the control of farms, such as weather and uncertainty in input supply etc., frontier functions may vary across farms and over time for the same farm. In addition, there may be measurement errors in the dependent variable and the production function may not be completely specified. For these reasons the introduction of a stochastic component becomes important. The stochastic frontier production function model formulated by Aigner et al., (1977) will be used in this study to measure technical efficiency. This model is explained in detail in the next Chapter.

3.6 Testing the Production Model

The conceptual production model outlined in section 3.2 was tested in accordance with the objectives of this study, as given in Chapter 1. The test was undertaken in four stages. First, production function analysis was undertaken to explain the average technology practised in the study areas. Second, a stochastic frontier production function model was fitted for the study area, using the exact specifications of technology derived from the first stage. Third, farm specific technical efficiency measures were estimated using the estimated stochastic frontier production function model. Fourth, technical efficiency indices derived in the third stage were related to a set of socio-economic and institutional variables to identify factors determining technical inefficiency.

CHAPTER 4

METHODOLOGY

4.1 Introduction

Methodological issues regarding the estimation of technical efficiency related to a stochastic frontier production function are outlined in this Chapter. Section 4.2 deals with average production function analysis and the assumptions involved, economic specifications, statistical specifications and selection of variables are discussed in this section. In Section 4.3 the stochastic frontier production model is presented. The estimation procedure involved in estimating the stochastic frontier production function is then discussed and the method of analysing technical efficiency is outlined.

4.2 Average Production Function Analysis

4.2.1 Assumptions

Production function analysis is useful for obtaining measurements of the relationship between output of a crop and the inputs used at the farm level under different conditions to be studied. In this study the following assumptions are made.

1. Observations across the farming community are made at one point in time. Farmers are expected to have different circumstances e.g., different sizes of land holdings, and input applications and other factors incorporated in the production model; see Figure 3-1.
2. Perfect competition both in factor and product markets prevails, and farmers are price takers in both markets.[1]

---

[1] In the study area institutionally fixed prices prevail for fertilizers, seeds, agrochemicals and credit. Land rentals for tenant lands are also institutionally determined. There are guaranteed price schemes operating for paddy and other field crops.

3. Farmers are motivated by profit maximization based on expected profit and thus the production process can be explained by a single equation model.
4. All the farmers in the domain have equal access to information on alternative technologies.

4.2.2 Economic Specification

The concept of the frontier was criticised as being relative and artificial. Critics of this persuasion believe that the divergence between the average and the frontier production functions are due to inputs that were left out in the estimation procedure and inclusion of all the inputs will relate interfarm variability in productivity to variability in input levels rather than to technical inefficiency (Muller, 1970 and Shapiro and Muller, 1977). They also argue once we include all the variables differences in productivity except the differences due to random elements will disappear and the frontier and the average production functions become identical. Muller (1970) found that inclusion of a information variable reduced productivity differences substantially. Therefore, for the hypothetical production model (Figure 3-1) presented in Chapter 3 we have to specify a production function considering all three categories of variables: quantities of inputs, quality of inputs and environmental variables. Since the socio-economic and institutional variables influence the first two categories of inputs, they too have to be taken into account if the model is to be specified as exactly as possible. It becomes obvious that once the production function is fully specified, interfarm productivity differences will be trivial. However, this does not serve our purpose as it does not provide a way of separating the effect of those factors that explain productivity differentials from those inputs and environmental factors that influence the technical production relationship. Johnson (1964) identified those factors causing productivity differences as 'non conventional inputs' and argued that they should not be treated as factors of production and attempts to do so will 'reduce the effectiveness with which production function analysis can be carried out and reduce our ability to understand (1) the creation of technological advance (2) the performance of the managerial process and (3) the process of investing in and of improving the human agents'. Management and efficiency related inputs, under socioeconomic and institutional categories in the production model, are responsible for productivity differences. Physical quantities of various technical inputs and environmental factors determine the technical relationships of production.

In this study, the first stage of analysis examines the technical relationships between farm paddy production and technical and environmental inputs. The factors hypothesized to explain interfarm productivity differences will be used in the fourth stage in explaining technical efficiency differences.

Multicollinearity is a familiar problem in empirical production function studies, and selection of variables for the functional relationship requires minimizing the degree of multicollinearity. Exclusion of any relevant variable will bias the estimates of the parameters. Inclusion of irrelevant variables will not bias the estimates, but will increase the chances of multicollinearity and errors due to autocorrelation, and will also reduce the degrees of freedom (Heady and Dillon, 1961).

Inputs, output and profit of a farm firm are determined by the underlying production function. Traditional production models assume deterministic profit maximization, and as a result, the system of equations which comprises the production model has inputs that are dependent on disturbance terms (Zellner et al., 1966). This makes estimation of the production function as a single equation model difficult, as this procedure leads to biased and inconsistant estimates of parameters. However, it is more reasonable to assume farm profits are stochastic in nature and that farm firms behave on the basis of a mathematical expectation of profits (Zellner et al., 1966). This assumption overcomes simultaneous equation bias and enables estimation of a technical production function as a single equation model using OLS.

In the economic specification of a production model, the exclusion of management is likely to produce biased estimates of the coefficients. As was explained above, management related variables will be considered separately in Stage 4 of the analysis. No attempt is made to incorporate management into the technical production function, and the specification of the production function is solely based on technical relationships.

Another question is whether to include risk and uncertainty in the analysis. Risk and uncertainty in agriculture can be divided into yield and price risks. Farmers can be expected to respond to high variability in yields and prices by lowering the level of inputs used and by not adopting new technologies. In this study area, price risk can be assumed away, since a guaranteed price scheme has been operating for paddy for a considerable time. Swan found a strong and statistically significant correlation between crop failure and lack of irrigation facilities in 13 paddy cultivating districts in Sri Lanka. However, he also found that Kurunegala district was a noteworthy exception, as the rainfed paddy cultivation practised in the southern wet and wet intermediate zones of the district was fairly reliable (Swan, 1967). Therefore, we can assume minimum variability under rainfed conditions. Since the availability of water in major tanks is adequate for the greater or 'Maha' season, the same can be assumed for the farms in this category. There is yield variability for farms fed by minor tanks, but the sample size for this category is small (25) compared to the size of the pooled sample (201) so it could be ignored.

4.2.3 Selection of Variables

The dependent variable, Y, output measured in metric tons per farm, is regressed against a set of independent variables. These variables are classified in two categories: production input variables (X_{1i}, $X_{2i}, \ldots,$ x_{ni}; $D_{1i}, \ldots,$ D_{ni}); and environmental variables (W_{1i}, W_{2i} ,$W_{3i}, \ldots, W_{ni}$; $D_{ni+1}, \ldots, D_{mi}$). and the function can be described as in Equation (4.1):

$$Y_i = f(X_{1i}, X_{2i}, \ldots, X_{ni}; D_{1i}, \ldots, D_{ni}/W_{1i}, W_{2i}, \ldots, W_{ni}; \quad (4.1)$$

$$D_{ni+1}, \ldots, D_{mi})$$

Production functions are fitted for the pooled sample of farms comprising 100 observations under irrigated conditions and 103 observations under rainfed conditions. The total sample for irrigated conditions is made up of 75 farmers from the major irrigation area and 25 farmers from minor irrigation area. Account is taken of output variability in the pooled sample due to different methods of irrigation, crop establishment and soil fertility by including dummy variables in the regression analysis. Separate regressions for irrigated and rainfed areas could be fitted, but instead, a single regression is run with differential intercept and slope dummies for the interactions of irrigation with other explanatory variables. Fitting a single regression in this manner is equivalent to fitting two regressions separately (Johnston, 1984, p.227). This method was preferred for three reasons. First, there is little variation in the method of establishment between farms with a particular form of irrigation. For instance, on most paddy parcels in rainfed areas paddy was broadcast, while a majority in irrigated areas transplanted (Table 2-5). Thus the method of establishment dummy , as expected, is not significant in separate regressions for either irrigated or rainfed farms. In the pooled sample, there is adequate variation in this variable and the effect of method of establishment can be studied in a meaningful manner. Second, the interaction of irrigation with other variables can be more explicitly incorporated with differential slope dummies in a pooled regression. Third, testing of hypotheses of differences in coefficients for a particular input between groups is more convenient with this method. For instance, a test as to whether the coefficient of herbicide cost is significantly different between two irrigation methods is simply determined by the significance of the coefficient of the differential slope dummy (Johnston, 1984, p.227)

For farmers who cultivated more than one parcel of paddy, quantities of inputs applied to each parcel are added. In constructing per farm values for qualitative variables which are represented by dummies, an additional dummy is created to account for mixed responses. For instance, there were farmers who transplanted paddy in one parcel and broadcast in another. In such cases, a second 'mixed dummy' variable is used to account for mixed responses. Variations due to differences in soil fertility, drainage and method of water supply are introduced via dummy variables, as shown below.

4.2.4 Production Input Variables

Production input variables were classified into two categories: essential and non essential inputs. Three inputs, land area, land preparation labour and quantities of seed paddy are essential. All other technical inputs are considered nonessential.

1. Land Area in Hectares; The total land area planted to paddy in Maha 1983/84 in each farm is considered as the variable land. If the farmer has cultivated more than one parcel of paddy it is the sum of the areas of individual parcels. Heterogeneity in the quality of land is not considered in constructing this variable since it is dealt with via dummy variables for soil fertility and drainage. The land variable is designated X_1.

2. Labour in Mandays; Labour spent on harvesting and threshing of paddy is excluded at the outset. From the remaining total mandays of labour, the amounts spent on application of fertilizer, pesticides and herbicides are considered separately with these inputs. There are some operations that are carried out by female labour, especially transplanting of paddy. Therefore for the transplanting operation we take one female day as equivalent to a male labour day. However, labour spent on crop establishment depends on the method of establishment. Transplanting requires more labour than broadcasting (see Chapter 2, section, 2.8.5). Since the methods of establishment are studied with a dummy variable, the quantities of labour spent on crop establishment also are excluded to circumvent the problem of multicollinearity. One female labour day was considered equivalent to 0.75 mandays in other operations, while one child labour day is considered equivalant to 0.5 mandays. Two variables are constructed from the remaining total number of preharvest labour mandays.

   a. X_2; Total number of mandays per hectare in land preparation; Land preparation for paddy includes number of operations; general land preparation involving clearing the vegetative growth, clearing bunds and plastering them, ploughing, harrowing, puddling and levelling. In the study area draft power was used only for ploughing and harrowing. All other operations were done manually. Though a bullock power variable was also considered in this study the amount of labour used in driving bullocks was not excluded in constructing the land preparation labour variable. This was not expected to create a major problem due to multicollinearity since land preparation included number of activities most of which used labour only and amounts of labour used in driving buffaloes was very little compared to the total amount of labour used in all land preparation activities.

   b. X_4; Total number of mandays for manual weeding

3. Quantity of Seed Paddy in Kg; Quantity of seeds used on individual farms is variable X_3.

4. Fertilizer ;Use of organic manure, or straw from paddy is not widespread in the area, so only chemical fertilizer was considered in this study. Fertilizer cost and nutrient quantities[2] are studied to determine the relationship between fertilizer and per farm output of paddy. In constructing the fertilizer cost variable, expenditure on its application is added. If the total expenditure on fertilizer alone is used as a variable, its marginal product will also include the marginal product of the labour used to apply fertilizer. Therefore, it is necessary to add this labour cost to the total cost of fertilizer. Since the prices of various fertilizers are fixed by government, in a small area there are no differences in prices. The three variables thus selected are

    a. X_5; Total cost of fertilizer including the cost of labour for application

    b. X_6; Total quantity of Nitrogen (N) in Kilograms.

    c. X_7; Total quantity of Phosphorus (P_2O_5) in Kilograms.

    d. X_8; Total quantity of Potash (K_2O) in Kilograms .

5. Expenditure on Agrochemicals; Two more variables for pesticides and herbicides were constructed and designated as X_9 and X_{10} respectively. As in the case of fertilizer, costs of labour for application of these agrochemicals are added to respective costs.

6. Number of Days of Bullock Power; Few farmers use tractor power for ploughing and harrowing Bullock power is the main form of draft power used by the farmers, and is designated as X_{11}. All the farms selected for this production function study used bullock power for ploughing and harrowing.

7. D_1 and D_2 Dummy Variable for Method of Establishment; For transplanting $D_1 = 1$, for broadcasting $D_2 = 1$ and for farms which used both, $D_1 = D_2 = 0$.

4.2.5 Environmental Variables

Differential intercept dummy variables were used for soil fertility, drainage and for method of irrigation. In addition differential slope dummy variables were used for the interaction of irrigation with other explanatory variables.

---

[2] Quantities of different nutrients added to soil are calculated from quantities of different types of fertlizer using the conversion ratios given in Appendix Table E-1.

1. Soil Fertility Dummy; Values for soil fertility dummies are assigned based on farmers assessment of soil fertility. Farmers' assessment is available as a range of their perceptions, indicated in terms of very good, good , average, poor, very poor. This assessment may or may not be actually indicative of the soil fertility since this is not based on any form of soil analysis. Three dummy variables are assigned to four levels of soil fertility. If the soil fertility is very good or good $D_3 = 1$, if average $D_4 = 1$, for other ratings $D_5 = 1$, and for the farms which reported more than one of these $D_3 = D_4 = D_5 = 0$.

2. Drainage Dummy; This variable is again farmers' assessment as indicated in terms of well drained, moderately drained or ill drained. If the farmers rating of drainage is well drained $D_6=1$, for all other inferior ratings $D_7 = 1$ and for farms which reported more than one response $D_6 = D_7 = 0$.

3. Irrigation Dummy; The pooled sample comprises farmers from irrigated and rainfed conditions. A dummy variable D_8 is assigned for this purpose; if the farm is irrigated $D_8 = 1$ and it is rainfed $D_8 = 0$. No farms in the sample studied reported paddy parcels with more than one irrigation method. This differential intercept dummy variable was used along with differential slope dummies to ascertain whether the shift in production function due to irrigation was Hicks neutral. These differential slope dummy variables were constructed by multiplying the value of a given variable for a particular observation by the respective value of the dummy variable. For instance, the differential dummies for seed cost and herbicide cost were $D_8 * \ln X_3$ and $D_8 * X_{10}$, respectively.

4.2.6 Functional Specification

Before selecting a functional form we have to examine the likely shape of the production curve in the situation concerned. Production theory tells us that the slope of the production curve depends on the nature of complementarities and substitutability between different inputs. In agriculture the relationship between inputs exhibits two characteristics: complimentarities with variable proportions of inputs and full substitutability (Ott, 1962). The transcendental production function is ideal for representing the first characteristic, whereas the Cobb-Douglas form is capable of representing the second. The transcendental production function has an added advantage of being able to represent all three stages of production (Halter et al., 1959),while the Cobb-Douglas form is able to represent only the second stage in which a firm enjoys positive but diminishing marginal production under the assumption of perfect competition. The Cobb-Douglas form represents the rational behaviour of farm producers and it is widely used in empirical agricultural production function analysis.

The Cobb-Douglas functional form was selected here, with a modification to overcome the log transformation problem of zero levels of application of nonessential inputs by some farmers in the sample. Conventional inputs like land area, land preparation labour and seed quantity are considered as essential inputs and all other inputs non essential. The essential inputs enter into the production function in a multiplicative form and the nonessential inputs in an exponential form, as shown in equation (4.2). The Cobb-Douglas functional form with similar modifications has been used by others (Lingard et al., 1983; Hati and Rudra, 1973). The production model in logarithmic form is as follows.

$$\ln Q_i = \ln\alpha + \sum_{j=1}^{8} \theta_j D_{ji} + \sum_{k=1}^{3} \beta_k \ln X_{ki} + \sum_{l=4}^{11} \beta_l X_{li} + u_i \qquad (4.2)$$

Where; Q_i = paddy output of ith farm measured in metric tons

D_{ji}= values for dummy variables, j= 1,2,....,8 of the ith farm

X_{ki}= values for essential inputs, k = 1, ...,3 of the ith farm

X_{li}= values for non essential inputs, l = 4, 5 (or 6, 7, 8),..,11 of the ith farm

u_i= statistical disturbance term with usual classical properties as shown in next section

4.2.7 Statistical Specification and Estimation

In empirical studies of production functions it is always believed that differences exist between the actual value and the estimated value of the random dependent variable. In statistical theory these differences are called 'disturbances or 'statistical noise'. In production function studies we have to specify the structure of the behaviour of this disturbance term across observations to account for explanatory variables which were not included in the analysis (Cramer, 1969). The disturbance term also represents errors in observation and measurement or statistical noise such as random weather effects.

An average production function, as commonly estimated, can be written as follows.

$$Y = f(X) + u \tag{4.3}$$

The structure of the disturbance term in this case is specified using the following assumptions:

(i) The expected value of u for each observation is zero.

i.e, $E(u_i) = 0$

(ii) u_i's are not serially or autocorrelated, i.e. they are independent of time and no two u_i's are correlated.

$E(u_i u_j) = 0 \quad i \neq j$

(iii) u_i's are independently distributed with x_i's.

i.e, $E(X_i u_i) = 0$

(iv) u_i is normally distributed as $N(0,\sigma^2)$

If these assumptions hold the production function can be estimated using the ordinary least square (OLS) method, which minimizes the sum of squared difference between the estimated and observed values of the random variable Y.

Variation in the dependent variable due to this disturbance term, which is randomly distributed, is assumed not to be significant. This can be verified by the estimate of coefficient of determination, R^2. However, this type of analysis does not explain the productivity differences which can be observed between observations. In this study average production functions using the functional form selected under 4.2.6 are fitted to identify the average technology.

4.3 Stochastic Frontier Production Function

Stochastic frontier production functions, or the composed error model, were recently introduced (Aigner et al., 1977 ; Meeusen and Broek, 1977). According to this the error of a stochastic frontier model is composed of two parts, as shown below.

$$y_i=\alpha+\sum_{j=1}^{m} \beta_j x_{ij}+u_i+v_i \tag{4.4}$$

where; $\epsilon_i = u_i + v_i$

- u_i , a one-sided error component, captures the effect of inefficiencies related to the stochastic frontier. It is the difference between observed and the best practice output. It may be either zero or negative.

- v_i, a symmetric component permits random variation of the frontier across farms and, over time for the same farm due to random factors beyond a firm's control and measurement errors etc. It may be either positive, negative, or zero.

If there is no random change in climatic factors and statistical errors are negligible ($v_i = 0$) the above frontier can be written as

$$Y_i=\alpha+\sum_{j=1}^{m} \beta_j X_{ij}+u_i \tag{4.5}$$

If the farm uses the best practice technique ($u_i= 0$), while there are random changes and statistical errors, the frontier can be written as

$$Y_i=\alpha+\sum_{j=1}^{m} \beta_j X_{ij}+v_i \tag{4.6}$$

The former model is called the 'full frontier' while the latter is called an average production function; models which have both u_i and v_i terms are called 'Pseudo Frontier Functions' (Battese and Corra, 1977). The above model '(4.4) can be estimated by specifying the density functions of u_i and v_i with a maximum likelihood technique. Aigner et al. (1977) assumed a truncated normal (half normal) distribution for u_i and a normal distribution for v_i

4.3.1 Empirical Estimation of the Stochastic Frontier Production Function.

For the economic and statistical specification given in equation (4.4), we can write the empirical frontier production function as.

$$y_i=\sum_{j=0}^{11} \beta_j X_{ij}+\epsilon_i \tag{4.7}$$

where; $\epsilon_i = u_i + v_i$

and y is the logarithm of yield actually obtained X_0 is equal to 1, X_1, X_2 and X_3 are logarithms of essential inputs and X_4 and X_5 (or X_6, X_7, X_8), X_9, X_{10} and X_{11} are non essential inputs.[3] If we assume a truncated normal (half normal) distribution for u_i and a normal

---

[3] Note that dummy variables were ommited for simplicity in exposition

distribution for v_i, the corresponding density functions can be written as follows

$$f_u(u_i)=1/\sqrt{1/2\pi}.1/\sigma_u.\exp(-u_i^2/2\sigma_u^2), \text{if} u_i<0 \quad (4.8)$$

$$= 0, \text{ otherwise}$$

$$f_v(v_i)=1/\sqrt{1/2\pi}.1/\sigma_v.\exp(-v_i^2/2\sigma_v^2) \quad (4.9)$$

where; $-\infty<v<\infty$

However, the random variables u_i and v_i cannot really be observed. Hence, we have to specify the density function for the observed random variable, Y, combining these two density functions. The density function for Y can be given as

$$f_Y(y_i) = f_E(y_i - x_j\beta_j) \quad (4.10)$$

where $f_E(.)$ denotes the density function for ϵ_i.

Assuming independence between u_i and v_i and between these disturbance terms and explanatory variables following Zellner, Kmenta and Drez's (1960) behavioural assumption the density function for ϵ_i is obtained from the joint probability density function for u_i and v_i. Note that the value of the random variable ϵ_i never exceeds the value of the random variable, v_i i.e,

$$\epsilon_i \le v_i$$

this is because $\epsilon_i = u_i + v_i$ and u_i is a negative random variable. Assuming $v_i = w_i$, the probability density function can then be obtained using a convolution formula (Taha, 1976).

$$f_E(\epsilon_i)=\int_{-\infty}^{\infty} f_v(W)f_u(\epsilon_i-w)dw \quad (4.11)$$

Solution of this integration exercise (see Kalirajan, 1979; Appendix 3.1) yields

$$f_E(\epsilon_i)=1/\sigma\sqrt{1/2\pi}\exp\{-1/2(u_i+v_i)^2/\sigma^2\}\{1-F(u_i+v_i).\sigma_u/\sigma.\sigma_v\} \quad (4.12)$$

where F(.) is the cumulative distribution function of the standard normal random variable and, $\sigma^2 = \sigma_u^2 + \sigma_v^2$ also, with parameterization introduced by Battese and Corra (1977), $\gamma = \sigma_u^2/(\sigma_u^2 + \sigma_v^2)$ the above expression can be written as[4]

$$f(\epsilon_i) = 1/\sigma\sqrt{1/2\pi}\exp[\{-1/2\epsilon_i^2/\sigma^2\}\{1-F(\epsilon_i \cdot \gamma/(1-\gamma))\}] \qquad (4.13)$$

Substituting $y_i - x_j\beta_j = \epsilon_i$ in the equation results in the density function for $f(Y_i)$

$$f(y) = \frac{1}{\sigma\sqrt{1/2\pi}} \exp\frac{-1/2(y-x\beta_j)^2}{\sigma^2} [1-F[(y-\beta_j x_j)(\frac{\gamma}{1-\gamma})]] \qquad (4.14)$$

$$\text{where; } \gamma = \frac{\sigma_u^2}{\sigma_u^2+\sigma_v^2}$$

Now the likelihood function for the probability density function of obtaining sample values of $(Y_1, Y_2, Y_3, \ldots. Y_n)$ can be written.

$$L^*(Y;\Theta) = \prod_{i=1}^{n} \{1/\sigma\sqrt{\pi/2}[1-F(y_i-\beta x)/\sigma) \qquad (4.15)$$

$$\sqrt{\gamma/(1-\gamma)} . e^{-1/2(y_i-\beta x_i)^2/\sigma^2}\}$$

where Θ , the parameter to be estimated, is equal to (β, σ^2, γ) The maximum likelihood method can be employed to find the values for parameter Θ which maximizes the above likelihood function. Since the natural logarithm of a function also has the maximum value at the same position as the original function it will be convenient to continue with the logarithm of the likelihood function.

---

[4] This parameterization is slightly different from λ introduced by Aigner et al., (1977). Paramerization γ is preferred to λ of Aigner et.al on grounds of computational convenience. γ is easier to explain since it ranges from 1 to zero whereas λ which is equal to σ_u/σ_v ranges from zero to infinity.

$$L(Y:\theta) = -n/2.\ln\pi/2 -n/2.\ln \sigma^2 + \sum\ln[(1 - F(W_i)] -1/2\{(1-\gamma)/\gamma\}\sum W_i^2 \qquad (4.16)$$

where $W_i = (Y_i - x_i\beta)((1-\gamma/\gamma).1/\sigma^2)^{1/2}$

Maximum likelihood estimates of θ, maximizing the likelihood function, can be obtained by first deriving partial derivatives

$\partial L/\partial\beta$, $\partial L/\partial\sigma$ and $\partial L/\partial\gamma$

with respect to elements of θ, (β, σ, and γ, respectively) and setting them equal to zero and solving simultaneously. These partial derivatives are given in Kalirajan (1979, pp.95-96) and, it is very difficult to express ML estimates for the parameters in closed form from these simultaneous equations using ordinary methods as they are quite complicated. Therefore, numerical methods were used to find a convergence solution. Among the different algorithms available the Newton-Raphson (NR) technique seemed to have a number of advantages. It enabled location of a convergence solution more quickly than other available techniques as it uses second order derivatives. Rapid convergence is obtained if the initial estimates are in the close vicinity of the ML estimates (Bard, 1974). As with most of the other algorithms, the NR technique is also unable to converge to a solution if the function is not well behaved (Harville, 1977; Taha, 1976). Another problem with the NR method is the possibility of successive estimators overshooting the true solution. To restrain this Kale (1962) suggested a method of allowing a predetermined, specified proportion of change at every iteration and thereby limiting the movement of successive estimators within the close proximity of the true solution.

The modified NR estimator is

$$\theta_1 = \theta_0-\alpha[\partial L^2(Y;\theta_0)/\partial\theta\partial\theta`]^{-1}.\partial L(Y;\theta_0)/\partial\theta \qquad (4.17)$$

where α is the predetermined proportion of change and ranges from 0 - 1;

$\partial L/\partial\theta\}$ and $\partial L^2/\partial\theta\partial\theta`$

are first and second partial derivatives of the likelihood function evaluated at the initial estimator θ_0. A number of researchers have used this modified estimator (Battese and Corra, 1977; Kalirajan, 1979).

OLS estimates of parameters describing the average technology were taken as initial estimators. It was reasonable to think that these estimates were in the close vicinity of the true estimators and could be thought of as the lower bound values. Hence, OLS estimates of the intercept β_0, other parameters β_j and variance σ^2 were used, along with various values for γ ranging from 0 to 0.9 as initial estimates.

4.4 Analysing Technical Efficiency

In estimating the frontier production function we were concerned with the placement and the shape of the production frontier, so that the resultant frontier corresponded to the notion of best practice production function. Having established this, technical efficiency could now be calculated. Aigner et al., (1977), using their stochastic frontier model, were able to derive only an average technical efficiency for the sample. Similar exercises carried out by Meeusen and Broeck (1977), and Forsund and Hjalmarsson (1974) also produced only average technical efficiency measures. They could not estimate technical efficiency for individual observations in the sample. Both the average and farm specific technical efficiencies were measured in this study.

4.4.1 Sources of Variation in the Frontier Output

It is clear from the discussion of the model of Aigner et al(1977) (Equation 3.13) that there are two sources of variation in the dependent variable, y_i. Therefore it was necessary to assess the strength of each of the two components. This was done by comparing the variance of the composed error term $[\epsilon_i]$, σ^2 with the variance of the technical inefficiency component $[u_i]$, σ_u^2.

This can be achieved by calculating the variance ratio, σ_u^2/σ^2, which is equal to γ, using the parameterization introduced by Battese and Corra (1977). Estimates of this variance ratio were readily obtained from the ML estimation.

the variance ratio $\gamma = \sigma_u^2/\sigma^2$

where $\sigma^2 = \sigma_v^2 + \sigma_u^2$

1. When σ_v^2 approaches zero, u_i is the predominant error in equation 1. As a result γ will approach 1. This implies that as γ approaches 1 variation in y is mainly due to differences in technical efficiency. This can be statistically tested to see whether the estimated value of γ is significantly different from zero.

2. Similarly when σ_u^2 tends to zero, the variation in y is mainly explained by the stochastic disturbance term, If this happens γ approaches zero. If the estimated value of γ is not significantly different from zero we may conclude that technical inefficiency is trivial.

4.4.2 Measuring Technical Efficiency in Relation to the Stochastic Frontier Production function

A technical efficiency measure in relation to the stochastic frontier production function should compare the level of output a farmer can obtain by combining a given set of inputs using his state of technology without the influence of stochastic elements, with the level of output he could obtain if he had adopted the best practice technology. Thus this is not simply a comparison of the observed output with the best practice output, because observed output could have been different if the farm was not affected by random elements, and therefore observed output should be adjusted by separating the effects of stochastic elements before comparing it with the best practice output. A procedure to obtain a measure of 'adjusted observed output' can be outlined with the help of our empirical frontier production function as follows.

$$Y_i^F = \prod_{k=1}^{3} X_k^{\beta_k} \exp \sum_{l=4}^{l=11} \beta_l X_l + u_l + v_i \qquad (4.18)$$

where Y_i^F is the maximum level of output farm i can obtain by adopting the best practice technology for its given set of inputs, u_i is the disturbance term related to technical inefficiency. A measure of 'adjusted observed output' can be obtained by dividing the equation (4.18) by e^{u_i}.[5] This results in

---

[5] This is equivalent to substracting the shortfall in output due to technical inefficiency from the best practice output, Y_i^F

$$Y_i^F/e^{u_i} = \prod_{k=1}^{3} X_k^{\beta_k} \exp \sum_{l=4}^{11} \beta_l X_l + v_i$$

Now technical efficiency can be calculated dividing the 'adjusted observed output' by the best practice output.

$$TE = (Y_i^F/e^{u_i}).1/Y_i^F$$

$$= \frac{1}{e^{u_i}}$$

This estimator gives us a better tool compared to calculating technical efficiency in relation to a deterministic frontier as used by Timmer (1971) and Mijindadi and Norman (1984) since it accounts for the variations in the observed output due to random elements.

The shortfall in output due to technical inefficiency for the ith farm S_i, can be calculated as follows

$$S_i = Y_i^F(1 - 1/e^{u_i})$$

4.4.3 Average Technical Efficiency

Since v_i has a normal distribution and u_i has a half normal distribution the density function for e_i, given in equation (4.12) is asymmetric around zero, with its mean given by the following formula (Aigner et al. 1977).

$$E(\epsilon_i) = E(u_i) = \sigma_u\sqrt{2/\pi} \qquad (4.19)$$

$E(u_i)$, measures the population mean of the disturbance term u_i. An estimate of mean technical efficiency can be given by $1/e^{E(u_i)}$.

4.4.4 Farm Specific Technical Efficiency

In earlier studies on technical efficiency in relation to stochastic frontier production functions farm specific technical efficiency was calculated by comparing the actual output with the best practice output. This was made possible because of high values for the variance ratio, γ which were not significantly different from zero were reported in these studies (Kalirajan, 1979 and 1981). A statistically significant high values for γ implies that variation in output in relation to the frontier production function was mainly due to differences in levels of technical inefficiency. This method involved simply attributing the residual related to the stochastic frontier production function, $u_i + v_i$ to technical inefficiency. Therefore farm specific technical efficiency may be underestimated since we are not separating the systematic error term, v_i from the technical inefficiency related disturbance term, u_i, even though the variance ratio was found to be not significantly different from 1.

In order to measure farm specific technical efficiency measures as outlined in section 4.4.2 we need estimates of u_i values for individual observations. This involves separating the systematic error component v_i from the technical inefficiency related disturbance u_i and measuring individual values of u_i. Farm specific u_i values can be derived from the conditional distribution of u_i, given ϵ_i or $(v_i - u_i)$ (Jondrow et al., 1982).[6]

Waldman (1984) examined this method along with two other estimating methods of technical efficiency and found that the conditional expectation estimators are preferable. Under the assumption of a half normal distribution for u_i and normal distribution for v_i, the conditional mean of u , given (v - u) is

$$E(u/v-u)=\int_{-\infty}^{0} u.f(u/v-u)du \qquad (4.20)$$

$$\text{where; } f(u/v-u) = \frac{f(u, v-u)}{f(v-u)}$$

The density function of u, given (u - v) can be written using the density function of u_i and v_i given in equation (4.8) and (4.9), respectively.

$$f(u/v-u) = \sigma_u\sigma_v/2\sigma.\exp\{-\sigma^2/2\sigma_u^2\sigma_v^2\ (u + \epsilon_i\sigma_u^2/\sigma^2)\}1/(1-F) \qquad (4.21)$$

---

[6] In determinining the conditional expectation of u_i Jondrow et al. (1982) assumed u_i is non negative and it may take values of either zero or greater than zero and ϵ_i was assumed to be equal to $v_i - u_i$. The stochastic frontier production function model of Aigner et al. (1977) outlined in Chapter 4 assumes $\epsilon_i = u_i + v_i$ and

$u_i \leq 0$

However, it is easily seen that both of these specifications are identical.

where $\epsilon = v - u$ and F(.) is a standard normal distribution function. Solution of (4.20) yields conditional expectation (E(u/v-u)) of u_i, given $v_i - u_i$. Hence, the E(u/v - u), the conditional mean of u_i, given $(v_i - u_i)$[7] with the parameterization $\gamma = \sigma_u^2/\sigma^2$ is

$$E(u/v-u) = \sigma_v\sigma_u/\sigma\{f(.)/[1-F(.)] - \epsilon_i/\sigma.\sqrt{\gamma/(1-\gamma)}\} \qquad (4.22)$$

where f(.) is the standard normal density function and both the F(.) and f(.) are evaluated at

$\epsilon_i/\sigma\sqrt{\gamma/(1-\gamma)}$.

The individual estimates of conditional mean, u_i are obtained by substituting the corresponding value for ϵ_i. This conditional mean of u_i, given by E(u/v-u) can be used as a point estimator of u_i. Now farm specific technical efficiency can be calculated by taking the antilogs of negative of u_i's (by evaluating the ratio $1/e^{u_i}$) as shown in section 4.4.2.

4.4.5 Factors Affecting Technical Efficiency

Socio-economic and institutional factors identified in the hypothetical production model, given in Figure 3-1,are hypothesized to cause differences in the measured technical efficiency betwen farms. A linear regression model is fitted to explain the empirical relationships that exists between different levels of technical efficiency and these factors. The model is presented, along with results of OLS regression, in Chapter 5.

---

[7] For a proof, see Jondrow et al., 1982)

CHAPTER 5

RESULTS AND DISCUSSION

5.1 Introduction

The present chapter deals with the estimation procedures and results from estimation of farm specific technical efficiency. It also examines socio-economic factors that are responsible for variations in individual efficiencies at the farm level between individual farms. Estimates of parameters of the production function specified in section 4.2.6 of Chapter 4 are obtained through OLS regression procedure and are discussed in section 5.2. The procedure for obtaining estimates of the parameters of frontier production function using OLS estimates as lower bound values and the fitted frontier is discussed in section 5.3. Analysis of technical efficiency involves the calculation of mean technical efficiency for the population and calculation of farm specific technical efficiency for individual observations in the sample. Farm specific technical efficiency values presented in section 5.4.4 are then used in section 5.5 to explore empirical relationships between efficiency levels and socio-economic variables.

5.2 Average Production Function

5.2.1 Selection of Variables

An initial selection of variables to be entered into production model was made in Chapter 4. Maddala (1977, pp. 124-127) discusses five procedures developed by statisticians to add or delete variables systematically.[1] According to him all these are mechanical procedures

---

[1] These are listed as (a) all possible regressions, (b) a backward elimination or step down procedure, (c) a forward selection or step up procedure, (d) stepwise regression and (e) optimum regression. He also discusses drawbacks of these different procedures.

to some extent and liable to be misused. In this study the procedure of selecting variables was mainly guided by our hypothetical model of production discussed in Chapter 3. The process started with a simple model comprising essential inputs to which were gradually added new variables at successive stages to give more robustness to the model. To find the relationship between fertilizer and farm paddy output two sets of alternative variables were used: fertilizer cost and nutrient quantities. Inclusion of quantity of Nitrogen as a variable was found to give a better fit in terms of adusted $\bar{R}^2$ than using fertilizer cost. Therefore, the nitrogen variable was retained to represent the effect of fertilizer. The other nutrients, P_2O_5 and K_2O were found to be insignificant. The final model was arrived at after careful examination of signs and magnitudes of coefficients for their stability at each stage. Coefficients of all the variables except pesticide costs, dummy variables for soil fertility levels and all 'mixed dummy' variables were found to be significant, with expected signs and acceptable magnitudes and thus contributed positively to the adjusted $\bar{R}^2$ estimate. The stability in magnitudes and signs of coefficients was maintained at every stage of addition or deletion of variables. Both land preparation labour and power variables were found to be significant and the correlation coefficient between them was only -0.33. Since land preparation labour variable included number of activities most of which used labour only the correlation between this and power variable was low as was expected (Chapter 4). Inclusion of power variable to the model at a last step in a stepwise regression was not found to affect the stability of coefficients already included in the model and in addition, positively contributed to the adjusted $\bar{R}^2$. The shift dummy for irrigation was found to be significant with a positive sign. This implies an upward shift in the production function when irrigation is provided. So far no effort was made to verify whether the shift in production function is Hicks neutral or non neutral. A Hicks non neutral shift in a production function occurs when the slope coefficients change as a result of irrigation. This was studied using slope dummies in relation to all the quantity input variables and the method of establishment dummy. This is also a way of studying the interaction of irrigation with other explanatory variables. It is reasonable to expect some meaningful effects of soil fertility and drainage when irrigation is available, so two more differential dummies were included for interactions.[2]

Slope dummies were included in the model but most were found to be insignificant. Irrigation slope dummy with herbicide cost and the differential dummy with fertile soils, D_{3*8} were found to be significant with negative and positive coefficients respectively. The negative sign of the first of these two new variables implies that the slope coefficients of the herbicide cost variable for irrigated and rainfed areas are significantly different in magnitude. Thus the response to investment in herbicides was greater in rainfed areas when compared to irrigated areas. Slope dummies for land and power variables were also found to be significant. However, these two slope dummy variables were not included in the final model for two reasons. First, their presence in the model was found to create problems of multicollinearity which often occur when many slope dummy variables are introduced. When these two terms are present the irrigation shift dummy variable becomes insignificant with a negative coefficient. Second, the irrigation slope dummy with the land variable had a negative sign, implying land in irrigated areas is less productive than land in rainfed areas. This does not make any sense since irrigation is a land augmenting technology. In addition, there are no agronomic or economic reasons to hypothesize the slope coefficients of the power variable will differ between irrigated and rainfed areas. Thus the exclusion of both the interaction terms with land and power was found to restore stability, and the irrigation dummy became significant. The empirical model finally derived is outlined below.

---

[2] The values for differential dummy variables are constructed by multiplying respective values of the first dummy variable by that of the second. For instance, the soil fertility- irrigation differential dummy can be constructed as $D_{3,8} = D_3{*}D_8$.

5.2.2 Empirical Average Production Function

$$\begin{aligned} \ln Q_i = \ln \alpha - \theta_1 D_1 + \theta_2 D_8 + \theta_3 D_{3,8} \\ + \beta_1 \ln X_1 + \beta_2 \ln X_2 + \beta_3 \ln X_3 + \beta_4 X_4 \\ + \beta_5 X_6 + \beta_6 X_{10} - \beta_7 D_8 X_{10} \\ + \beta_8 X_{11} + \epsilon_i \end{aligned} \tag{5.1}$$

Where D_1 = method of establishment dummy $D_1 = 1$ for broadcasting, $D_2 = 1$ for transplanting and $D_1=D_2=0$ for farms adopted both the methods.

D_8 = irrigation dummy, $D_8 = 1$ for irrigated and $D_8 = 0$ for rainfed.

$D_{3,8}$= differential dummy for irrigation and and soil fertility interaction, $D_{3,8} = 1$ for very good or good soil in irrigated areas and $D_{3,8} = 0$ for other combinations.

X_1 = land area in hectare

X_2 = land preparation labour in mandays

X_3 = quantity of seeds in kilogram

X_4 = manual weeding labour in mandays

X_6 = quantity of nitrogen in kilograms

X_{10} = cost of herbicides in Rupees

D_8X_{10}= differential slope dummy for the interaction between irrigation and cost of herbicides

X_{11} = bullock power in number of hours

Results of OLS estimation of the empirical model (5.1) are given in Table 5-1. All the variables in the empirical model have significant coefficients with expected signs. The variables of seed, nitrogen, herbicide cost and the method of establishment dummy were highly significant at the 0.005 level. Transplanting is a better method of crop establishment than the traditional method of broadcasting. Transplanting enables the farmer to maintain an optimal plant density and at the same time helps him to control weeds more conveniently. The negative sign of the method of establishment dummy indicates a transplanted paddy crop gave a higher output. Statistical significance of differential slope dummy for the interaction of irrigation with herbicide cost implies that the coefficients of herbicides in rainfed and irrigated areas were significantly different (Johnston, 1984)[3] We have to be very cautious in interpreting the effect of herbicides. This is because chemical herbicides do not increase yields directly. They increase yield indirectly by eliminating the weed competition. Farmers in irrigated areas have lesser weed problems than those in rainfed areas since they can control weeds by flooding the field. For farmers in rainfed areas this is not possible, and because of inadequate water supply, paddy fields become weedy. Since manual weeding becomes very costly under such circumstances farmers tend to undertake chemical weeding.

The magnitudes of estimated values of coefficients are within an acceptable range. At this stage, output elasticities were not calculated using OLS estimates. It is better to use Maximum Likelihood Estimates of coefficients of the frontier production function to calculate these since the frontier production function corresponds to the theoretical notion of a production function. This is considered in the discussion of frontier production functions in section 5.3.2.

---

[3] This can also be seen by calculating the standard error of the coefficient of herbicide cost for irrigated areas. From the above empirical production function (5.1) it is clear that the coefficients of herbicide cost in irrigated and rainfed areas are $\beta_6 - \beta_7$ and β_6, respectively. The standard error of the estimate of $\beta_6 - \beta_7$ was calculated using the formula given by Gujarati (1970, p. 14) which defines

$$s.e\ (\beta_6 - \beta_7) = [\mathrm{Var}(\beta_6) + \mathrm{Var}(\beta_7) - 2\mathrm{Cov}(\beta_6, \beta_7)]^{1/2}$$

The standard error was found to be 0.0010 which indicates that the coefficient $\beta_6 - \beta_7$ is not significant and therefore the coefficients of this variable was significantly differnt in irrigated and rainfed areas.

5.3 Frontier Production Function

5.3.1 Estimation Procedure

As explained earlier the Newton-Raphson iterative method was used to obtain the Maximum Likelihood Estimates of the frontier model. The computer programme given in Appendix F was used for this purpose. OLS estimates given in Table 5-1 were used as initial values for the iteration process. The residual mean square for the OLS regression was taken as the initial estimate for the variance, σ^2. A full range of values starting from 1 to 0 were assumed for the variance ratio γ to make sure that true ML estimates of the frontier model were obtained. It was found that, for the sample studied, whatever the value assumed for γ, the iterative procedure converged to the same solution with stability in parameters. Thus we are satisfied that the estimates are the true ML estimates. In order to overcome the problem of successsive estimators 'overshooting' the true values of the parameters, the programme was modified to allow for smaller changes in parameter estimates at each iteration. The modification was to change the parameter estimates at each iteration by one tenth of that defined by the Newton-Raphson technique. Thus the value of α in equation 4.17 in Chapter 4 was made equal to 0.1 at each iteration. The parameter estimates corresponding to the lowest negative values of the log likelihood function were selected as the Maximum Likelihood estimates for the sample of observations studied. The corresponding value for the log likelihood function was -35.75.

5.3.2 Empirical Frontier Production Function

$$\begin{aligned} \ln Q_i = {} & \ln \alpha - \theta_1 D_1 + \theta_2 D_8 + \theta_3 D_{3,8} \\ & + \beta_1 \ln X_1 + \beta_2 \ln X_2 + \beta_3 \ln X_3 \\ & + \beta_4 X_4 + \beta_5 X_6 + \beta_6 X_{10} \\ & - \beta_7 D_8 X_{10} + \beta_8 X_{11} + u_i + v_i \end{aligned} \tag{5.2}$$

All the terms in equation (5.2) have same definitions as in the empirical average production function in equation (5.1) except the last two disturbance terms, u_i and v_i. As already defined, the disturbance term u_i stands for technical inefficiency and is assumed to have a truncated normal distribution whereas the disturbance term v_i explains the variability due to stochastic elements and has a full normal distribution. Maximum Likelihood Estimates of the parameters of the empirical frontier production function model (5.2) are presented in Table 5-1 along with the OLS estimates of the average production function.

Table 5-1: Estimates of Parameters of Average Production Function and Stochastic Frontier Production Function

Coefficient	OLS Estimates of Av. Production Function	ML Estimates of Stochastic Production Frontier
Constant	-0.3780** (0.2172)	0.0163 (0.1874)
D_8 (Irrigation)	0.1945* (0.0776)	0.1563** (0.0740)
D_1 (method of estab)	-0.2655* (0.0820)	-0.2482* (.0.0720)
$D_{8,3}$ (irrig*soil)	0.1169*** (0.0839)	0.0872 (0.0740)
$\ln x_1$ (land)	0.3294* (0.0742)	0.3327* (0.0636)
$\ln X_2$ (LP Labour)	0.0984** (0.0589)	0.1156* (0.0300)
$\ln X_3$ (seeds)	0.1735* (0.0653)	0.1653* (0.0300)
X_4 (weeding labour)	0.0059*** (0.0042)	0.0045*** (0.0030)
X_6 (nitrogen)	0.0026* (0.0009)	0.0026* (0.0009)
X_{10} (herbicides)	0.0032* (0.0011)	0.0026* (0.0009)
D_8 *X_{10} (irrig*herb)	-0.0030* (0.0011)	-0.0024* (0.0009)
X_{11} (bullock power)	0.0067** (0.0037)	0.0053** (0.0030)
Log Likelihood Function	-248.17	-35.75
R^2	0.6688	
$\bar{R}^2$	0.6498	
F	35.069	
σ^2	0.1449	0.2836
σ_u^2		0.2325
σ_v^2		0.0510
γ		0.8200 (0.0758)

Notes: values given within parenthesis are asymptotic standard errors

* significant at 1 percent level

** significant at 5 percent level

*** significant at 10 percent level

ML estimates of all the coefficients except for the interaction dummy for soil fertility and irrigation were found to be significant. Though this interaction term was not significant the difference between calculated t ratios of OLS and ML estimates was small. Since this interaction dummy was only marginally significant (at 10 percent level) with OLS estimates, its insignificance with MLE is quite possible. The OLS constant term was significantly different from natural log zero, whereas the ML estimate of the constant was not. Since the Antilog of natural log zero is equal to 1 this implies that the MLE constant is not significantly different from 1 whereas the OLS constant is significantly different. The Antilog of the ML constant estimate, 1.016, is obviously not different from 1. Hence it is clear that the ML intercept term has shifted upward; the shift was 56 percent. The magnitudes of the coefficients of explanatory variables have not changed appreciably. Similar results have been reported by Kalirajan (1979, 1981), Kalirajan and Flinn (1982) and Battese and Corra (1977). The ML variance estimate, σ^2 has become larger than the corresponding value of the OLS estimate. The interesting and important result was the high value of 0.82 for the variance ratio γ. This estimate was significantly different from zero and implies that 82 percent of the variation of farm output related to the stochastic frontier production function was due to technical inefficiency.

5.3.3 Output Elasticities of the Production Frontier

Output elasticities were calculated for each of the quantity input variables in the model and presented in Table 5-2. ML estimates of coefficients of land , seeds, and land preparation labour directly measure the output elasticity in relation to the respective inputs. ML estimates of coefficients of other inputs were used to calculate output elasticity values for these inputs. Output elasticities for these inputs were calculated at the arithmetic mean level of input application given in Table 5-2.

Table 5-2 shows that land is the most important variable with the highest output elasticity. A one percent increase in land area brings 0.30 percent increase in output. One percent increases in seeds and land preparation labour also contribute to increased output by 0.16 and 0.11 percent respectively. Nitrogen was found to be the important

Table 5-2: Mean Level of Input Application and Output Elasticities

Input	Unit	Mean Level of Input Use	Output Elasticity
Land	hectare	0.90	0.3327
Land prep.labour	manday	26.62	0.1156
Seeds	kilogram	44.00	0.1653
Weeding labour	manday	4.95	0.0223
Nitrogen	Kilogram	33.25	.0864
<u>Herbicide cost</u>			
-Irrig.	Rupee	23.67	0.0004
-Rainfed	Rupee	18.92	0.0491
Power	hours	16.10	0.0853

Note: The following formula was used to calculate output elasticities for non essential inputs given in the empirical production frontier.

$$\eta_i = \partial y/\partial x_i \bar{X}_i/\bar{Y} = \beta_i \bar{X}_i$$

where; $\partial y/\partial x_i = \beta_i \bar{Y}_i$

β_i are the ML estimates reported in Table 5-1 and $\bar{X}_i$ are arithmetic mean level of inputs.

purchased input, even though its output elasticity was slightly less than 0.1 percent. In general the output elasticities of different inputs reveal that the essential inputs like labour, seed and land still play an important role in contributing to farm output.

5.4 Technical Efficiency Analysis

5.4.1 Mean Technical Efficiency

The population mean of technical inefficiency related u_i disturbence term can be calculated using the formula

$$E(u_i)=\sigma_u\sqrt{2/\pi}$$

, where $E(u_i)$ measures the population mean of u_i and σ_u is the standard deviation of the u_i disturbance term. The values for σ_u can be calculated from σ_u^2 given in Table 5-1. Substituting this estimate gives a value of 0.38 for the population mean of u_i. Mean technical efficiency can be estimated as $1/e^{0.38}$ which is equal to 68 percent.

5.4.2 Farm Specific Technical Efficiency

Farm specific values of u_i disturbance term were calculated using the formula given in (4.22) of Chapter 4 which was derived by Jondrow et al. (1982) using the concept of conditional probability of u_i, given $u_i - v_i$. This formula yields values of u_i for individual observations and they may take values either zero or greater than zero ($u_i \geqslant 0$) as explained in section 4.4.3 of Chapter 4. A frequency distribution of u_i values is given in Table 5-3. This shows a wide range in u_i disturbance across farms from 0.07 to 1.66

Table 5-3: Frequency Distribution of Farm Specific Conditional Mean of u_i

Conditional Mean of u_i	No of Farms	% Reporting	Cumulative %
0.07 - 0.22	32	15.8	15.8
0.23 - 0.38	31	15.3	31.1
0.39 - 0.54	21	10.3	41.4
0.55 - 0.70	28	13.8	55.2
0.71 - 0.86	20	9.8	65.0
0.87 - 1.02	22	10.8	75.8
1.03 - 1.18	21	10.3	86.1
1.19 - 1.34	18	8.9	95.0
1.35 - 1.50	5	2.5	97.5
1.51 - 1.65	5	2.5	100.0
Total	203	100.0	

Source: Estimation

The distribution of u_i disturbance is skewed toward zero. About 65 percent of farms had values of u_i within the range of 0.07 to 0.86 and another 35 percent of farms had values of u_i within the range of 0.87 to 1.66 but with the same dispersion of 0.79.

The skewed distribution of the u_i disturbance term toward zero confirms that the u_i disturbance term follows fairly closely a half normal or truncated normal distribution. Hence, this behaviour of the u_i disturbance term is in conformity with our assumption of a half normal distribution which was made in the process of deriving the likelihood function corresponding to the estimated frontier. The density function for u_i given in equation (4.8) of Chapter 4 corresponds to this assumption and was combined with the density function for v_i given in equation (4.9) through the convolution formula to derive the density function of the composed error term, $f(u_i+v_i)$ from which the likelihood function for the dependent variable Y was derived. Therefore, we are satisfied with our estimation of the frontier production function.

Farm specific technical efficiency measures were calculated following the procedure given in section 4.4.2 of Chapter 4.

Table 5-4: Frequency Distribution of Farm Specific Technical Efficiency

Technical Efficiency	No of Farms	Percent Reporting	Cumulative Percentage
0.19 - 0.25	8	4.0	4.0
0.26 - 0.30	20	9.8	13.8
0.31 - 0.35	21	10.3	24.1
0.36 - 0.40	20	9.8	33.9
0.41 - 0.45	11	5.4	39.3
0.46 - 0.50	17	8.3	47.6
0.51 - 0.55	16	7.8	55.4
0.56 - 0.60	14	7.0	62.4
0.61 - 0.65	12	6.0	68.4
0.66 - 0.70	12	6.0	74.4
0.71 - 0.75	11	5.4	79.8
0.76 - 0.80	10	5.0	84.8
0.81 - 0.85	8	4.0	88.8
0.86 - 0.90	21	10.3	99.1
0.91 - 0.93	2	0.9	100.0
Total	203	100.0	

Source: Calculation

The frequency distribution of technical efficiency given in Table 5-4 shows a wide range (19 to 93 percent) of technical efficiency and about 47 percent of farms were within the efficiency rankings of 19 to 50 percent. Another 32 percent of farms were within the efficiency range of 51 to 75 percent.

The technical efficiency estimator used in this study compares the observed output adjusted for stochastic elements with the best practice output. Thus the technical inefficiency which is equal to $1 - 1/e^{u_i}$ measures the shortfall of output per unit output of the best practice technology. Average best practice farm output for the study area was 1.45 metric tons and, with a mean level of technical inefficiecy of 1 - 0.68 the average shortfall in output can be calculated as 0.46 metric tons. Average observed farm output adjusted for stochastic variations was 0.98 metric tons. This indicates that farm output can be increased by 47 percent from the present level by improving technical efficiency of farmers in the study area.

Therefore, these results indicate that the level of physical performance of many rice farms in the study area were well below the frontier levels and there is great scope for improving individual farm performance and increasing the aggregate rice output substantially by appropriate policy measures.

5.4.3 Factors Causing Variations in Farm Specific Technical Efficiency

Farm specific technical efficiency was hypothesized to be influenced by a number of socio-economic variables. Therefore a test was applied next to determine the existence of empirical relationships between these hypothesized variables and measured farm specific technical inefficiency values. The individual technical efficiency values were regressed against these socio-economic variables. The empirical model of this relationship can be outlined as follows, and the results of OLS regression are presented in Table 5-5.

$$T_i=a_0+\sum_{j=0}^{4} a_j p_j+\sum_{k=1}^{2} b_k D_k+g_i \tag{5.3}$$

Where T_i = technical efficiency index of the ith farmer

p_{1i} = technical knowledge score, ranging from 0 to 8

p_{2i} = number of years of formal education

p_{3i} = number of years of farming experience

p_{4i} = off farm income, Rs/annum

D_{1i} = dummy variable for land tenure
D_1=1 for owner cultivation and
D_1=0 for tenant cultivator

D_{2i} = dummy variable for farming status
D_2=1 for full time farmer

D_2=0 for part time farmer

g_i = error term with normal properties

Values for individual observations of the variable technical knowledge were constructed using information collected on farmers' awareness of the recommended quantities of purchased inputs: fertilizer, pesticides, herbicides and fungicides and the timing of application. In total, eight questions were asked of farmers: two questions per input, one whether they knew the recommended quantity and the other on recommended timing of application. A score of 1 was given for all affirmative answers, and zero was given for negative answers. The technical knowledge score for a farmer was constructed by simply adding these scores. Thus the highest score a farmer could attain was 8 and the lowest was 0. The off farm income variable was the amount of money earned by the farmer during the 1983/84 cultivation year through other farm and non farm work.

OLS regression results of the model (5.3), given in Table 5-5, show that all variables except land tenure and part time / full time dummy were significant and had the expected signs. Of the significant variables, technical knowledge and formal education were significant at the 1 percent level. Modern new improved varieties are management intensive and require use of purchased inputs such as fertilizers, herbicides and pesticides. These inputs need to be applied at the right time in the recommended quantities to achieve the highest efficiency. Therefore, this was an important variable in explaining efficiency differentials. OLS regression revealed that those farmers who possessed more technical knowledge were able to achieve higher levels of technical efficiency. Education also contributed to technical efficiency by improving a farmer's management skills and understanding of the new rice technology package. It equips farmers with skills of reading and numeracy and educated farmers are therefore better able to understand printed materials about various farm recommendations, and agricultural programmes on radio, and to calculate costs and returns. The positive sign of the education variable in our regression indicated that the more educated the farmer , the more efficient he was. Multicollinearity between farmers' education levels and technical

Table 5-5: Results of OLS Regression on Variables, Technical Efficiency Values and Marginal $\bar{R}^2$ values

Coefficient of	Estimate	Marginal R^2
Constant	0.2588* (0.0496)	
Technical Knowledge	0.0285* (0.0285)	0.1866
Education	0.0169* (0.0042)	0.0437
Experience	0.0010*** (0.0007)	0.0060
Full Time/Part Time	0.0267 (0.0267)	0.0014
Land Tenure	0.0321* (0.0259)	0.0007
Off-Farm Income	-0.000006*** (0.000004)	0.0038
R^2	0.2647	
$\bar{R}^2$	0.2422	
F	11.7570	

Source: Regression Analysis

Notes: figures given in parentheses are the standard errors of estimates

* significant at 1 percent level

*** significant at 10 percent level

knowledge can not be ruled out. However, the correlation coefficient between these two variables was -0.13 and the regression results were not found to be seriously affected by the presence of these two variables.

The insignificance of land tenure dummy indicated that tenant farmers were more or less as efficient as owner cultivators and is in contrast to the findings on higher level of productivity of owner cultivators compared to tenants in Hambantota district of Sri Lanka (Izumi and Ranatunga, 1971, cited in Lipton, 1978).

The regression results also revealed that farm experience contributed to a higher level of efficiency. Useful farming skills are also acquired through experience. There is no substitute for experience in acquiring skills of some farming activities e.g. preparing land to a fine tilth, taking precautionary actions against pest and disease outbreaks. The coefficient of off-farm income was also found to be significant with negative sign. The survey revealed that a considerable number of farmers engaged in subsidiary income generating activities (Chapter 2) to supplement farm income. The negative sign of the coefficient of this variable indicates that as farmers earned more money from non farm or other farm activities he became less efficient. Off-farm income variable can be considered as a proxy for the level of importance a farmer places on his farming activities. More income earned from off-farm activities means the farmer had placed less importance on own farm activities and as a result, he may not have adopted the best practice. Multicollinearity can also exist between off-farm income and part time / full time dummy variables. However, regression results were not found to be seriously affected by inclusion of these variables and the coefficient of correlation between them was only 0.15.

The regression model explained only 26 percent of the variations observed in technical efficiency. The relative contribution of each factor was determined by comparing the marginal $\bar{R}^2$ values obtained, at each successive stage of adding a new variable to the model. The marginal $\bar{R}^2$ values given in Table 5-5 indicate that farmers' technical knowledge explained about 18 percent of the variation in technical efficiency and education accounted for about 4 percent. The low R^2 for the regression points to the substantial part of the variation in technical efficiency that is still unexplained. Possessing knowledge of various technologies does not guarantee higher levels of efficiency. What is also important is to determine whether farmers have translated this knowledge into practice. Thus, in addition to technical knowledge, other aspects of the technology and whether farmers have really practised them should be studied. Constraints on input availability may be one reason for not applying inputs at the recommended quantities and at the right time. These factors can be expected to further explain technical efficiency differences considerably. However, due to time constraints this measurement was not attempted in this thesis.

CHAPTER 6

SUMMARY AND CONCLUSIONS

Efficiency is an important concept in economics. However, until recently, the general tendency was to recognize it only as allocative efficiency. Achieving the highest level of allocative efficiency had been identified as the optimization problem in most economic models. Allocative efficiency deals with allocating scarce resources available to a farm in an economically efficient manner. Another kind of efficiency is concerned with obtaining the highest possible output from a given combination of inputs for a given technology and is called technical efficiency. This is a farm specific problem over which a farm concerned has considerable control. However, technical efficiency did received little attention in economic theory, which until recently identified it as a purely technical problem rather than an economic problem (Henderson and Quandt, 1958). Consequently most empirical work on the economic performance of farmers reached the conclusion that farmers were generally efficient, thereby lending support to Schultz's (1964) efficient but poor hypothesis. In most such studies this judgement was based on allocative efficiency, at the same time presupposing perfect technical efficiency. This neglect of technical efficiency in traditional theory of firm implied that policy makers were not properly guided. Policy makers make decisions on development strategies based on their perceptions about farm level performance which are influenced by received theories. The efficient but poor hypothesis led most of them to emphasize long term major investments such as large irrigation schemes and new technologies rather than agricultural extension and farmer education programmes that are much cheaper and ways to achieve short run agricultural growth.

Varied levels of technical efficiency can be observed in a farming community because of the slow adjustment process which occurs with technical change. In this domain there is an important difference for a particular technology between 'best practice' and the average practice. Agricultural growth and economic growth in general require improving individual farms to the best practice level of technology application. The factors that cause a farm to use a best practice technology rather than an average practice technology are closely related to those factors which determine the agricultural growth rate.

In Sri Lanka there have been remarkable achievements in the development and spread of a HYV technology package for rice during the last two decades and a half. Nevertheless, it has been consistently found that farm level production was still well below the experiment station levels and the levels of production that could be achieved on the farm with research level management. Major irrigation and land development projects such as the Mahaweli Ganga Development Programme, that are designed to give major impetus to further development of the rice based subsistence agricultural sector are under way. In this context it is very important to upgrade farm level physical performance as high as possible to enable the stated objectives of these development programmes to be achieved. Determination of the factors that cause some farms to use the best practice technology rather than the average will help policy makers choose appropriate policy measures for the already established rice growing areas, and in addition, will help to guide policy in planning new development projects more effectively.

Performances of individual farms in a farming community using the same technology can be below the best practice level for three reasons: pure statistical disturbance, technical inefficiency and allocative efficiency. The objectives of this thesis were first, to examine farm specific technical efficiency across a rice farming community in Sri Lanka and second, to identify factors causing differential levels of technical efficiency.

The methodology used in the thesis was based on the concept of the frontier production function introduced by Farrell (1957). A frontier production function which could be estimated using information collected from a sample of farmers corresponds to the concept of the best practice technology introduced by Salter (1966) and also to the theoretical notion of a production function in the Neo-classical sense.

The model used was the stochastic frontier production function developed by Aigner et al. (1977) and Meeusen and Broek (1977). The stochastic frontier production function provides a better estimating tool than the earlier deterministic frontier production models used by Aigner and Chu (1968) , Timmer (1971) and Mijindadi and Norman (1984) as it considers random elements, and its estimation yields parameters with desired statistical properties. It has two independent disturbance terms: u_i, for technical efficiency and v_i for random statistical disturbance. Farm specific technical inefficiency within the specification of a stochastic frontier production function can be modelled in different ways by specifying a distribution for the technical inefficiency term, u_i. The particular variant of the stochastic frontier production function used in this thesis assumed a truncated normal or half normal distribution for technical inefficiency. There was no method of measuring farm specific technical inefficiency values related to a stochastic frontier production function until recently, and researchers who applied this model were only able to calculate an average technical efficiency measure for the farm population they studied. Recent improvements made to this methodology by Jondrow et al (1982) in estimating farm specific technical efficiency values based on the theory of conditional probability, were used in this study.

The data used were collected from a sample of 203 rice farmers in Kurunegala district in Sri Lanka. Information pertaining to the Maha 1983/84 season was used. The whole sample included 100 farmers with irrigated conditions (75 and 25 in major and minor irrigation conditions, respectively) and 103 farmers with rainfed conditions.

An average production function was fitted to describe the average production technology in the area. The empirical production function estimated had a modified Cobb-Douglas form in which essential inputs of land, land preparation labour and seed were specified in familiar multiplicative form and nonessential inputs of weeding labour, nitrogen quantity, herbicide cost and farm power were incorporated in exponential form. This particular variant of the Cobb-Douglas form was used first, to circumvent the problem of zero level of application of non essential inputs and second, to make a distinction between essential and nonessential inputs. Dummy variables were used for irrigation and method of establishment. Intercept differential dummies were tried for these variables, and irrigation was allowed to interact with other explanatory variables. All of these variables and differential slope dummies for the interaction of irrigation with herbicide cost and a differential intercept dummy for the interaction of irrigation with fertile soil were found to be significant with expected signs.

All the essential and nonessential quantity inputs were found to contribute positively to farm rice output. Provision of irrigation shifted the production function upward, and farms which adopted transplanting operated on a higher level of production function than farms which broadcast paddy. The effect of soil fertility was pronounced when the farms with fertile soils were located in irrigated areas. Herbicides had a better response in rainfed than in irrigated areas. This was because rainfed areas became very weedy if rains arrived late and manual weeding was prohibitively expensive, whereas farms in irrigated areas had less of a weed problem.

The specification arrived at the average technology was embodied in the stochastic frontier production function estimated through Maximum Likelihood methods. The Newton-Raphson iterative technique, with OLS estimates of the average production function as lower bound values, was used to obtain parameters of the stochastic frontier production function. The estimated frontier had coefficients of inputs that were similar to OLS estimates except for the intercept term. The intercept of the stochastic frontier production function had shifted upward significantly.

A statistically significant value of 0.82 was found for the variance ratio which indicated that 82 percent of the variation of farm rice output related to the frontier was due to technical inefficiency. Mean level of technical efficiency was found to be 0.68. Farm specific technical efficiency values ranged from 19 to 93 percent. Nearly 47 percent of the sampled farmers were found to operate within 19 to 50 percent level of technical efficiency. This implies that there were a considerable number of farmers operating below the level of best practice technology and the shortfall in output by not adopting the best practice was substantial and it was found that farm rice output can be increased by 47 percent by improving technical efficiency. Therefore, if these farmers can be helped to adopt the best practices, a substantial increase in total rice output could be achieved. In addition, the assumption of a half normal distribution for modelling technical inefficiency was found to be satisfactory for the sample studied since farm specific u_i disturbance were found to be skewed toward zero.

The factors causing technical efficiency variations were studied using a linear regression model. The measured farm specific technical efficiency values were regressed against farmer technical knowledge, number of years of formal education, number of years of farm experience, off farm income, full time or part time farming and land tenure. All these explanatory variables, except land tenure and full time/part time dummy were found to be significant. Of these, farmers' technical knowledge was found to be the most important variable, explaining about 18 percent of the variation in technical inefficiency and positively contributing to technical efficiency. Similar results were obtained by Shapiro and Muller (1977) using a more or less similar information variable. Therefore we may conclude, assuming technology as a constant between farms and assuming simple maximizing behaviour, that the farms with higher levels of technical efficiency possessed more technical knowledge than farms with low levels of technical efficiency. Formal education also was found to significantly contribute to higher levels of technical efficiency: the contribution being four percent of the variation in technical efficiency. Though we may generally conclude that the more educated the farmer was the more efficient he was, findings on a threshold number of years of education would have been more useful for practical policy purposes (Lockhead et al., 1980). This is important since agricultural extension may not be of much use if most farmers are already educated at higher levels, since education and extension act as substitutes (Moock, 1981).

Tenant farmers and share croppers were found to be more or less efficient as owner cultivators. This is contrary to the findings on higher productivity of owner cultivators compared to tenants in the Hambantota district of Sri Lanka (Izumi and Ranatunga cited in Lipton, 1978). Farming experience and off-farm income were also found to be significant, but their contributions to variation in technical inefficiency were very small. Thus we may conclude from this study that technical knowledge and formal education were the important explanatory variables determining various levels of technical efficiency in the sample of farmers studied. However, the unexplained part of variation in technical efficiency was substantial. A considerable portion of this unexplained variation may be explained by the application aspect of the technical knowledge which could not be studied here due to a time constraint.

BIBLIOGRAPHY

ABDUL HAMEED, N.D.(ed.), 1977. Rice Revolution in Sri Lanka, United Nations Research Institute for Social Development (UNRISD), Geneva.

AHAMED, I., 1973. 'Green Revolution with or without Tractors: The Case of Sri Lanka', Marga Quarterly Journal, Vol.2, no.1, pp. 65-74.

AIGNER,D.J. and CHU, S.F., 1968. 'On Estimating the Industry Production Function', American Economic Review, Vol.58. no.4, pp.826-39.

AIGNER, D.J., LOVELL, C.A.K. and SCHMIDT, P., 1977. 'Formulation and Estimation of Stochastic Frontier Production Function Models',Journal of Econometrics, Vol.6, no. , pp.21-37.

AMERASINGHE, N., 1977. 'The Minipe Colonization Scheme in N.D. Abdul Hameed (ed.), 1977. Rice Revolution in Sri Lanka, UNRISD, Geneva, pp.75-115.

ARTI, 1981. Kurunegala District Rural Development Project, Analysis of the Preproject Situation, Research Study No.45, Agrarian Research and Training Institute, Colombo.

BACHMAN, K.L. and PAULINO, L.A., 1979. Rapid Food Production Growth in Selected Developing Countries; A Comparative Analysis of Underlying Trends 1961-76, Research Report 11, The International Food Policy Research Institute, Washington, D.C.

BARD, Y., 1974. Nonlinear Parameter Estimation, Academic Press, New York.

BARDHAN, P.K., 1973. 'Size Productivity and Returns to Scale: An Analysis of Farm-level data in Indian Agriculture', Journal of Political Economy, Vol.81, no.6, pp.1370-86.

BARKER, R., 1979. 'Adoption and Production Impacts of the New Rice Technology - the Yield Constraints Problem', in IRRI, 1979. Farm Level Constraints to High Rice Yields in Asia 1974-77, International Rice Research Institute, Los Banos, The Philippines, p.1-26.

---------, and HERDT, R.W., 1979. Rainfed Lowland Rice as a Research Priority - An Economist View, Research Paper Series No.26, The International Rice Research Institute, Los Banos, The Philippines.

---------, and PAL, T.K., 1979. Barriers to Increased Rice Production in Eastern India, Research Paper Series No. 25, The International Rice Research Institute, Los Banos, The Philippines.

BATTESE, G.E. and CORRA, G.S., 1977. 'Estimation of a Production Frontier Model: with Application to the Pastoral Zone of Eastern Australia', Australian Journal of Agricultural Economics, Vol.21, no.3, pp.169-79.

BROWN L., 1968. 'Seeds of Change, The Agricultural Revolution in Asia', Foreign Affairs, Vol.4, pp.688-698.

BYERS, T.J., 1972. 'The Dialectics of India's Green Revolution', South Asian Review, Vol.5, pp.99-116.

CHOW, G.C., 1960. 'Test of Equality between Sets of Coefficients in Two Linear Regressions', Econometrica, Vol.28, no.3, pp.591-605.

CORRA, G.S., 1976. Statistical Models for Frontiers; with Application to the Pastoral Zone of Eastern Australia, Unpublished B.Ag.Ec. thesis, University of New England, Armidale.

CRAMER, J.S., 1969, Empirical Econometrics, North Holland Publishing Company, London.

DALRYMPLE, D.G., 1974. Development and Spread of High Yielding Varieties of Wheat and Rice in the Less Developed Nations, Foreign Agricultural Economics Report No.95, The United States Department of Agriculture, Washington, D.C.

De DATTA, S.K., GOMAS, K.A., HERDT, R.W. and BARKER, R., 1978. A Hand Book on the Methodology for an Integrated Experiment Survey on Rice Yields Constraints, International Rice Research Institute, Los Banos, The Philippines.

DIAS, H.D., 1977. 'Selective Adoption as a Strategy for Agricultural Development: Lessons from Adoption in South Eastern Sri Lanka, in B.H. Farmer (ed.), 1977. Green Revolution? Technology in Rice Growing Areas of Tamil Nadu and Sri Lanka, MacMillan, London, pp.54-84.

FARRELL, M.J., 1957. 'The Measurement of Productive Efficiency', Journal of the Royal Statistical Society, Series A, Part 3, Vol. 120, pp.253-81.

FARMER, B.H. (ed.), 1977. Green Revolution ? Technology and Change in Rice Growing Areas of Tamil Nadu and Sri Lanka, McMillan, London.

---------, 1979. 'The Green Revolution in South Asian Rice Fields', Journal of Development Studies, Vol.15, no.4, pp.304-19.

FERGUSON, C.E., 1966., Microeconomic Theory, Homewood, Irwin.

FLINN, J.C., 1980. Some Considerations in Yield Gap Research, Agricultural Economics Department, Paper 80-01, International Rice Research Institute, Los Banos, The Philippines,

FORSUND, R.R. and HJALMARSSON, L., 1974. 'On the Measurement of Productive Efficiency', Swedish Journal of Economics, Vol.76, no.2 , pp.141-53.

---------, LOVELL, C.A.K. and SCHMIDT, P., 1980. 'A Survey of Frontier Production Functions and their Relationship to Efficiency Measurements', Journal of Econometrics, Vol.13, pp.5-25.

FRANKEL, F.R., 1971. India's Green Revolution: Economic Gains and Political Costs, Princeton University Press, Princeton.

GOTSCH, C.H., 1972. 'Technical Change and the Distribution of Income in rural Areas', American Journal of Agricultural Economics, Vol.54, no.2, pp.324-41.

GRIFFIN, K., 1974, The Political Economy of Agrarian Change, An Essay on the Green Revolution, First Edition, MacMillan, London.

GUJARATI, D., 1970. 'Use of Dummy Variables in Testing for Equality between Sets of Coefficients in Linear Regressions: A Generalization', The American Statistician, Vol.24, no.5, pp.18-22.

GUNASENA, H.P.M., JINADASA, A.P, JOGARATNAM, T. and PREMAKUMAR, V., 1977. 'Giritale, Sri Lanka, 1975-76', in IRRI, 1977. Constraints to High Yields on Asian Rice Farms, An interim Report, International Rice Research Institute, Los Banos, The Philippines, pp.157-176.

HALTER, A.N. and CARTER, H.O., 1959. 'A Note on Transcendental Production Function', Journal of Farm Economics, Vol.39, no.4, pp.966-74.

HARGROVE, T.R., 1979. Diffusion and the Adoption of Genetic Materials Among Rice Breeding Progammes in Asia, Research Paper Series No.18, The International Rice Research Institute, Los Banos, The Philippines.

HARRIS, J., 1977. 'Pahalagama: A Case Study of Agricultural Change in Frontier Environment', in B.H. Farmer (ed.), 1977. Green Revolution ? Technology and Change in Rice Growing Areas of Tamil Nadu and Sri Lanka, McMillan, London, pp.143-54.

HARVILLE, D.A., 1977. 'Maximum Likelihood Approaches to Variance Component Estimation and to Related Problems', Journal of the American Statistical Association,Vol.72, pp.320-38.

HATI, A.K. and RUDRA, A., 1973. 'Calculation of Efficiency Indices', Economics and Political Weekly, Vol.8, pp.17-20.

HAYAMI, Y. and RUTTAN, V.W., 1971. Agricultural Development: An International Perspective, The John Hopkins Press, London.

HEADY, E.O. and DILLON, J.L., 1961. Agricultural Production Functions, Iowa State University Press, Ames, Iowa.

HENDERSON, J.M. and QUANDT, R.E., 1958. Microeconomic Theory: A Mathematical Approach, McGraw-Hill, New York.

HERDT, R.W., 1979. 'An Overview of the Constraints Project Results', in IRRI, 1979. Farm Level Constraints to High Rice Yields in Asia 1974-77, International Rice Research Institute, Los Banos, The Philippines, pp.395-411.

----------, and MANDAC, A.M., 1981. 'Modern Technology and Economic Efficiency of Philippine Rice Farmers', Economic Development and Cultural Change, Vol.29, no.2, pp.375-400.

THE INTERNATIONAL LABOUR OFFICE, 1971. Matching Employment Opportunities and Expectation - A Programme of Action for Ceylon, report, The International Labour Office, Geneva.

THE INTERNATIONAL RICE RESEARCH INSTITUTE, 1977. Constraints to High yields on Asian Rice Farms, An Interim Report, International Rice Research Institute, Los Banos, The Philippines.

---------, 1979. Farm Level Constraints to High Rice Yields in Asia, 1974-77, International Rice Research Institute, Los Banos, The Philippines.

IZUMI, K. and RANATUNGE, A.S., 1973. 'Environmental and Social Constraints on Paddy Production under Existing Condition in Sri Lanka: A Case Study of Hambantota District', Seminar Paper No.45 in ARTI-IDS, 1973. Seminar on Economic and Social Implications of HYVs: Papers and Proceedings (mimeo), Agrarian Research and Training Institute, Colombo.

JOGARATNAM, T., DIAS, T.N.S. and JAYAWARDENA, A., 1979. 'Constraints to High Rice Yields in Sri Lanka in IRRI, 1979. Constraints to High Yields on Asian Farms, An Interim Report, International Rice Research Institute, Los Banos, The Philippines, pp.323-348.

JOHL, S.S., 1974. 'Gains of the Green Revolution: How they have been Shared in Punjab', Journal of Development Studies, Vol.11, pp.178-189.

JOHNSON, G.L., 1964. 'A Note on Non Conventional Inputs and Conventional Production Function', in C. Eicher and Witt (eds.), 1964. Agriculture in Economic Development, Third edition, McGraw-Hill, New York.

JOHNSTON, J., 1984. Econometric Methods, McGraw-Hill, Singapore.

JONDROW, J., LOVELL, C.A.K., MATEROV, I.S. and SCHMIDT, P., 1982. 'On the Estimation of Technical Inefficiency in the Stochastic Frontier Production Function Model', Journal of Econometrics, Vol.19, pp.233-238.

KALE, B.K., 1962. 'On the Selection of the Likelihood Equations by Iteration Process', Biometrica, Vol.49, pp.479-86.

KALIRAJAN, K.P., 1979. 'An Analysis of the Performance of the High Yielding Variety Programme in Coimbatore District, Tamil Nadu', Unpublished Ph.D. dissertation, Australian National University, Canberra.

---------, 1981. 'An Econometric Analysis of Yield Variability in Paddy Production', Canadian Journal of Agricultural Economics, Vol.29, pp.283-294.

---------, and Flinn, J.C., 1981. 'Comparative Technical Efficiency in Rice Production', The Philippines Economic Journal, Vol.XX, no.1, pp.31-43.

---------, 1982. 'On Measuring Yield Potential of the High Yielding Varieties Technology at Farm Level', Journal of Agricultural Economics, Vol.XXXIII, no.2, pp.227-235.

---------, and FLINN, J.C., 1983. 'The Measurement of Farm Specific Technical Efficiency', Pakistan Journal of Applied Economics, Vol.II, no.2, pp.167-180.

---------, and SHAND, R.T., 1985. 'Measuring Location Specific and Farm-Specific Technical Efficiency: An Analysis of the Kemubu Project in Malaysia, Empirical Economics, (forthcoming).

KAPPAGODA, A., 1974. 'Development Planning Techniques in Sri Lanka', Economic Bulletin for Asia and Pacific, Vol.25, no.2/3, pp.89-107.

KUZNETS, S., 1969. Economic Growth and Structure, Oxford University Press, London.

LAU, L.J. and YOTOPOULOS, P.A., 1971. 'A Test of Relative Efficiency and Application to Indian Agriculture', American Economic Review, Vol.62, pp.94-110.

LINGARD, J., CASTILLO, L. and JAYASURIYA, S., 1983. 'Comparative Efficiency of Rice Farms in Central Luzon, The Philippines', Journal of Agricultural Economics, Vol.XXXIX, No.2, pp.163-1973.

LIPTON, M., 1978. 'Inter-Farm, Inter-Regional and Farm-Non-farm Income Distribution: The Impact of New Cereal Varieties', World Development, Vol.6, no.3, pp.319-337.

LOCKHEED, M.E., JAMISON, D.T. and LAU, L.J., 1980, 'Farmer Education Farm Efficiency: A Survey', Economic Development and and Cultural Change, Vol.29, no.1, pp.37-76.

MADDALA, G.S., 1977. Econometrics, International Student Edition, McGraw-Hill, Tokyo.

MEEUSEN, W. and BROECK, J.V.D., 1977. 'Efficiency Estimation from Cobb-Douglas Production Functions with Composed Errors', International Economic Review, Vol.18, no.2, pp.435-444.

MIJINDADAI, N.B. and NORMAN, D.W., 1984. 'Efficiency Differentials in the Traditional Agriculture of Northern Nigeria', Agricultural Systems, Vol.14, pp.213-228.

MOOCK, P.R., 1981. 'Education and Technical Efficiency in Small-Farm Production', Economic Development and Cultural Change, Vol.29, no.4, pp.723-739.

MOORE, M.P., ABEYRATNE, F., AMARAKOON, R. and FERRINGTON, J., 1983. 'Space and the Generation of Socio-economic Inequality on Sri Lanka's Irrigation Schemes', Marga Quarterly Journal, Vol.7, no.1, pp.1-32.

MULLER, J., 1970. 'On Sources of Measured Technical Efficiency: The Impact of Information', American Journal of Agricultural Economics, Vol.56, no.4, pp.730-38.

MURAKAMI, T., 1974. 'Physiological Aspects of Water Control in the Cultivation of Indica Rice Varieties', in the Association Japanese Agricultural Scientific Societies (ed.), 1974. pp.252-274.

NICHOLSON, N.K., 1984. 'Landholding, Agricultural Modernization and Local Institutions in India', Economic Development and Cultural Change, Vol.32, no.3, pp.569-593.

OSHIMA, H.T., 1971. 'Income Inequality and Economic growth, The Post War Experience of Asian Countries', Malayan Economic Review, Vol.15, no.2, pp.7-41.

OTT, A.E., 1962. 'Production Functions, Technical Progress and Economic Growth', International Economic Papers,no.11, pp. 102-40.

PAL, T.K., 1978. 'The Gap Analysis - Some Observations', Paper Presented at the Farm Level Rice Yields Constraints Conference on April 24-26, International Rice Research Institute, Los Banos, The Philippines.

PEARCE, A., 1977. 'Technology and Peasant Production', Development and Change, Vol.8, pp.129.

RICHARD, P. and GOONERATNE, W., 1980. Basic Needs, Poverty and Government Policies in Sri Lanka, International Labour Office, Geneva.

SALTER, W.E.G., 1966. Productivity and Technical Change, Cambridge University Press, London.

SANDARATNE, N., 1972, 'Tenancy in Ceylon's Paddy Lands: the 1958 Reform', South Asian Review, Vol.5, no.2, pp.117-36.

SCHULTZ, T.W., 1964. Transforming Traditional Agriculture, Yale University Press, New Haven.

---------, 1968. Economic Growth and Agriculture, McGraw-Hill, New York.

SELVADURAI, J., 1977. 'Palannoruwa Village (Western Province)' in

Abdul Hameed (ed.), 1971. Rice Revolution in Sri Lanka, UNRISD, Geneva, pp.165-209.

SELVANAYAGAM, S., 1977. 'Palamunai Village', in N.D. Abdul Hameed (ed.), 1977. Rice Revolution in Sri Lanka, UNRISD, Geneva, pp.211-277.

SENADHIRA, D., DHANAPALA., M.P. and SANDANAYAKE, C.A., 1980. 'Progress of Rice Varietal Improvement in the Dry Zone of Sri Lanka', Paper Presented to the Rice Symposium 1980, Organized by the Department of Agriculture, Nov. 1980, BMICH, Colombo.

SHAPIRO, K.H. and MULLER, J., 1977. 'Sources of Technical Efficiency: The Modernization and Information', Economic Development and Cultural Change, Vol.25. pp.293-316.

---------, 1983. 'Efficiency Differentials in Peasant Agriculture and their Implications for Development Policies', Journal of Development Studies, Vol.19, no.2, pp.179-190.

SINGH, I. and DAY, R.H., 1975. 'Factor Utilization and Substitution in Economic Development: A Green Revolution Case Study', Journal of Development Studies, Vol.11, no.3, pp.155-77.

SNODGRASS, D.R., 1966. Ceylon - An Export Economy in Transition, Irwin Inc., Homewood, Illinois.

SRI LANKA - CENTRAL BANK OF CEYLON, 1979. Annual Report-1978, Central Bank of Ceylon, Colombo.

---------, 1983. Annual Report-1982, Central Bank of Ceylon, Colombo.

SRI LANKA - DEPARTMENT OF AGRICULTURE, 1981. Agro Ecological Map of Sri Lanka, Department of Agriculture, Peradeniya.

---------, 1979, Statistical Information on Agricultural Crops, Department of Agriculture, Peradeniya

---------, 1984(a), Bench Mark Survey, District Report Kurunegala District, Department of Agriculture, Peradeniya.

---------, 1984(b). Cost of Cultivation of Agricultural Crops - Yala 1983, Vol.I, Paddy, Agricultural Economics Study No.36, Department of Agriculture, Peradeniya.

---------, 1984(c). Cost of Cultivation of Agricultural Crops - Maha 1983/84, Vol.I, Paddy, Agricultural Study No 37, Department of Agriculture, Peradeniya.

SRI LANKA - DEPARTMENT OF CENSUS AND STATISTICS, 1959. Statistical Abstract of Sri Lanka, Ministry of Plan Implimentation, Colombo.

---------, 1974. Census of Agriculture 1973, Ministry of Plan Implementation, Colombo

---------, 1979. Statistical Abstract of the Democratic Socialis Republic of Sri Lanka, Ministry of Plan Implementation, Colombo.

---------, 1982. Statistical Pocket Book of the Democratic Socialist Republic of Sri Lanka, Ministry of Plan Implimentation, Colombo.

---------, 1983(a). 'Paddy Statistics - Gross Extent Sown, Average Yields and Production by Districts: 1982/83 Maha', Department of Census and Statistics, Colombo.

---------, 1983(b). 'Paddy Statistics - Gross Extent Sown, Average Yields and Production by Districts: 1983 Yala', Department of Census and Statistics, Colombo.

---------, 1984. 'Paddy Statistics - Gross Extent Sown, Average Yields and Production by Districts: 1983/84 Maha', Department of Census and Statistics, Colombo.

SRIVASTAVA, U.K. and HEADY, E.O., 1973. 'Technological Change and Relative Factor Shares in Indian Agriculture - An Empirical Analysis', American Journal of Agricultural Economics, Vol.55, no.3, pp.509-14.

SWAN, S.B.St.C., 1967. 'Paddy Crop Failure and Variable Yields in Ceylon', Pacific Viewpoint, Vol.8, no.2, pp.159-73.

TIMMER, C.P., 1971. 'Using a Probabilistic Frontier Production Function to Measure Technical Efficiency', Journal of Political Economy, Vol.79, pp.776-94.

TAHA, H.A., 1976. Operations Research, Collier, Macmillan, London.

YAMADA, N., 1974. 'Technical Problems of Rice Production in Tropical Asia, in The Association of Japanese Agricultural Scientific Society (ed.), 1974. Rice in Asia, University of Tokyo Press, Tokyo, pp.170-191.

WALDMAN, D.M., 1984. 'Properties of Technical Efficiency Estimators in the Stochastic Frontier Model', Journal of Econometrics, Vol.25, pp.353-364.

THE WORLD BANK., 1979. Sri Lanka - Staff Appraisal Report, Kurunegala Rural Development Project No. 2292a-CE, The World Bank, Washington, D.C.

ZELLNER, A., KMENTA, J. and DREZE, J., 1966, 'Specification and Estimation of Cobb-Douglas Production Function Models', Econometrica, Vol.34, pp. 784-795.

APPENDIX A

AGRICULTURAL STATISTICS

Table A-1: Area Under Major Crops in Sri lanka

Crop	Area (Ha)
Export[a]	
Tea	244,918
Rubber	230,451
Coconut	451,472
Consumption[b]	
Paddy	824,807
Chillies	32,035
Onions	12,081
Green gram	22,856
Cowpea	40,678
Black gram	17,419
Potatoes	6,626
Maiz	27,274
Ground Nut	13,631
Gingelly	31,600
Soyabean	14,570

Source: a. Sri Lanka - Department of Census and Statistics, 1982. Statistical Pocket Book of the Democratic Socialist Republic of Sri Lanka, Ministry of Plan Implementation, Colombo, p.60.

b. Paddy; Sri Lanka - Department of Census and Statistics, 1983(a) and 1983(b). Paddy Statistics-Extent Sown, Harvested, (Gross and Nett), Average yield and Production by Districts, Department of Census and Statistics, Colombo.

Other Crops; Sri Lanka - Department of Agriculture, 1983(a) and 1983(b). Administrative Reports Maha 1982/83 and Yala 1983, Department of Agriculture, Peradeniya.

Notes: Area under export crops are for 1981 and area under other crops correspond to total area cultivated in Maha 1982/83 and Yala 1983.

Table A-2: Adoption of Different Types of Paddy Varieties under Irrigated Conditions in Yala 1983

District	New Improved		Old Improved		Traditional	
	% farms	% extent	% farms	% extent	% farms	% extent
Matara	84.0	85.9	10.0	9.7	6.0	4.4
Ratnapura	78.0	86.9	6.0	4.6	16.0	8.5
Hambantota	96.0	98.1	2.0	0.8	2.0	1.1
Udawalawe	86.0	86.7	-	-	14.0	13.3
Gampaha	100.0	100.0	-	-	-	-
Kurunegala	100.0	100.0	-	-	-	-
Puttalam	100.0	100.0	-	-	-	-
Kegalle	100.0	100.0	-	-	-	-
Kandy	100.0	100.0	-	-	--	
Matale	100.0	100.0	-	-	-	-
Nuwara Eliya	60.0	59.6	32.0	36.0	8.0	5.4
Badulla	84.0	91.6	16.0	8.4	-	-
Monaragala	100.0	100.0	-	-	-	-
Jaffna	92.0	91.5	-	-	-	-
Vavuniya	92.0	91.5	-	-	-	-
Mullaitivu	90.0	93.5	-	-	-	-
Anuradapura	100.0	100.0	-	-	-	-
Polonnaruwa	100.0	100.0	-	-	-	-
Kalawewa	100.0	100.0	-	-	-	-
Trincomalee	100.0	100.0	-	-	-	-
Batticaloa	94.0	91.4	4.0	2.3	2.0	6.3
Amparai	100.0	100.0	-	-	-	-
Sri Lanka	93.5	97.6	3.7	1.5	2.7	0.9

Source: Sri Lanka - Department of Agriculture, 1984(b), Cost of Cultivation of Agricultural Crops - Yala 1983, Agricultural Economics Study No 36, Department of Agriculture, Peradeniya.

Table A-3: Adoption of Different Paddy Varieties under Irrigated Conditions in Maha 1983/84

District		New Improved		Old Improved		Traditional	
		%	%	%	%	%	%
		farms	extent	farms	extent	farms	extent
Matara		92.0	95.1	8.0	4.9	-	-
Ratnapura		84.0	79.8	-	-	16.0	20.1
Hambantota		96.0	96.3	-	-	4.0	3.7
Udawalawe		90.0	90.8	2.0	1.3	8.0	7.9
Gampaha		94.0	92.2	-	-	-	-
Kurunegala			100.0	100.0	-	--	
Puttalam	66.0	61.4	30.0	32.0	4.0		6.6
Kegalle		96.0	97.3	-	-	4.0	2.7
Kandy		89.0	92.0	-	-	-	-
Matale		94.0	95.8	-	-	-	-
Nuwara Eliya		58.0	55.4	32.0	35.4	10.0	9.2
Badulla		90.0	95.1	10.0	4.9	-	-
Monaragala		92.0	94.9	-	-	8.0	5.1
Vavuniya		80.0	91.8	20.0	8.2	-	-
Mannar		98.0	97.8	2.0	2.2	-	-
Kilinochchi		92.0	91.1	8.0	8.9	-	-
Mullaitivu		88.0	82.7	15.0	13.0	-	-
Anuradapura		100.0	100.0	-	-	2.0	2.0
Kalawewa		98.0	98.0	-	-	-	-
Polonnaruwa		96.2	97.5	-	-	3.8	2.5
Trincomalee		100.0	100.0	-	-	-	-
Amparai		100.0	100.0	-	-	-	-
Batticaloa		88.0	83.5	12.1	16.5	-	-
Sri Lanka		90.8	92.0	5.5	5.3	3.7	2.7

Source: Sri Lanka - Department of Agriculture, 1984(c). Cost of Cultivation of Agricultural Crops, Agricultural Economics Study No 37, Department of Agriculture, Peradeniya.

Table A-4: Adoption of Different Types of Paddy Varieties under Rainfed Conditions in Yala 1983

District	New Improved		Old Improved		Traditional	
	% farms	% extent	% farms	% extent	% farms	% extent
Colombo	72.0	71.0	-	-	28.0	29.0
Kalutara	42.0	36.8	-	-	58.0	63.2
Galle	95.0	94.0	2.1	2.2	3.0	3.8
Matara	78.0	85.1	12.0	8.2	10.0	6.7
Ratnapura	68.0	76.7	-	-	32.0	23.3
Gampaha	100.0	100.0	-	-	-	-
Kurunegala	100.0	100.0	-	-	-	-
Kegalle	100.0	100.0	-	-	-	-
Kandy	100.0	100.0	-	-	-	-
Matale	98.0	99.2	-	-	2.0	0.8
Sri Lanka	84.3	85.0	4.0	2.3	11.7	12.7

Source: Sri Lanka - Department of Agriculture, 1984(b) Cost of Cultivation of Agricultural Crops Yala 1983, Agricultural Economics Study No 36, Department of Agriculture, Peradeniya.

Table A-5: Adoption of Different Types of Paddy Varieties under Rainfed Conditions in Maha 1983/84

District	New Improved		Old Improved		Traditional	
	% farms	% extent	% farms	% extent	% farms	% extent
Colombo	94.0	95.0	-	-	6.0	4.1
Kalutara	63.0	62.9	5.0	5.6	32.6	31.5
Galle	98.0	98.9	2.0	1.1	-	-
Matara	80.0	82.2	14.0	12.0	6.0	5.8
Ratnapura	82.0	84.9	4.0	2.7	14.0	12.4
Gampaha	94.0	97.3	-	-	-	-
Kurunegala	100.0	100.0	-	-	-	-
Puttalam	66.0	73.2	26.0	13.5	8.0	13.3
Kegalle	100.0	100.0	-	-	-	-
Kandy	90.0	95.2	-	-	-	-
Matale	78.0	76.5	10.0	9.1	12.0	14.4
Jaffna	30.0	24.4	56.0	66.6	14.0	9.0
Vavuniya	74.0	81.3	26.0	18.7	-	-
Mannar	92.	94.8	8.0	5.2	-	-
Kilinochchi	74.0	82.4	22.0	16.1	4.0	1.5
Anuradapura	38.0	32.0	62.0	68.0	-	-
Polonnaruwa	93.0	95.4	4.7	4.2	2.3	0.4
Amparai	93.0	93.9	-	-	-	-
Batticaloa	82.0	74.9	18.0	25.1	-	-
Sri Lanka	80.2	74.9	11.8	16.3	8.0	8.8

Source: Sri Lanka - Department of Agriculture, 1984(c). Cost of Cultivation of Agricultural Crops Maha 1983/84, Agricultural Economics Study No 37, Department of Agriculture, Peradeniya.

Table A-6: Area, Production and Yields of Rice for Sri Lanka (from 1953/54 to 1982/83)

Year	Area[a] '000 ha	Production '000 MT	Yields[b] MT/ha
1953/54	507.6	441.3	1.05
1954/55	545.3	506.6	1.17
1955/56	487.3	384.6	1.05
1956/57	488.9	443.9	1.13
1957/58	559.6	519.4	1.14
1958/59	530.0	505.2	1.20
1959/60	587.9	610.2	1.25
1960/61	595.9	620.5	1.27
1961/62	621.8	690.5	1.29
1962/63	632.4	705.9	1.36
1963/64	641.8	725.4	1.39
1964/65	589.2	520.7	1.22
1965/66	654.6	663.0	1.25
1966/67	663.5	796.5	1.46
1967/68	705.5	935.8	1.63
1968/69	692.0	955.5	1.76
1969/70	759.3	1123.5	1.80
1970/71	726.2	970.5	1.63
1971/72	726.5	912.5	1.63
1972/73	725.5	912.5	1.56
1973/74	825.1	1114.2	1.56
1974/75	696.1	802.5	1.49
1975/76	724.2	871.0	1.49
1976/77	828.4	1166.8	1.70
1977/78	875.7	1314.6	1.73
1978/79	839.0	1333.1	1.83
1979/80	845.0	1483.3	2.00
1980/81	877.1	1074.1	2.04
1981/82	844.6	1498.8	2.24
1982/83	824.5	1726.8	2.51

Source: Sri Lanka - Department of Census and Statistics, 1959. Statistical Abstract of Sri Lanka, Ministry of Plan Implementation, Colombo.

Sri Lanka - Department of Census and Statistics, 1983(a) and 1983(b). Paddy Statistics-Extent Sown, Harvested (Gross & Nett), Average Yield and Production by Districts 1982/83 Maha and 1983 Yala, Departrment of Census and Statitics, Colombo.

Sri Lanka - Department of Census and Statistics cited in Department of Agriculture, 1979. Statistical Information of Agricultural Crops, Department of Agriculture, Peradeniya.

Notes: a. Gross sown area
b. Yield per hectare of nett harvested area

APPENDIX B

SAMPLE DISTRIBUTION BY VILLAGES

Table B-1: Sample Distribution in Major Irrigation Areas

Village	No of Farmers	No of Parcels
Hipawwa	6	22
Manapaya	6	16
Moragasgoda	1	2
Madimulla	1	3
Moragaswila	1	1
Morutawa	20	43
Udamulla	1	2
Ambalawa	1	7
Nagolla	1	1
Kosgahapellessa	2	4
Dehelwehera	1	2
Embalwewa	2	2
Handapanwela	1	1
Poramulla	6	8
Walupola	7	17
Hagamuwa	4	7
Udawela	4	5
Damunugala	10	27
Total	75	170

Table B-2: Sample Distribution in Minor Irrigation Areas

Village	No of Farmers	No of Parcels
Daramitipola	2	3
Talgodapitiya	13	24
Ibbagamuwa	5	15
Kalagaswewa	2	2
Migahakumbura	3	4
Total	25	48

Table B-3: Sample Distribution in Rainfed Areas

Village	No of Farmers	No of Parcels
Daramitipola	8	9
Pahala Gokarella	3	9
Hiddana	9	16
Pahalawalpola	8	12
Ihalawalpola	14	27
Nindapella	18	36
Gokarella	9	10
Ihala Gokarella	11	29
kirindigalla	17	30
Kanduluwa	6	22
Total	103	205

APPENDIX C

SOCIO-ECONOMIC CHARACTERISTIC OF FARM FAMILIES

Table C-1: Age Distribution of Respondent Farmers (percent reporting)

Category	< 20	21-30	31-40	41-50	51-60	>60	Av.Age
Major Irrign.	1.0	4.7	18.9	20.1	27.4	26.9	47.81
Minor Irrign,	.00	4.0	20.0	32.0	24.0	20.0	49.28
Rainfed	.08	17.3	27.3	16.5	20.6	17.3	45.42
District	.08	14.9	23.2	19.5	23.6	17.8	46.4

Source: Survey Data

Table C-2: Distribution of Family members by Age Groups and Sex

Category	Males LT 16	Females LT 16	Males GT 16	Fem GT 16
<u>Major Irrigation</u>				
% reporting	31.5	26.3	64.2	89.4
Av. number	1.6	1.3	1.8	1.8
% of total	14.3	9.3	32.2	44.1
<u>Minor Irrigation</u>				
% reporting	28.0	44.0	60.0	80.0
Av. number	1.8	1.6	2.1	1.5
% of total	10.1	20.2	35.9	33.7
<u>Rainfed</u>				
% reporting	30.6	31.4	56.2	73.6
Av. number	1.5	1.5	1.8	1.8
% of total	13.9	14.4	31.2	40.4
<u>District</u>				
% reporting	31.2	31.2	60.7	81.8
Av. number	1.5	1.5	1.9	1.8
% of total	13.6	12.9	32.1	41.3

Source: Survey Data

Table C-3: Literacy and Number of Years of Schooling (percent reporting)

Item	Major Irig.	Minor Irig.	Rainfed	District
Literacy	92.6	92.0	96.7	94.6
No.yrs. Schol				
Nil	6.3	8.0	2.0	4.5
1st-5th std.	45.3	24.0	33.8	37.3
6th-8th std.	28.4	28.0	37.2	32.8
9th-10th std.	7.3	20.0	13.2	11.6
11th and above	12.6	20.0	13.2	13.7

Source: Survey Data

Table C-4: Number of Years of Farming Experience (percent reporting)

Category	< 10	11-20	21-30	31-40	41-50	> 50
Maj Ir.	14.7	22.1	20.0	22.1	14.7	6.4
Min Ir.	32.0	20.0	12.0	20.0	16.0	.0
Rain	23.1	29.7	16.5	13.2	14.0	3.3
Dist	20.7	25.7	17.4	17.4	14.5	4.0

Source: Survey Data

Table C-5: Part Time and Full Time Farming (percent reporting)

Item	Maj.Ir	Min. Ir	Rainfed	District
Full Time	65.9	44.0	62.0	61.6
Part Time	29.8	44.0	36.4	34.5
None	4.2	12.0	1.7	3.7

Source: Survey Data

Table C-6: Occupation of the Farm Respondent
(percent reporting)

Occupation	Maj.Ir	Min Ir	Rainfed	District
Own Farm Only	7.4	16.0	11.6	10.4
Other Farm	1.1	.0	.0	.04
Non Farm	.0	.0	.8	.04
Own+Other Fm	47.4	28.0	35.5	39.4
Own+Non Farm	10.5	20.0	14.9	13.7
All three	29.5	24.0	34.7	31.5
Does not Work	4.2	12.0	2.5	4.1

Source: Survey Data

Table C-7: Occupation of Other Family Members; Adults Over 16 Years
(percent reporting)

Category	Major Irrig	Minor Ir.	Rainfed	District
M-Own Fm FT	28.4	8.0	19.0	29.2
M-Own Fm PT	40.0	40.0	35.5	51.1
M-Other Fm FT	.0	.0	.8	.0
M-Other Fm PT	17.9	8.0	9.1	17.4
M-Off Fm FT	2.1	.0	.0	1.0
M-Off Fm PT	1.1	.0	.0	.0
F-Own Fm FT	4.2	8.0	1.7	3.3
F-Own Fm PT	85.3	24.0	81.8	78.8
F-Other Fm FT	1.1	.0	.0	.0
F-Other Fm PT	22.1	12.0	11.6	16.1
F-Off Fm FT	2.1	.0	.0	.0
F-Off Fm PT	1.1	.0	.0	.0

Source: Survey Data

Table C-8: Allocation of Farmers Labour between Alternative Activities during Maha 1983/84 (average number of hours spent per month and percent farmers reporting)

Item	Sept 83	Oct	Nov	Dec	Jan	Feb
Highland						
Maj	8.8	9.2	6.4	11.6	8.8	.5
	(22)	(26)	(17)	(27)	(24)	(.01)
Min	7.2	7.2	7.2	7.2	7.2	7.2
	(28)	(28)	(28)	(28)	(28)	(28)
RF	7.2	8.0	7.6	8.8	10.0	.4
	(28)	(39)	(36)	(41)	(32)	(3)
Ds	7.6	8.4	7.2	9.6	9.2	.4
	(26)	(29)	(24)	(30)	(28)	(2)
Lowland						
Maj	2.4	54.0	93.5	22.0	8.8	.5
	(6)	(71)	(87)	(53)	(32)	(2)
Min	5.6	52.0	68.8	16.0	9.6	
	(24)	(76)	(84)	(40)		(36)
RF	2.4	35.6	85.2	18.0	6.4	
	(7)	(61)	(93)	(42)		(25)
Ds	3.2	47.2	86.4	19.6	7.6	.4
	(8)	(55)	(90)	(41)	(29)	(.08)
Other Farm						
Major	-	9.6	22.3	2.8	.8	-
	-	(26)	(58)	(6)	(2)	-
Minor	-	8.8	16.8	4.0	-	-
	-	(20)	(40)	(4)	-	-
RF	.16	4.5	21.2	1.2	.4	-
	(.8)	(14)	(58)	(6)	(.8)	-
Ds	3.2	7.6	21.2	2.0	.4	-
	(.04)	(19)	(56)	(6)	(1)	-
Off Farm						
Maj	23.1	21.1	14.6	22.0	16.3	8.0
	(22)	(25)	(20)	(23)	(9)	(6)
Min	40.0	36.8	30.4	40.0	38.4	
	(36)	(36)	(36)	(36)		(36)
RF	30.0	27.6	21.2	29.2	28.4	-
	(30)	(30)	(28)	(30)		(30)
Ds	29.2	30.8	20.4	28.0	28.0	8.0
	(26)	(29)	(25)	(31)	(29)	(2)

note: percent farmers reporting is given within parentheses

Source: Survey Data

Table C-9: Farm Size Distribution

Operational Holding Size(ha)	Number ('000)	% of Total	Area ('000 ha)	% of Total
0 - .40	42	24	8	3
.41 - 1.20	69	40	46	17
1.21 - 4.00	52	30	101	38
4.10 - 8.00	5	3	26	10
8.00 +	4	2	85	32
Total	172	100	667	100

Source: Sri Lanka - Department of Census and Statistics, 1974. Census of Agriculture 1973, Department of Census and Statistics, Colombo.

Table C-10: Size Distribution of High Land (percent reporting)

Category	< .20 ha	.21-.40 ha	.41-.80 ha	.81-1.20 ha	1.21-1.60 ha	Av. ha
Maj. Ir	56.8	16.8	24.2	1.0	1.0	.81
Min. Ir	44.0	12.0	16.0	20.0	8.0	1.44
Rain	58.6	19.8	12.4	4.9	3.3	.92
Dist.	56.4	17.8	17.4	4.9	2.9	.0

Source: Survey Data

Table C-11: Number of Parcels Per Farm
(percent reporting)

No of Parcels	Major Irrig.	Minor Irrig.	Rainfed	District
At Least One	100.0	100.0	100.0	100.0
At Least Two	70.5	56.0	54.5	60.9
At Least Three	35.0	28.0	23.1	28.6

Source: Survey Data

Table C-12: Size Distribution of Low Land Parcels
(percent reporting)

Categ:	< .20 ha	.21-.40 ha	.41-.80 ha	>.81 ha	Av ha
Mj. Ir	67.2	27.2	5.1	.0	.34
Mn. Ir	60.8	30.4	8.6	.0	.27
Rainfed	62.3	29.3	7.9	.0	.26
District	64.1	28.4	6.8	.0	.29

Source: Survey Data

Table C-13: Ownership of Low Land Parcels
(percent reporting)

Type of Tenure	Major Irrig	Minor Irrig	Rainfed	District
Owned Singly	50.6	58.0	46.5	49.8
Owned Jointly	12.8	6.5	13.4	12.7
Rented in	37.1	34.7	40.0	37.4
Other				

Source: Survey Data

Table C-14: Crops Cultivated on High Land
(percent reporting)

Crop	Major Irrig	minor Irrig	Rainfed	District
Coconut	62.0	57.8	56.0	59.3
Coconut+Banana	15.8	26.3	17.3	18.0
Coconut+Other	3.2	5.2	1.3	2.5
Banana	9.5	.0	2.6	5.1
Other				

Source: Survey Data

APPENDIX D

AVAILABILITY OF INPUTS, TECHNICAL KNOWLEDGE, TIMING OF CROP ESTABLISHMENT AND RAINFALL IN THE STUDY AREA

Table D-1: Availability of Inputs
(percent reporting)

Input	Major Irrig	minor Irrig	Rainfed	District
Fertilizer	96.8	100.0	99.2	97.8
Pesticide	95.5	100.0	100.0	99.3
Herbicide	96.0	96.0	100.0	97.4
Fungicide	93.9	95.8	100.0	96.9

Source: Survey Data

Table D-2: Knowledge on Recommended Quantity and Timing
(percent reporting)

Tech Knowledge	Major Irrig	Minor Irrig	Rainfed	District
Fert Quantity	81.1	70.83	59.5	69.1
Fert Timing	80.8	70.8	58.8	68.7
Pest Quantity	73.4	62.5	53.7	62.0
Pest Timing	69.5	58.3	51.3	59.8
Herb Quantity	54.2	70.8	46.7	52.3
Herb Timing	53.8	62.5	44.2	50.0
Fung Quantity	33.7	42.1	30.4	32.8
Fung Timing	34.2	40.0	29.5	32.6

Source: Survey Data

Table D-3: Timing of Establishment of Rice
(percent parcels reporting)

Item	Major Irrig	Minor Irrig	Rainfed	District
Month				
Sept 83	.0	.0	.5	.2
Oct	4.9	8.7	5.8	6.3
Nov	80.2	91.3	89.3	86.8
Dec	13.7	.0	4.4	7.5
Jan 84	.5	.0		.3
Timing				
Early	6.0	2.2	2.4	3.8
On Time	84.1	65.0	79.6	77.6
Late	9.9	32.6	17.5	16.2

Source: Survey Data

Table D-4: Number of Rainy Days Reported During Maha !983/84
(percent parcel reporting)

No of Days	Major Irrig	Minor Irrig	Rainfed	District
15-20	25.5	15.5	13.2	19.9
21-25	41.3	40.0	46.1	37.7
26-30	24.4	31.1	32.9	32.7
> 30	8.9	13.3	7.6	9.5

Source; Survey Data

APPENDIX E

FERTILIZER RECOMMENDATIONS

Table E-1: Fertilizer Recommendations for Improved Varieties in Low Country Intermediate Zone

a) Nursery fertilizer for transplanted crops (1/10 ha)
Basal (V1 - 3:30:10) .... 30.0 Kg
Urea (10 days after sowing) (46:0:0).. 7.5 Kg

b) 3 month varieties - Broadcast sown (B/S) and Transplanted(T/P)

	B/c (Kg/ha)	T/P (Kg/ha)
Basal at levelling (3:30:10)	185	185
2 weeks - Urea (46:0:0)	62	93
4 weeks - Urea (46:0:0)	31	76*
6 weeks - TDM (30:0:0)	76	-

* TDM mixture (30:0:20) is applied to transplanted crops (not urea)

c) 3.5 month varieties - Broadcast sown and Transplanted(T/P)

	B/S (Kg/ha)	T/P (Kg/ha)
Basal at levelling (3:30;10)	185	185
2 weeks - Urea (46:0:0)	62	93
4 weeks - Urea (46:0:0)	31	-
5 weeks - Urea (30:0:20)	-	76
7 weeks - TDM (30:0:20)	76	-

d) 4-4.5 month varieties - Broadcas sown (B/S) and Transplanted(T/P)

	B/S (Kg/ha)	T/P (Kg/ha)
Basal at levelling (3:30:0)	185	185
2 weeks - Urea (46:0:0)	62	62
4 weeks - Urea (46:0:0)	-	62
6 weeks - Urea (46:0:0)	62	-
7 weeks - TDM (30:0:0)	-	76
10 weeks - TDM (30:0:20)	76	-

APPENDIX F

COMPUTER PROGRAMME

```
     DIMENSION Y(203),X(203,11),A1(13),B(13),D(13),V(13,13),SZX(13),
     1SX2(13,13)
C     DIMENSION Z,ZZ,VK1,SZ,BA,AA,A2,SZ2,FL,VAL,FB,GAM,S
C     THIS PROGRAM USES THE NEWTON-RAPHSON TECHNIQUE TO APPLY A
C     FRONTIER PRODUCTION FUNCTION FOR THE RICE FARMS IN KURUNEGALA
C     DISTRICT OF SRI LANKA
C     ----------------------------------------------------------------
C     N = NO OF OBSERVATIONS    TOL = ACCURACY
C     K = NO OF INDEP.VARIABLES
      READ(1,20)N,K,TOL,IND
   20 FORMAT(2I3,1X,F6.4,I3)
      DO 21 I=1,N
   21 READ(1,22) Y(I),(X(I,J),J=1,11)
C-------------------------------------------------------------------
C     INPUT DATA STARTING WITH DV THEN FOLLOWED BY INVS
C
C
C     ------------------------------
  22  FORMAT(F6.4,F2.0,1X,8F7.2,2F4.1)
      K1=K+1
      K2=K+2
C--------------------------------------
C     ESTIMATES OF PARAMETERS
C--------------------------------------
      READ(1,23) (B(I),I=1,K2)
   23 FORMAT(11F7.4/2F7.4)
      IF(IND.EQ.1)GO TO 30
      DO 25 I=1,N
      Y(I)=ALOG(Y(I))
      DO 25 J=2,4
   25 X(I,J)=ALOG(X(I,J))
      GO TO 40
 30    CONTINUE
 40    CONTINUE
      NITS=0
      VAL1=-10000.
  99  VAL=0
      S=SQRT(B(K1))
      SZ2=0
      A2=0
      SZ=0
      VK1=0
      DO 41 I=1,K2
      D(I)=0
      A1(I)=0
      SZX(I)=0
      DO 41 J=1,K2
```

```
      V(I,J)=0
   41 SX2(I,J)=0
      DO 42 I=1,N
      Z=Y(I)
      DO 43 J=1,K
   43 Z=Z-X(I,J)*B(J)
      ZZ=Z/B(K1)
      VAL=VAL-Z**2/(2.*B(K1))
      Z=(Z/S)*SQRT(B(K2)/(1.-B(K2)))
      CALL NORPRB(Z,FU,FB,FF)
      VAL=VAL+ALOG(FB)
      FL=-ALOG(SQRT(2.*3.141593))-(Z**2/2.)
      FL=EXP(FL)
      SZ2=SZ2+Z*Z
      A2=A2+FL*Z/FB
      AA=FL/(FB**2)
      BA=(FL-FB*Z)
      SZ=SZ+Z
      VK1=VK1+AA*BA*Z*Z
      V(K2,K2)=V(K2,K2)+AA*(BA*Z*Z+(4.*B(K2)-1.)*FB*Z)
      DO 50 J=1,K
      A1(J)=A1(J)+(FL/FB)*X(I,J)
      SZX(J)=SZX(J)+Z*X(I,J)
      V(K1,J)=V(K1,J)+AA*BA*Z*X(I,J)
      V(K2,J)=V(K1,J)
      D(J)=D(J)+ZZ*X(I,J)
      DO 50 L=1,K
      SX2(L,J)=SX2(L,J)+X(I,J)*X(I,L)
  50   V(L,J)=V(L,J)+AA*BA*X(I,J)*X(I,L)
   42 CONTINUE
C     END OF LOOP ALLOWING FOR ALL TERMS WITH I SUBSCRIPT
      GAM=(1.-B(K2))/B(K2)
      FN=N
      D(K1)=-FN/(2.*B(K1))+(GAM*SZ2+A2)/(2.*B(K1))
      D(K2)=-A2/(2.*B(K2)*(1.-B(K2)))
      V(K1,K1)=(FN/2.-GAM*SZ2-0.75*A2-0.25*VK1)/(B(K1)**2)
      V(K2,K2)=-V(K2,K2)/(4*B(K2)**2*(1.-B(K2))**2)
      V(K1,K2)=(A2+VK1)/(4.*B(K1)*B(K2)*(1.-B(K2)))
      V(K2,K1)=V(K1,K2)
      DO 60  I=1,K
      D(I)=D(I)+A1(I)/(S*SQRT(GAM))
      V(K1,I)=-(SZX(I)*SQRT(GAM)+A1(I)/(2.*SQRT(GAM))+V(K1,I)/(2.*SQRT(
     1GAM)))/S**3
      V(I,K1)=V(K1,I)
      V(K2,I)=(A1(I)+V(K2,I))/(2.*S*B(K2)**0.5*(1.-B(K2))**1.5)
      V(I,K2)=V(K2,I)
      DO 60 J=1,K
   60 V(I,J)=-(SX2(I,J)+V(I,J)/GAM)/B(K1)
      VAL=VAL-0.5*FN*ALOG(B(K1))
      WRITE(2,100) VAL
  100 FORMAT(' ',8X,' LIKELIHOOD FN',5X,F14.6)
      CALL BHML(B,D,V,K2)
      NITS=NITS+1
      IF(B(K2).LT.0)B(K2)=0.05
      IF(1.0.LT.B(K2))B(K2)=0.95
      IF(NITS-300)99,99,101
  101 STOP
      END
      SUBROUTINE NORPRB(X,P,Q,Z)
```

```
C  ROUTINE TO FIND LEFT TAIL AND RIGHT TAIL PROBABILITY FOR A
C      STANDARD NORMAL DEVIATE X. ORDINATE IS ALSO FOUND (7).
      DIMENSION A(5),CONNOR(17)
C     DIMENSION S,X,Z,Y,P,Q
      DATA CONNOR
     1/ 8.0327350124E-17, 1.4483264644E-15, 2.4668270103E-14,
     2 3.9554295164E-13, 5.9477940136E-12, 8.3507027951E-11,
     3 1.0892221037E-9, 1.3122532964E-8, 1.4503852223E-7,
     4 1.4589169001E-6, 1.3227513228E-5, 1.0683760684E-4,
     5 7.5757575758E-4, 4.6296296296E-3, 2.3809523810E-2,
     6 0.1,               0.333333333333   /
      DATA RRT2PI / 0.3989422804/
      S=X
      Y=S*S
      IF(S)10,11,12
   11 Z=RRT2PI
      P=0.5
      Q=0.5
      GO TO 31
C   SARIES APPROXIMATION
   10 S=-S
   12 Z=RRT2PI*EXP(-0.5*Y)
      IF(S-2.5)13,14,14
   13 Y=-0.5*Y
      P=CONNOR(1)
      DO 15 L=2,17
15    P=P*Y+CONNOR(L)
      P=(P*Y+1.0)*X*RRT2PI+0.5
      Q=1.0-P
      GO TO 31
C   CONTINUED FRACTION APPROXIMATION
   14 A(2)=1.0
      A(5)=1.0
      A(3)=1.0
      Y=1.0/Y
      A(4)=1.0+Y
      R=2.
   19 DO 17 L=1,3,2
      DO 18 J=1,2
      K=L+J
      KA=7-K
18    A(K)=A(KA)+A(K)*R*Y
   17 R=R+1.
      IF(A(2)/A(3)-A(5)/A(4))19,20,19
   20 P=(A(5)/A(4))*Z/X
      IF(X)21,11,22
   21 P=-P
      Q=1.0-P
      GO TO 31
   22 Q=P
      P=1.0-P
   31 CONTINUE
  100 RETURN
      END
      SUBROUTINE INVERT(XX,N)
      DIMENSION XX(13,13),IPIV(13)
C     DIMENSION AMAX
C
C     COMPLIMENTS OF ADRIAN PAGAN
```

```
C     SUBROUTINE INVERT INVERTS A MATRIX XX
C
   20 FORMAT(' ',13F9.5)
      DO 1 I=1,N
    1 IPIV(I)=0
      DO 11 I=1,N
      AMAX=0.
      DO 5 J=1,N
      IF(IPIV(J))2,2,5
    2 IF(ABS(XX(J,J)-AMAX))4,4,3
    3 ICOL=J
      AMAX=ABS(XX(J,J))
    4 CONTINUE
    5 CONTINUE
      IPIV(ICOL)=1
      IF(AMAX-1.0E-8)6,6,7
    6 WRITE(2,12)
      STOP
    7 CONTINUE
      AMAX=XX(ICOL,ICOL)
      XX(ICOL,ICOL)=1.0
      DO 8 K=1,N
    8 XX(ICOL,K)=XX(ICOL,K)/AMAX
      DO 11 J=1,N
      IF(J-ICOL)9,11,9
    9 AMAX=XX(J,ICOL)
      XX(J,ICOL)=0.
      DO 10 K=1,N
   10 XX(J,K)=XX(J,K)-XX(ICOL,K)*AMAX
   11 CONTINUE
      DO 15 I=1,N
   15 WRITE(2,20) (XX(I,J),J=1,N)
      RETURN
C
   12 FORMAT(/'SINGULAR MATRIX--TERMINATE'/)
      END
      SUBROUTINE BHML(B,D,XX,M)
      DIMENSION B(M),XX(13,13),D(M),SE(13)
      WRITE(2,10)(B(I),I=1,M)
   10 FORMAT(6X,' PARAMETER ESTIMATES',/,6X,6F11.6/5F11.6)
      CALL INVERT(XX,M)
   12 FORMAT(6X,' STANDARD ERRORS',/6X,10F9.6,/10F9.6,////)
      DO 20 I=1,M
      DO 20 J=1,M
   20 B(I)=B(I)-XX(I,J)*D(J)*.005
      RETURN
      END
```

Source: Adapted from Corra (1976)