The Australian Centre for International Agricultural Research (ACIAR) was established in June 1982 by an Act of the Australian Parliament. Its mandate is to help identify agricultural problems in developing countries and to commission collaborative research between Australia and developing country researchers in fields where Australia has a special research competence.

ACIAR TECHNICAL REPORTS SERIES

This series of publications contains technical information resulting from ACIAR-supported programs, projects, and workshops (for which proceedings are not being published), reports on Centre-supported fact-finding studies, or reports on other useful topics resulting from ACIAR activities. Publications in the series are distributed internationally to a selected audience.

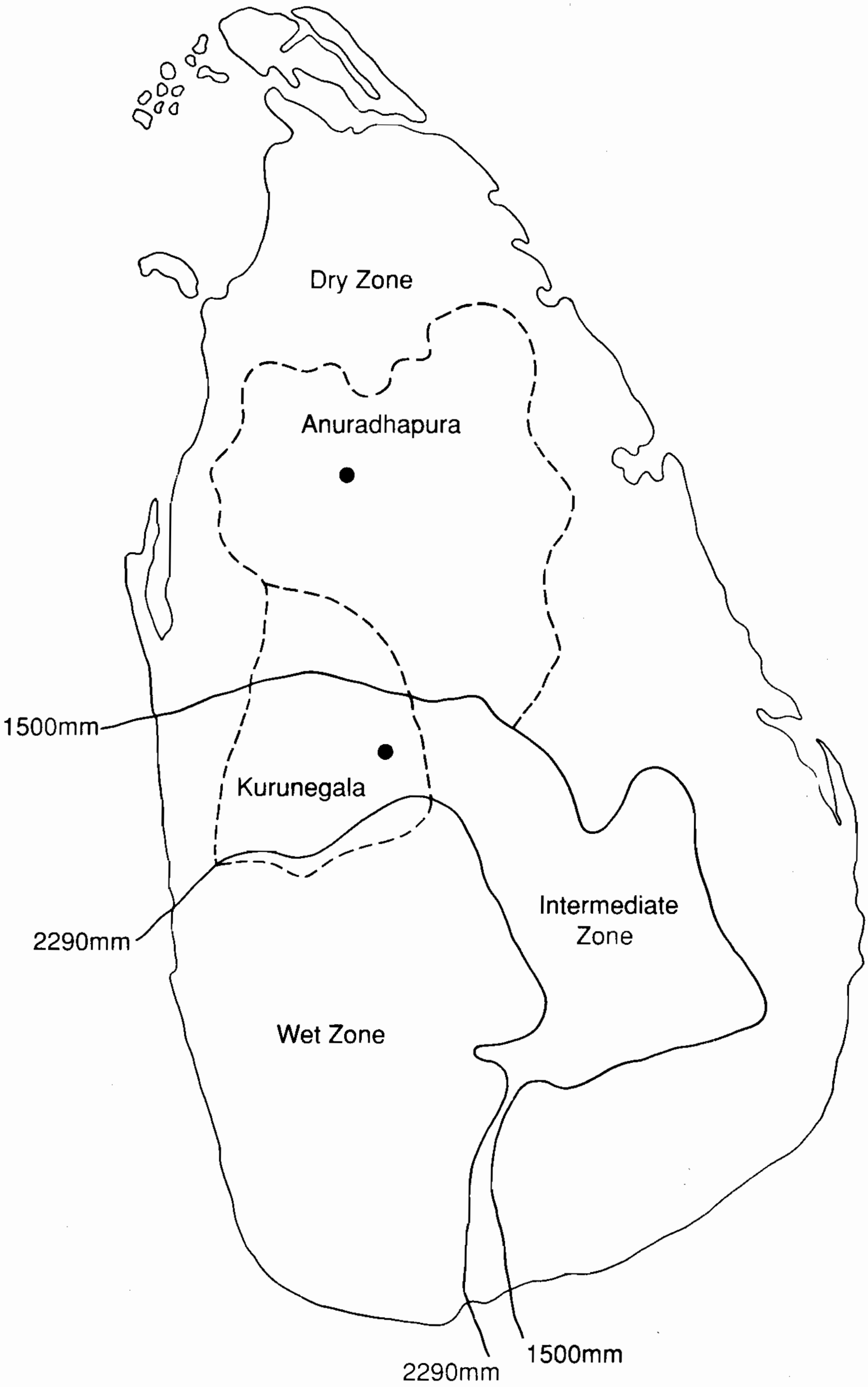
Menz, Kenneth M. (ed.) 1990. Rice Production in Sri Lanka: A Combined Agronomic/Economic Study in the Intermediate and Dry Zones. ACIAR Technical Reports No. 17, 51p.

ISBN 1 86320 022 3

Typeset and laid out by: Abb-typesetting Pty Ltd, Collingwood, Victoria.

Cover photo by: Neil McKee

Rice Production in Sri Lanka



General location map of Sri Lanka showing climatic zones and principal locations.

Rice Production in Sri Lanka

A Combined Agronomic/Economic Study in the Intermediate and Dry Zones

Kenneth M. Menz, Editor

Australian Centre for International Agricultural Research
Canberra 1990

Contributors

G.A.C De Silva	Division of Agricultural Economics, Department of Agriculture, Peradeniya, Sri Lanka
M.P. Dhanapala	Central Rice Breeding Station Batalagoda, Ibbagamuwa, Sri Lanka
C. Fazekas de St.Groth	CSIRO Division of Water and Land Resources, GPO Box 1666, Canberra, ACT, 2601, Australia
S.K. Jayasuriya	Research School of Pacific Studies, The Australian National University, Canberra, Australia. Present address: Economics Department, La Trobe University, Bundoora, Victoria, 3083, Australia
K.P. Kalirajan	National University of Singapore. Present address: Research School of Pacific Studies, The Australian National University, GPO Box 4, Canberra, ACT, 2601, Australia
B.M.K. Perera	Agricultural Research Station, Maha, Illuppallama, Sri Lanka
N.F.C Ranaweera	Economics and Projects Division, Department of Agriculture, Paradeniya, Sri Lanka. Present address: Department of Agricultural Economics, International Rice Research Institute, PO Box 933 Manila, Philippines
R.T. Shand	Research School of Pacific Studies, The Australian National University, GPO Box 4 Canberra, ACT, 2601, Australia
D.B. Wickramasinghe	Central Rice Breeding Station, Batalagoda, Ibbagamuwa, Sri Lanka
R. Wetselaar	CSIRO Division of Water and Land Resources, GPO Box 1666, Canberra, ACT, 2601, Australia

Contents

Editor's Preface

In 1983 ACIAR approved two complementary projects: one to study the environmental constraints to increased productivity of rainfed rice-based farming systems in the lowland and upland areas of Sri Lanka and the Philippines (the agronomic project), and the other to focus on the socioeconomic factors responsible for the difference between potential productivity and actual farm performance (the economic project). These projects linked scientists from the following institutions:

CSIRO Division of Water and Land Resources,
Department of Economics, Research School of Pacific Studies,
  The Australian National University,
Sri Lanka Department of Agriculture,
Philippine Department of Agriculture,
College of Agriculture, University of the Philippines at Los Baños,
Department of Economics and Statistics, National University of
  Singapore.

A mid-project workshop was held in Kandy, Sri Lanka, in March 1985, which helped shape later work. The proceedings were published and copies are available through ACIAR.

In mid 1987 the project leaders and other scientists and extension workers attended a 5-day workshop in Iloilo, Philippines to review the results of the projects, to prepare recommendations concerning the adequacy of current extension practices, and to define future research needs in this area. Abstracts of the papers presented at the workshop were published as ACIAR Technical Reports No. 8. A series of working papers was produced during the economics project. These are frequently referred to in this report, and can be obtained by writing to ACIAR.

Subsequent to the workshop, analysis of the data continued and expanded versions of the papers were written. These papers are presented in this report on the Sri Lankan component of the project. The Philippine component has been published by ACIAR as Technical Reports No. 13.

The workshop and the Philippine and Sri Lankan publications were financially supported by the Australian International Development Assistance Bureau (AIDAB). Their support is generously acknowledged, as is that of Peter Lynch and Camilla Fazekas de St. Groth in producing this publication. The project work was coordinated by Dr J.V. Remenyi (now at Deakin University) and Dr J.G. Ryan, Deputy Director of ACIAR.

Kenneth M. Menz
Research Program Coordinator
Economics and Farming Systems
ACIAR

Foreword

Irrigated rice has been the major source of food production increases in Asia over the last 30 years. While some potential remains for productivity increases in irrigated cereal production, the best land and the least expensive areas for irrigation development have already been taken up. In order for production to keep pace with future population growth, productivity improvements from rainfed areas will be necessary.

In response to this need two projects — one agronomic and one economic — were commissioned by ACIAR focusing on areas where water is likely to be a limiting factor for rice production. Importantly the results from these projects have relevance not just to the two countries but throughout the rainfed rice production areas of Asia.

G.H.L. Rothschild
Director, ACIAR

Introduction

At present, rice production from the 747 000 ha of riceland in Sri Lanka is insufficient to feed its population of 17 million people. The national average rice yield is 3.5 t/ha, which is less than half of the yields obtained at experiment stations using new, improved varieties and other modern technology. The reasons for this difference in yield had been investigated for the fully irrigated areas of the country by comparing farmers' and researchers' yields in the farmers' environment. There was a need to undertake similar studies in areas where water could be a factor limiting output. To this end, socioeconomic farm surveys and agronomic experiments on farmers' fields were undertaken over six rice-growing seasons.

The two districts selected for study were Kurunegala in the Intermediate Zone and Anuradhapura in the Dry Zone. Both districts experience a bimodal pattern of rainfall; most of this rain falls in the major (*Maha*) season which extends from October to February, and less falls in the *Yala* season which extends from April to June. Rice is grown on rainfed land and on land irrigated from major and minor dams or tanks; these comprise the three main water regimes. The major tanks support nationally managed irrigation systems which command large, contiguous rice-growing areas. Minor tank schemes are managed by local communities and command irrigated rice areas ranging up to about 50 ha. The study areas irrigated from major tanks are typically located at low-landscape positions, while those irrigated from minor tanks are at a generally higher elevation, normally not distant from the major tank schemes.

The broad objectives of the socioeconomic project were to: (1) determine the performance of farmers and crops within complex farming systems located in less favourable areas of production, including individual crops within the system; (2) compare farmers' crop performance with that achievable under field trial conditions; (3) determine and quantify factors contributing to yield gaps between farmers and field trials.

A series of farm-level surveys was undertaken over a number of crop seasons and years which took account of all crop, other farm and nonfarm activities. These surveys were paralleled in the agronomic project by complementary field trials which were designed to test and extend the technology under varying conditions. To quantify and explain the range in farm performance under different agro-environmental and socioeconomic settings, a frontier production function framework was used. Broadly, this approach gives the frontier or best practice performance for any given set of input levels. Performance levels below the frontier (i.e. the degree of technical efficiency) can be quantified. Other techniques were then applied to determine why farmers failed to reach their frontiers. In other words, farmers were individually ranked according to their technical performance, and attempts were made to identify the factors that determined the rankings. Based upon this, certain policy implications can be drawn. The approach also permits measurement of the other component of overall economic efficiency, viz. allocative efficiency.

Kurunegala is one of the major rice growing distircts in Sri Lanka. Nearly 11% or 79 000 ha of the total riceland is located in this district, the major part of which lies in the low country (up to 300 m above sea level) and has an annual rainfall of 1500–2290 mm. About 20% of Kurunegala's total riceland is under major tanks, 40% is under minor tanks and the remaining 40% is rainfed. During the course of the project, it was found that there were also farms with mixed, irrigated/rainfed conditions. The study areas chosen were close to the Central Rice Breeding Station at Batalagoda.

Anuradhapura district is representative of the low country and receives an annual rainfall of about 1500 mm. The major portion of this, about 910 mm, is received during the *Maha* season with about 410 mm during the *Yala* season. The rest of the year is generally dry, particularly during the south-west monsoon from May to August. The study areas were located in two places. One was Rajangana, with a large dam and irrigation scheme, where farmers also cultivate upland crops. The second area was near the Agricultural Research Station at Maha Illuppallma and comprised a number of minor tank areas.

In this report Chapter 1 summarises the results of the agronomic field experiments, comparing researchers' and farmers' yields. In Chapter 2, the farming systems and associated socioeconomic farm surveys are described. The economic analysis is presented in Chapter 3 with the methodology underlying it in Chapter 4. A water balance study, highlighting the influence of water availability on yield of rainfed rice, is outlined in Chapter 5. The conclusions are set out in Chapter 6.

CHAPTER ONE

Agronomic Aspects of the Rice-yield Gap Between Farmer and Researcher

B.M.K. Perera, M.P. Dhanapala, D.B. Wickremasinghe, C. Fazekas de St. Groth and R. Wetselaar

Average rice yields have shown a marked increase during the last few decades since the introduction of high-yielding varieties, but there have been indications that many farmers have not been obtaining the high yields that could be achieved through the application of modern rice technology. Studies associated with the yield gap and the possible reasons for its existence have been confined to fully irrigated areas (Gunasena et al. 1977, Jogaratnam et al. 1979) and there was a need to undertake similar studies in the North Central Dry Zone.

The aim of the agronomic project was to determine the magnitude of this gap in two agroecological regions, the Intermediate and the Dry Zones. To this end, a series of onfarm experiments was initiated to quantify the gap over three seasons. Thereafter, a second series of onfarm experiments was conducted, also over three seasons, to try to identify and quantify the agronomic factors contributing to the yield gap. CSIRO collaborated in this second series. Both series were conducted in the two districts Kurunegala and Anuradhapura and covered *Maha* (major) and *Yala* (minor) seasons and the different water regimes. The results of these studies, together with their implications, are given below.

Methods

The onfarm experiments of the first series covered *Maha* 1983–84, *Yala* 1984 and *Maha* 1984–85. In each season, about 15 experiments were conducted in each of the two districts, Kurunegala and Anuradhapura, each experiment consisting of two large plots, one being managed as the farmer normally treated his land at that location, the other being managed by the researcher as per recommendations of the Department of Agriculture.

The experiments of the second series were conducted during *Yala* 1985, *Maha* 1985–86 and Yala 1986, again in both districts. In each season, there were 12 to 19 experiments (Table 1). Each of these consisted of four treatments (Table 2) by two replicates in an incomplete factorial design. In the analysis of the grain yield data, some experiments could not be included (Table 1), because of adverse conditions such as severe water stress, little or no grain formation, or trampling by elephants.

In both series, the experiments covered a range of water regimes and rice varieties of different durations. The method (sowing or transplanting) and timing of crop establishment were deter-

Table 1. Number of experiments initiated, and those abandoned or not considered as representative, for the second series of experiments.

	Kurunegala		Anuradhapura	
	Initiated	Abandoned	Initiated	Abandoned
	Number of experiments			
Yala 1985	6	1	6	1
Maha 1985–86	12	0	7	1
Yala 1986	6	0	7	4

Table 2. Description of treatments in the experiments of the second series.

Treatment	Description
$W_0F_0P_0$	Farmer inputs in terms of weed control (W), fertilizer (F), and insect pest control (P)
$W_1F_0P_0$	Rec.* weed control + F_0P_0
$W_1F_1P_0$	Rec. weed control + rec. fertilizer + P_0
$W_1F_1P_1$	Rec. weed control + rec. fertilizer + rec. insect pest control

*Recommended by the Sri Lanka Department of Agriculture.

mined by the farmer, as was the initial land preparation, with the researcher having the option of improving on this cultivation for the treatments managed by him. In the Anuradhapura district, the researcher always used the same variety and seed stock as the farmer; however, in the Kurunegala district, the seed material used for researcher-managed plots of the first series was provided by the Central Rice Breeding Station (CRBS), while the selection of the variety depended on the farmer. For the second series, all treatments were planted with the same variety as selected by the farmer, but supplied by CRBS. In all experiments of both series, the water management for all plots was left entirely to the farmer.

The recommended fertilizer applications are given in the Appendix. Both farmers and researchers applied N in the urea form, P as triple superphosphate, and K as muriate of potash. In both cases, all P was always applied at crop establishment. The N and K fertilizers were applied as split applications, either according to the wishes of the farmer or according to the recommendations.

For the first series, the plot sizes were 100 m^2 and 500 m^2 for Kurenegala and Anuradhapura respectively; in each case, about 20% of these plots was harvested for grain yield assessment. For the second series, the plot sizes were 8 m^2 and 10 m^2 respectively, of which 6 m^2 and 8 m^2 were cut for grain yield assessment respectively.

During the last two seasons of the second series (*Maha* 1985–86 and *Yala* 1986), plant samples were collected at anthesis from all plots in all experiments to assess dry matter and nitrogen uptake. To this end, the above-ground parts of whole plants were collected from two 0.25 m^2 areas in each plot. A subsample was oven-dried at 70°C. After grinding, this subsample was used for total N determination using a modification of the Kjeldahl digestion technique.

During the first series, soil samples were collected at all locations in the Kurunegala district and analysed for a wide variety of soil properties (Table 5). In addition, soil samples were taken during the last two seasons of the second series, at each location at the start of each season, for the determination of total soil N, ammoniacal N, and potentially available N during the season. After air-drying, the samples were crushed to pass a 1 mm sieve. Total N was determined according to Bremner (1965a); ammoniacal N was assessed by distillation of a 2N KCl extract, using MgO (Bremner 1965b), while for potentially available N, the incubation method of Waring and Bremner (1964) was used.

The grain yield gap was analysed by multiple regression using the GENSTAT (1983) statistical package, with the difference between researchers' and farmers' yields, calculated at each location, as the dependent variable.

Results

The first series

In all seasons, in both districts, and under all water regimes, the researcher-managed (R) plots gave significantly higher grain yields than the farmer-managed (F) plots (Table 3). From the socioeconomic point of view, the yield gap (R yield minus F yield) is of more interest than the actual yields. Furthermore, working with the yield gap rather than the R and F yields eliminates some of the considerable variation between locations, mainly due to environment. The yield-gap means presented in Table 4 appear to decrease with time. This trend is more marked in the Kurunegala district, perhaps reflecting the fact that in that district most of the farmers selected for the trials had experiments on their farms for the three seasons, while in the Anuradhapura district different farmers were selected each season. It has been reported that farmers tended to increase their inputs in order to meet the perceived challenge by the researcher.

One important aspect of the increased inputs by the farmer was a possible closing of the fertilizer-

Table 3. Mean grain yields for researcher- and farmer-managed fields for each season and each district, for the first series of experiments.

		Maha 1983–84	*Yala* 1984	*Maha* 1984–85	Mean
			Grain yield (t/ha)		
Kurunegala	R*	5.62	4.92	5.00	5.19
	F*	3.96	3.54	4.14	3.89
	Mean	4.79	4.23	4.57	4.54
Anuradhapura	R	4.91	4.40	5.50	5.09
	F	3.25	3.16	4.19	3.64
	Mean	4.08	3.78	4.84	4.37
District mean	R	5.23	4.76	5.28	5.14
	F	3.57	3.42	4.17	3.77
	Mean	4.40	4.09	4.72	4.40

*R = researcher managed, F = farmer managed.

Table 4. Mean grain-yield gap (R* grain yield minus F grain yield) for each season and each district, for the first series of experiments.

	Maha 1983–84	*Yala* 1984	*Maha* 1984–85	Mean
		Grain yield (t/ha)		
Kurunegala	1.66	1.38	0.86	1.30
Anuradhapura	1.66	1.24	1.31	1.45
Mean	1.66	1.34	1.11	1.37

*R = researcher managed, F = farmer managed.

N gap (amount of fertilizer N used by the researcher minus amount of fertilizer N used by the farmer); this variable was therefore used in the analysis of the yield gap. Other factors, such as increased use of pesticides (and use of the appropriate ones), timing of fertilizer application, etc. were not measured, but could have been partly responsible for the yield-gap decrease in time.

Regression analyses on the yield gap showed fertilizer-N gap to be a significant explanatory variable, whereas water regime (major/minor tanks, rainfed) and variety (duration) were nonsignificant; the trend with time was also nonsignificant. Even in a separate analysis of the Kurunegala district, the time trend was nonsignificant, after the fertilizer-N gap effect, which was significant, had been removed.

In turn, the fertilizer-N gap was significantly different for the different water regimes, being highest for the rainfed and lowest for the major tanks, reflecting greater caution by the farmer when water supply is less reliable.

In reality, the yield gap is likely to be greater than the results in Tables 3 and 4 indicate, partly because of the observed influence of the researcher's activities on the farmer, and partly because the selection process of farmers participating in the experiments inevitably biases towards 'better' farmers.

There was a highly significant correlation between R and F grain yields (Fig. 1). This corre-

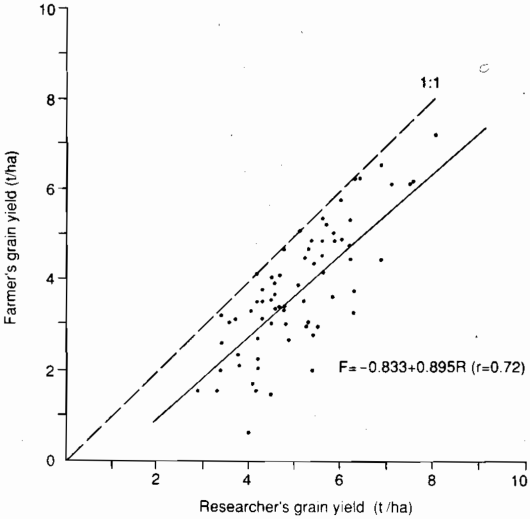


Fig. 1. Relationship between researcher's and farmer's grain yield for all locations for the first three seasons.

lation was improved by omitting five R–F comparisons on the grounds that a fair comparison could not be made in view of the extreme conditions of the F plots concerned. On that basis, there was no significant difference in slope between the two districts.

This relationship suggests that either both R and F yields were highly dependent on the farmer at each location, for each season, or that both R and F yields were influenced by other factors such as evironmental ones like soil and climate. The former implication is untenable as the farmer had little influence on the performance of the research-managed plots. Therefore, statistical analyses were carried out to test the relationship between the grain yields of the researcher-managed plots and a range of soil properties. None of the measured soil properties showed a significant correlation with grain yield (Table 5). Of these variables, total N content in the topsoil appears to be the most promising one to include in future tests for the development of yield-level predictions. Furthermore, no significant relationship could be found between the researchers' yields and season, district, water regime, variety (duration), applied N (within a narrow range at or above the recommendation), or time.

Table 5. Correlation coefficients between researchers' yields and some soil properties, measured in the Kurunegala district, for the first series of experiments.

	Correlation coefficient
pH	−0.38
Total N	0.51
Available P	0.13
Exchangeable K	−0.24
Cation exchange capacity	0. 18
Organic matter	0.06
Clay	0.22

No statistical analyses were undertaken on the Marginal Profit Ratios (MPR) in view of the wide variation in ratio values between individual plots. In Table 6 the means are presented for districts, seasons, and water regimes. Only in the Kurunegala district, for minor tanks, was the ratio less than 2. However, it should be kept in mind that of the 70 individual ratios, 17% were negative, while only 46% were less than 2. Further economic analyses would be required before any major conclusions can be drawn.

The second series

The grain yields for the two districts for all treatments are given in Table 7 for each season. Almost invariably, the yield increased as more recommended practices were applied. Since the experimental design was an incomplete factorial, it was not possible to test the effect of each recommended practice in isolation.

In the Kurunegala district, significant grain yield increases were obtained only through the addition of recommended insect pest control (W_1 F_1 P_1) in the first two seasons. In the third season, only the addition of recommended weed control (W_1 F_0 P_0) over farmer practice (W_0 F_0 P_0) increased grain yield significantly.

Table 6. Mean* Marginal Profit Ratios (MPR) by water regime, district, and season.

	Major tank	Minor tank	Rainfed	Mean
Kurunegala	3.22	1.53	2.74	2.60
Anuradhapura	5.51	3.45	—	3.93
Mean	3.96	2.90	2.74	3.26
	Maha 1983–84	*Yala* 1984	*Maha* 1984–85	
District mean	2.50	2.21	8.15	

*The means were calculated according to the formula:

$$\text{Mean MPR} = \frac{\Sigma_i\ [(RI_i - RC_i) - (FI_i - FC_i)]}{\Sigma_i\ (FI_i - FC_i)}$$

where

RI_i = income from the researcher-managed plot at location i,

RC_i = costs of the researcher-managed plot at location i,

FI_i = income from the farmer-managed plot at location i, and

FC_i = costs of the farmer-managed plot at location i.

Table 7. Rice grain yields for three seasons and two districts as affected by weed control, fertilizer, and insect pest control treatments (means of all locations within one district and one season) for the second series of experiments.

Season	District	No. of sites	$W_0F_0P_0$*	$W_1F_0P_0$*	$W_1F_1P_0$*	$W_1F_1P_1$*	S.E.D.
			Grain yield (t/ha)				
Yala 1985	K'gala	(5)	2.13 a	2.36 a	2.62 a	3.79 b	0.19
	A'pura	(5)	4.04 a	4.16 a	4.71 b	5.21 c	0.18
Maha 1985–86	K'gala	(12)	4.05 a	4.07 a	4.04 a	4.60 b	0.08
	A'pura	(6)	5.39 a	5.68 b	6.53 c	6.99 d	0.13
Yala 1986	K'gala	(6)	4.08 a	4.55 b	4.52 b	4.83 b	0.19
	A'pura	(3)	3.96 a	4.11 a	4.68 b	4.81 b	0.14
Means of seasons	K'gala	(23)	3.42	3.66	3.73	4.40	
	A'pura	(14)	4.46	4.65	5.35	5.67	
Yala 1985	Means of districts	(10)	3.09	3.26	3.67	4.50	
Maha 1985–86		(18)	4.72	4.88	5.29	5.79	
Yala 1986		(9)	4.02	4.33	4.60	4.82	

*For description of treatments, see Table 2.
**Data on the same line followed by a different letter differ significantly at the P=0.05 level.

In the Anuradhapura district, the addition of recommended fertilizer (W_1 F_1 P_0) to farmer practice + recommended weed control (W_1 F_0 P_0) increased grain yield significantly in all seasons. More than likely, this reflects the fact that in this district the farmers used much less fertilizer than the researcher (Table 8), presumably in view of the greater risk of crop failure. This risk is emphasised by the relatively high number of experiments that had to be omitted from the grain yield analyses due to failure (Table 1). In contrast, in the Kurunegala district, this risk is much less and the farmer used at least as much fertilizer as the researcher (Table 8); consequently the grain yields in this district for farmer practice + recommended weed control (W_1 F_0 P_0) were similar to those for farmer practice + recommended weed control + recommended fertilizer (W_1 F_1 P_0) (see also mean of seasons in Table 7).

The significant effect of additional fertilizer application (up to recommended level) in Anuradhapura and its absence in Kurunegala is also reflected in the data for dry matter (Table 9) and plant N yield (Table 10). For dry matter, as for

Table 8. Average amount of fertilizer–nutrient used by farmer and researcher for five out of the six seasons (data for *Yala* 1985 not available), for each district.

	Season 1 *Maha* 1983–84	Season 2 *Yala* 1984	Season 3 *Maha* 1984–85	Season 5 *Maha* 1985–86	Season 6 *Yala* 1986	Mean
			N, P_2O_5 or K_2O (kg/ha)			
K'gala RN*	99	101	108	103	93	101
FN	69	83	110	107	83	90
RP*	67	64	56	66	65	64
FP	45	47	46	46	34	44
RK*	53	51	47	54	54	52
FK	36	43	45	47	32	41
No. of locations	12	11	12	12	6	
A'pura RN	91	87	105	106	102	98
FN	69	53	75	43	70	63
RP	62	62	62	62	62	62
FP	22	21	30	6	23	20
RK	46	46	46	52	52	48
FK	23	12	26	7	23	14
No. of locations	15	5	15	6	3	

* R = researcher managed, F = farmer managed,
N = nitrogen fertilizer, P = phosphate fertilizer,
K = potassium fertilizer.

Table 9. Total plant dry matter (above-ground) at anthesis for two seasons and two districts as affected by weed control, fertilizer, and insect pest control treatments (means of all locations within one district and one season) for the second series of experiments.

Season	District	No. of locations	$W_0F_0P_0$*	$W_1F_0P_0$*	$W_1F_1P_0$*	$W_1F_1P_1$*	S.E.D.
					Dry matter (t/ha)		
Maha	K'gala	(12)	5.82a	5.76a	6.10a	6.31a	0.16
1985–86	A'pura	(6)	6.84a	7.46b	8.57c	8.58c	0.26
Yala 1986	K'gala	(6)	6.39a	7.11a	6.51a	6.24a	0.41
	A'pura	(6)	4.97a	5.60a	6.58b	6.85b	0.35
Means of seasons	K'gala	(18)	6.10	6.44	6.30	6.27	
	A'pura	(12)	5.90	6.53	7.57	7.71	
Maha 1985–86	Means of districts	(18)	6.33	6.61	7.33	6.35	
Yala 1986		(12)	5.68	6.35	6.55	6.54	

* For description of treatments, see Table 2.

** Data on the same line followed by a different letter differ significantly at the P=0.05 level.

Table 10. Plant-N yield in total dry matter (above-ground) at anthesis for two seasons and two districts as affected by weed control, fertilizer, and insect pest control treatments (means of all locations within one district and one season), for the second series of experiments.

Season	District	No. of locations	$W_0F_0P_0$*	$W_1F_0P_0$*	$W_1F_1P_0$*	$W_1F_1P_1$*	S.E.D.
					N yield (kg/ha)		
Maha 1985–86	K'gala	(12)	88a	88a	89a	98b	3.7
	A'pura	(6)	102a	105a	136b	150b	7.5
Yala 1986	K'gala	(6)	82a	85a	80a	76a	7.1
	A'pura	(6)	67a	68a	97b	97b	6.8
Means of seasons	K'gala	(18)	85	87	85	88a	
	A'pura	(12)	85	86	116	124	
Maha 1985–86	Means of districts	(18)	95	97	113	125	
Yala 1986		(12)	75	76	89	87	

* For description of treatments, see Table 2.

** Data on the same line followed by a different letter differ significantly at the P=0.05 level.

grain yield, there was an additional significant response to recommended weed control (W_1 F_0 P_o) over farmer practice (W_0 F_0 P_0) in *Maha* 1985–86. Since the dry matter is determined at anthesis, the weed control effect must have taken place in the early stages of growth, as could be expected.

The addition of recommended insect pest control in the presence of recommended weed control and fertilizer (W_1 F_1 P_1) had a significant effect on grain yield in four of the six seasons (Table 7). The fact that dry matter at anthesis was not affected at all (Table 9) and N yeild, also at anthesis, only on one occasion (Table 10) by the addition of recommended pest control, indicates that most of the insect problems checked by the recommended control occurred during grain formation. In *Yala* 1986, there was little occurrence of insect pests and hence there was no significant yield response to recommended insect pest control. The significance of this response in the previous two seasons in both districts suggests that, in general, farmers do not follow the recommendations for pest control sufficiently. It can be calculated from Table 7 that they stand to lose on average about 0.5 t/ha of grain for each crop.

The grain yield gap over six seasons

The graph of farmer-managed (F) and researcher-managed (R) grain yields over all seasons (Fig. 2) indicates that almost invariably the farmer obtained a lower yield than the adjacent researcher. The average grain yield gap (Table 11) was as high as 1.66 t/ha in *Maha* 1983–84 and as low as 0.55 t/ha in *Maha* 1985–86. Multiple regression analy-

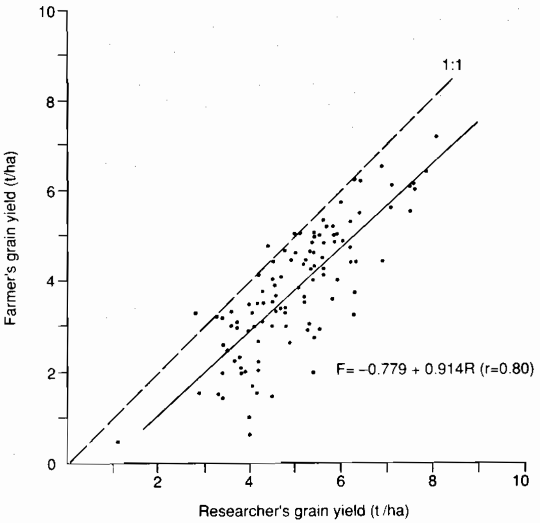


Fig. 2. Relationship between researcher's and farmer's grain yield for all locations for all six seasons.

sis showed that this gap (for which *Yala* 1985 had to be omitted because no N inputs were available) was significantly affected only by the fertilizer-N gap and time (season 1–6). The smaller the fertilizer-N gap, the smaller the grain yield gap, and there was a significant decrease of the yield gap in time.

Plant N yield and fertilizer-N recommendation

The results for the two districts confirm that N fertilizer plays an important role in determining grain yield. For the farmer, this input is a costly one and is therefore used with restraint. Where crop failure due to water stress is likely to occur, the farmer is more inclined to restrict its application. However, in cases where irrigation water is available when required the farmer is in a position to increase his grain yield by applying more N fertilizer. Unfortunately, at present the recommendations are not location-specific and are necessarily broad; their adoption could therefore lead to inputs above or below the optimum amount. Thus, there is a need for a recommendation adjusted to local conditions such as soil N supply.

In general, there is a relationship between plant-N yield at anthesis and grain yield (Sudjadi et al.

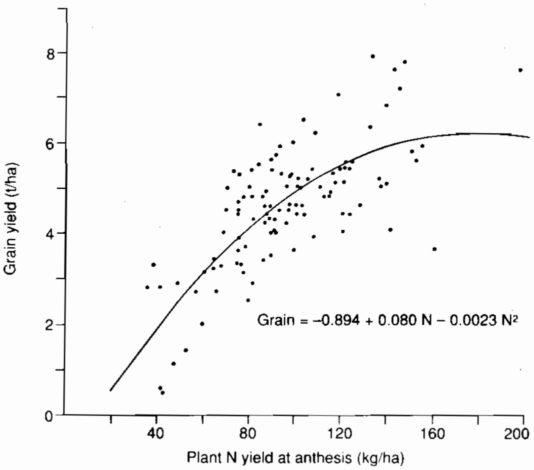


Fig. 3. Relationship between plant-N yield at anthesis and grain yield for all locations for the last two seasons.

Table 11. Grain yield and yield gap (R* grain yield minus F* grain yield) for six seasons and two districts (mean over all locations).

	Maha 1983–84	*Yala* 1984	*Maha* 1984–85	*Yala* 1985	*Maha* 1985–86	*Yala* 1986
			Grain yield (t/ha)			
Kurunegala						
R	5.62	4.92	5.00	3.79	4.60	4.83
F	3.96	3.54	4.14	2.13	4.05	4.08
Gap	1.66	1.38	0.86	1.66	0.55	0.75
Anuradhapura						
R	4.91	4.40	5.50	5.21	6.99	4.81
F	3.25	3.16	4.19	4.04	5.39	3.96
Gap	1.66	1.24	1.31	1.17	1.60	0.85
Mean gap**	1.66	1.31	1.09	1.42	1.08	0.80

*R = researcher managed, F = farmer managed.
** Unweighted mean.

1987). This relationship was investigated for the two seasons for which the relevant data were available for each district (Fig. 3). The N supply for the N yield (Ny) is determined by the amount of N available in the soil between establishment and anthesis. This availability is a function of the amount of ammoniacal N in the soil at time of establishment (Ne), the total amount of N in the topsoil (Nts) and the amount of fertilizer N applied (Nf). Thus,

$$Ny = a(Ne + b.Nts + c.Nf) \qquad (1)$$

where 'a' represents the proportion of available N taken up by the plant. The coefficient 'b' is the proportion of total N that is ammonified during the growing season, while coefficient 'c' is the proportion of fertilizer N not lost through processes such as denitrification, ammonia volatilisation, leaching and runoff.

A close relationship between Ny and actual plant-N yield would create a more solid basis for N fertilizer recommendations. However, in this study, no significant correlations between actual plant N yield and Ny were found, assuming coefficient values of $a=0.5$, $b=0.05$ (Wetselaar 1967) and $c=0.8$, or assuming $a=0.5$, $b=$incubation value for each soil (proportion of total soil N ammonified), and $c=0.8$. In addition, when equation (1) was fitted to the existing data, the variables on the right hand side of equation (1) were of no use in predicting plant-N yield. Clearly, the equation is not sufficiently general to cover all the processes that affect the magnitude of the coefficients.

In general, it must be concluded that it is not possible at this stage to make the current N-fertilizer recommendations more location-specific by using pre-establishment soil measurements.

Table 12. Comparison between researcher managed (R) and farmer managed (F) fertilizer–N efficiencies based on N inputs and plant-N yields.

	Plant N yield			Fertiliser N					
Soil No.	R	F	R-F	R	F	R–F	R>F*	R=F*	R<F*
				kg/ha					
Kurunegala *Maha* 1985–86									
1	124	116	8	120	98	22			
2	115	101	14	120	92	28			
3	79	49	30	120	63	57			
4	76	60	16	120	98	22	+		
5	97	121	−24	120	132	−12			
6	153	96	81	101	133	−32	+		
7	75	76	−1	87	119	−32	+		+
8	77	66	11	87	91	−4	+		
9	101	80	21	87	98	−11	+		
10	70	90	−20	91	117	−26		+	
11	98	98	0	91	129	−38	+	+	
12	122	103	19	86	114	−28	+	+	+
Anuradhapura *Maha* 1985–86									
28	151	139	12	87	52	35			
29	119	90	29	125	20	105			
30	134	85	49	87	18	69	+		
32	143	99	44	130	69	61	+		
33	198	108	90	87	50	37	+		
34	157	92	65	118	50	68	+	+	+
Anuradhapura *Yala* 1986									
22	83	91	−8	102	39	63			
23	81	57	24	101	97	4			
24	120	111	9	102	100	2	+		
26	52	26	26	102	84	18	+		
27	60	39	21	101	62	39	+	+	+

*R−F: the fertilizer N of the researcher and of the farmer were used equally efficiently, i.e. the recovery in the plant of the extra N applied by the researcher or the farmer was between 30% and 60%.

R>F: the fertilizer N of the researcher was used more efficiently than that of the farmer, i.e. the recovery in the plant of the extra N applied by the researcher was greater than 60%.

R<F: the fertilizer N of the farmer was used more efficiently than that of the researcher, i.e. the recovery in the plant of the extra N applied by the farmer was greater than 60%.

Fertilizer-N and plant-N efficiency

Paddy fields are reputed to induce low recoveries of fertilizer N in the plant, a recovery of only 40% being quite common. Such recoveries can only be calculated when the plant-N yield for controls (no fertilizer N) are known. In their absence, all that can be done is to make a comparison between the plant N yield (R) and the plant-N yield (F) for each site in relation to its respective inputs. If both R and F had the same N yield and the same N input, their fertilizer N would have been used equally efficiently (see R = F column in Table 12). On the other hand, if the N yield for R and F were the same, but the farmer had a higher N input, then it could be concluded that the researcher had used the fertilizer N more efficiently than the farmer (see R > F column in Table 12).

Such a comparison was made for all locations for which the relevant data were available (Table 12). It was assumed that R = F when between 30% and 60% of the fertilizer-N difference was recovered in the plant, as expressed by the extra plant-N yield. In only 17% of the comparisons was the farmer more efficient than the researcher, while in 61% of the cases the farmer was less efficient. This implies that there is scope for improvement in the way the farmer manages his N fertilizer, for example, through more extension advice on timing of application.

All N taken up by the plant contributes to the formation of grain i.e. in general, the higher the plant-N yield at anthesis, the higher the grain yield (Fig. 3). The efficiency of plant N to produce grain (the amount of grain produced per kg of plant N) is generally higher for plants with a lower N yield (Fig. 4). The actual results for the last two seasons compare reasonably well with the results of irrigated experiments located on a research station in N.E. Java, Indonesia, using the variety IR36. If only the researcher-managed treatments (W_1 F_1 P_1) that did not have any water stress are considered, the comparison with the Indonesian experiments is more favourable. The relatively high values at high plant-N yields might reflect the effect of a longer growing season for some of the varieties used, compared with the short-duration IR36 in Indonesia.

Overall, the results in Fig. 4 suggest that when paddy fields are properly managed and when water is not a limiting factor, the environment of the two districts together with the varieties used are conducive to a relatively high N efficiency in the rice plant.

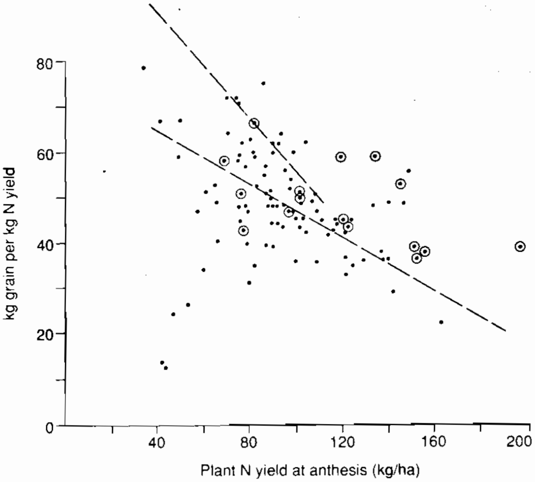


Fig. 4. Relationship between plant-N yield at anthesis and amount of grain produced per kg plant-N yield for all locations for the last two seasons.
● All locations
⊙ Only research-managed and only where no water stress
--- Results from researcher-managed experiments with IR36 in Indonesia (Sudjadi et al. 1987).

Discussion and Conclusions

Both series of onfarm experiments confirmed that there is a substantial yield gap between researcher-managed (R) and farmer-managed (F) plots, being on average as high as 1.66 t/ha in *Maha* 1983–84 and as low as 0.55 t/ha for *Yala* 1986 (Table 11), with an overall average of 1.23 t/ha. However, when we consider that:

(i) experiments on farmers' fields require the cooperation of the farmer himself; most probably a cooperative farmer is one of the better farmers,

(ii) it has been reported that farmers tended to increase their inputs and improve their management in order to meet the perceived challenge by the researcher,

it must be concluded that the actual yield gap is likely to be greater than that presented in Table 11.

The apparent temporal decrease of the gap could be due, in part, to a gradual adoption by the farmers of the recommendations of the Department of Agriculture, but since the magnitude of the gap was very location and season dependent, a longer series of yield gap measurements would be needed to draw a confident conclusion that the farmers' yields are improving. However, the fertilizer-N gap itself did not significantly decrease in time and therefore any decrease in yield gap was not due to increased N application by the farmers. More specifically, the analyses over the first series (first three seasons) and over both series (all six seasons) point to the fact that the farmer appears to 'manage' N fertilizer better, perhaps through better timing of application rather than through increasing the amount of N input. Yet, the results in Table 12 indicate that there is still scope for improvement of N fertilizer management by the farmer.

In the Kurunegala district, grain yield, dry matter, and plant-N yields were not affected in any of the last three seasons by switching from farmers' N input to researchers' N input (Tables 7, 9, and 10), while in Anuradhapura such a switch produced a significant difference in each season. For the former district, it is quite possible that both researchers and farmers applied too much fertilizer N, because, as has been said above, in most cases the farmer used his N input less efficiently than the researcher, and yet there was no significant difference in grain yield.

For the Anuradhapura district, the marked differences between researchers' and farmers' grain yields, due to the application of additional N up to the recommended amount, almost certainly reflect a greater cautiousness by the farmer in view of the risks associated with a drier climate. Economic assessments, based on location-specific probabilities of water availability, might provide the farmer with a better guide to the average amount of N fertilizer he can afford to apply. In addition, research should be undertaken to assess the possibility of postponing part of the N application until it is known that chances of crop failure due to drought are low. This would be greatly aided by provision of location-specific probabilities of water availability later in the growing season.

The results of the first three seasons showed that soil N content was a possible candidate for relating a soil property to grain yield. Further analyses, based on more detailed soil N availability measurements during the last two seasons, could not substantiate this. As a result, it was not possible to produce a simple model that would give more location-specific guidance for N-fertilizer recommendations. Therefore, the best strategy at present is for the farmer to manage his N fertilizer according to the Department of Agriculture recommendations when water is not likely to be a limiting factor.

Of the three components of the Department of Agriculture recommendation investigated over the last three seasons, weed control appears to have the least influence on the yield gap. This is not unexpected, as farmers have traditionally learned to control weeds. It must be kept in mind, however, that there might be seasons in which weed problems are more severe than those encountered during this project.

The results from the second series of experiment strongly indicate that insect pest control, especially during grain formation, is the most important factor that could improve farmers' yields. When the recommendations are not followed the farmer will, on average, lose 0.5 t/ha of grain. Nearly all farmers tried to take some measures to prevent or reduce the effects of insects, but were not always very successful. Increased extension by the Department of Agriculture related to pest identification and control could contribute to overcoming the pest problem. In addition, use could be made of the fact that, in the districts concerned, rice is grown in discrete pockets that lend themselves to regional control rather than to an individual farm approach.

The following conclusions emerge from the project:

(i) There is indeed a grain-yield gap between farmer-managed and researcher-managed fields, being on average about 1.2 t/ha. The major and most consistent factor contributing to this gap was lack of effective insect pest control, particularly during grain formation. There are indications, however, that this gap is decreasing in time. This is most likely due to improved farmers' practices, of which better management of N fertilizer was the most important one in this project.

(ii) A more intensive extension by the Department of Agriculture related to insect pest recognition and N-fertilizer management is warranted.

(iii) The possibility of controlling insect pests on a regional scale could be investigated.

(iv) A location-specific recommendation for N fertilizer rates based on easily measurable soil-N properties alone does not appear possible at present.

Acknowledgment

The laboratory N analyses of all soil and plant material for the second series by Mr. Rob Sageman of the CSIRO Division of Water and Land Resources, Canberra, Australia, are gratefully acknowledged.

References

Bremner, J.M. 1965a. Total nitrogen. In Black, C.A. ed. Methods of Analysis Part 2 Chemical and Microbiological Properties, Madison, Wisc. Am. Soc. Agron. 1149–1178.

1965b. Inorganic forms of nitrogen. In Black, C.A. ed. Methods of Analysis and Microbiological Properties, Madison, Wisc. Am. Soc. Agron. 1179–1237.

GENSTAT. 1983. A general statistical program, N.G. Alvey et al. Release 4.04. Rothamstead Experimental Station, Harpenden, U.K.

Gunasena, H.P.M., Jinadasa, A.P., Jogaratnam, T. and Premakumar, V. 1977. Giritale, Sri Lanka 1975–76. In: Constraints to high yields on Asian rice farms: An interim report. Los Baños, IRRI.

Jogaratnam, T., Dias, J.N.S. and Jayawardena, A. 1979. Constraints to high rice yields in Sri Lanka. In: Farm-level constraints to high rice yields in Asia. 1974–77. Los Baños, IRRI.

Sudjadi, M., Prawirasumantri, Y. and Wetselaar, R. 1987. Nitrogen fertilizer efficiency in lowland rice in Indonesia. In: Efficiency of nitrogen fertilizers for rice. Los Baños, IRRI, 123–134.

Waring, S.A. and Bremner, J.M. 1964. Ammonia production in soil under waterlogged conditions as an index of nitrogen availability. Nature 201, 951–952.

Wetselaar, R. 1967. Determination of the mineralization coefficient of soil organic nitrogen on two soils at Katherine, N.T. Aust. J. Exp. Agric. Anim. Husb. 7, 266–274.

Appendix

Fertilizer recommendations of the Sri Lanka Department of Agriculture for improved rice varieties in the low country dry zone of Sri Lanka

	(kg/ha)
A. For nursery for transplanted rice	
Basal V1 (3:30:10)	300
Ten days after sowing, urea (46:0:0)	75
B. 3–3.5 month varieties — direct sown	
At levelling, basal V1 (3:30:10)	185
Two WAS*, urea (46:0:0)	62
Five WAS, urea (46:0:0)	31
Seven WAS (for 3-month variety), TDM† (30:0:20)	124
Eight WAS (for 3.5-month variety), TDM (30:0:20)	124
C. 3–3.5 month varieties — transplanted	
At levelling, basal V1 (3:30:10)	185
Two WAT,** urea (46:0:0)	93
Five WAT (for 3-month variety), TDM (30:0:20)	124
Six WAT (for 3.5-month variety), TDM (30:0:20)	124
D. 4–4.5 month varieties	
At levelling, basal V1 (3:30:10)	185
Two WAS or WAT, urea (46:0:0)	62
Six WAS or 4 WAT, urea (46:0:0)	62
Ten WAS or 8 WAT, TDM (30:0:20)	124

*WAS = weeks after sowing.
**WAT = weeks after transplanting.
†TDM = top dressing mixture.

CHAPTER TWO

Technical and Socioeconomic Characteristics of the Survey Farms

G.A.C. De Silva, R.T. Shand and S.K. Jayasuriya

This chapter provides background information and descriptive analysis derived from the socioeconomic farm surveys carried out in Kurunegala and Anuradhapura districts. It covers input use and costs, including labour sources and material inputs, especially fertilizers, and use of credit. It also includes yields, incomes and their source and distribution. Finally, it describes technical practices, human capital variables and farm/farmers' attributes which could influence farm-level performance, as analysed in Chapter 3. Additional information is available in the project working paper series (Sri Lanka).

In each district, a random sample of farmers was selected for the surveys from the farmers' register at the Agrarian Service Centre. Survey sample sizes varied between seasons since, although the same farmers were interviewed over the entire period of the farm surveys, the number actually growing paddy varied. Sample sizes are shown in Table 1. In Kurunegala, the most consistently large sample was under major irrigation (126 to 150), where irrigation water was available for both seasons. The minor tank sample was much smaller. The important rainfed sample was large in *Maha* but smaller in *Yala* owing to uncertainty of water supplies. There was also a small mixed irrigated/rainfed sample. In 1985–86, it was decided to restrict the survey to the rainfed sample and in addition to carry out a Close Monitoring Survey (CMS) on a subsample, with six visits to each farmer during *Maha* 1985–86.

The Anuradhapura surveys were less comprehensive owing to limitations in the availability of survey staff. Only major irrigation and minor tanks were included, and in *Maha* 1985–86, only minor tanks were surveyed as these were the most important in terms of project objectives.

Table 1. Sample sizes for the Kurunegala and Anuradhapura farm surveys by water regime from 1983–84 to 1985–86.

Season	Year	Major Irrigation	Minor Tanks	Rainfed	Mixed
		Kurunegala			
Maha	1983–84	144	42	138	n.a.[a]
Yala	1984	150	34	114	61
Maha	1984–85	146	34	162	54
Yala	1985	126	n.a.[b]	30	36
Maha	1985–86	n.a.[d]	n.a.[d]	207	n.a.[d]
Maha (CMS)[c]	1985–86	n.a.[d]	n.a.[d]	50	n.a.[d]
		Anuradhapura			
Maha	1983–84	128	75	n.a.[e]	n.a.[e]
Yala	1984	n.a.[d]	98	n.a.[e]	n.a.[e]
Yala	1985	n.a.[d]	72	n.a.[e]	n.a.[e]

n.a. Not available.
[a] Included in the rainfed sample.
[b] Observations were too few for analysis.
[c] Close monitoring survey.
[d] Not surveyed in this season.
[e] Not surveyed in this district as area concerned is negligible.

Rice farm size was typically small in Kurunegala district. Over 50% were between 0.5 and 1.0 ha except for the rainfed sample in which the majority of farms were smaller (under 0.5 ha). Generally, there were few between 1.0 and 2.0 ha and there were no farms larger than 2.0 ha.

Mean total labour inputs per hectare in Kurunegala for the crop year 1983–84 were highest under major irrigation (124 persondays) as might be expected, followed by minor tanks and mixed (91 and 95 respectively), with the rainfed sample showing the lowest inputs of 79 persondays per hectare. There was a consistent negative relation between rice farm size and the level of total labour inputs in all four water regimes.

Hired labour was used in all four water regimes in Kurunegala, with mean values declining with lack of assurance of water from 39 persondays per hectare under major irrigation to only 14 persondays per hectare under rainfed conditions. The use of hired labour per hectare increased with rice farm size in all water regimes except for the mixed sample where there was no consistency. Hired labour as a proportion of total labour increased substantially with farm size under major irrigation and minor tanks, changed little under rainfed conditions and showed no consistent trend under mixed conditions.

Mean total material costs per hectare were highest under minor tanks and major irrigation, and, as could be expected, were substantially lower for the mixed sample and lowest under rainfed conditions. There was a reduction of costs per hectare with increasing farm size under minor tanks and mixed conditions, but no trend under major irrigation or rainfed conditions. Interestingly, there was no discernible trend in total material costs per hectare over the range of total income in any of the four water regimes, possibly because, as a later table will show, nonfarm income was important.

In general, mean fertilizer costs per hectare declined with the reduction in assurance of water, from Rs1270 per hectare under major irrigation to Rs1015 per hectare under mixed and Rs885 per hectare under rainfed conditions. There was little variation by farm size in costs per hectare under major irrigation and minor tanks but there were reductions with increasing farm size in the other two water regimes. Again, mean fertilizer costs per hectare showed no clear trends over the range of total incomes in any of the four water regimes.

Mean yields were consistently highest for all seasons under major irrigation, varying from 2.92 to 3.63 t/ha in Kurunegala (Table 2). There were no notable differences between mean yields under minor tanks and mixed conditions. In the first three seasons, mean yields were lowest under rainfed conditions. Mean yield under rainfed conditions varied substantially, from 1.90 to 3.27 t/ha over the five seasons. Yields in the fewer seasons surveyed in Anuradhapura did not vary as greatly, and ranged from 2.08 to 2.54 t/ha.

Table 2. Mean rice yields for survey farmers by season and water regime in Kurunegala and Anuradhapura districts from 1983–84 to 1985–86.

Season	Year	Major Irrigation	Mean Yield (t/ha) Minor Tanks	Rainfed	Mixed
			Kurunegala		
Maha	1983–84	3.42	2.58	2.29	n.a.[a]
Yala	1984	2.92	2.49	2.06	2.64
Maha	1984–85	3.63	3.30	3.27	3.32
Yala	1985	2.97	n.a.[b]	1.90	2.82
Maha	1985–86	n.a.[d]	n.a.[d]	3.17	n.a.[d]
Maha (CMS)[c]	1985–86	n.a.[d]	n.a.[d]	3.07	n.a.[d]
			Anuradhapura		
Maha	1983–84	2.12	2.08	n.a.[e]	n.a.[e]
Yala	1984	n.a.[d]	2.51	n.a.[e]	n.a.[e]
Yala	1985	n.a.[d]	2.54	n.a.[e]	n.a.[e]

n.a. Not available.

[a] Included in the rainfed sample.

[b] Observations were too few for analysis.

[c] Close monitoring survey.

[d] Not surveyed in this season.

[e] Not surveyed in this district as area concerned is negligible.

Table 3. Mean prices of paddy sold and hired labour costs by season and water regime in Kurunegala and Anuradhapura from 1983–84 to 1985–86.

Season	Year	Major Irrigation	Minor Tanks	Rainfed	Mixed
		Kurunegala			
Maha	1983–84				
Paddy output (Rs/kg)		3.12	3.12	3.12	n.a.
Hired labour (Rs/person day)		29.18	30.47	30.30	n.a.
Yala	1984				
Paddy		3.48	3.48	3.48	3.48
Labour		25.31	24.98	24.04	25.12
Maha	1984–85				
Paddy		3.57	3.57	3.57	3.57
Labour		21.87	22.10	22.20	22.62
Yala	1985				
Paddy		3.76	n.a.	3.76	3.76
Labour		26.11	n.a.	26.00	26.85
Maha	1985–86				
Paddy		n.a.	n.a.	3.75	n.a.
Labour		n.a.	n.a.	28.18	n.a.
		Anuradhapura			
		Major Irrigation/Minor Tanks			
Maha	1983–84				
Paddy			3.29		
Labour			29.18		
Yala	1984				
Paddy			3.32		
Labour			30.47		
Yala	1985				
Paddy			3.44		
Labour			30.30		

n.a. Not available. For details, see Table 1.

Average prices for paddy reflected the administered price each year, constant by water regime but showing increases over time (Table 3). Mean hired labour costs varied only slightly by water regime within seasons but varied more between seasons. Fertilizer prices were controlled and remained constant over the entire survey period.

Input costs, hired and total labour, paddy prices, yields and total incomes are presented in Table 4 for the crop year 1983–84 in Kurunegala.

In all four water regimes in Kurunegala, income from sources other than paddy comprised the bulk of cash incomes in all but a few income

Table 4. Mean costs and returns from rice production by water regime in Kurunegala district for the year 1983–84.

Item	Unit	Major Irrigation	Minor Tanks	Rainfed	Mixed
Mean farm size	ha	0.73	0.79	0.55	0.85
Total pre-harvest labour	person days/ha	124	91	79	95
Hired labour	person days/ha	39	36	14	28
Hired labour as % of total labour	%	33	39	16	30
Fertilizer cost	Rs/ha	1270	1104	885	1015
Other material input costs	Rs/ha	1431	1612	994	1174
Total material input costs	Rs/ha	2701	2716	1879	2189
Mean rice yield	t/ha	3.42	2.58	2.29	2.96
Paddy price — *Maha*	Rs/kg	3.12	3.12	3.12	3.12
— *Yala*	Rs/kg	3.48	3.48	3.48	3.48
Total Income[a]	Rs	8170	10603	6724	6612

Annual figures are weighted averages of *Maha* and *Yala* crops in 1983–84.

[a] Total income = income from rice sales + livestock sales + other crop sales + nonfarm income for both seasons, i.e. *Maha* and *Yala*.

groups. The consistency and size of the contribution of nonfarm income is of particular importance.

Technical Practices

Under major irrigation in Kurunegala district, Modern (Bg) varieties from Batalagoda Research Station dominated farmers' choices from *Maha* 1983–84 onwards (Tables 5–8). Traditional (village) varieties covered total paddy areas varying from 17% under major irrigation to 3% under mixed conditions. However by *Yala* 1985, village varieties covered only very small percentages of the total paddy areas, and had disappeared from areas under major irrigation and minor tanks.

Amongst the new improved varieties (NIVs), there was also a shift in preference. In *Maha* 1983–84 and 1984–85, the 4-month variety Bg 400-1 enjoyed popularity under major irrigation with over 25% of the total area. Varietal choice was dominated later in the survey period by the two 3-month varieties, Bg 34-8 and Bg 276-5. By *Maha* 1985–86, these two varieties covered 64%, 87%, 82% and 73% respectively of total paddy area in the four water regimes. By *Yala* 1985, the same locations recorded 74%, 94%, 97% and 88% under these varieties. Of the two, Bg 34-8 became the dominant variety in each season. Bg 400-1, a 4-month variety, maintained some popularity in *Maha*, but was less popular in *Yala*.

Methods of establishment showed considerable variation under major irrigation by season and over time. All farmers applied at least one fertilizer dressing in *Maha* seasons and almost all applied a second. The pattern was quite similar in *Yala* but with somewhat lower proportions applying a second and third dressing in *Yala* 1985.

Very high proportions of farmers used P and K fertilizers regardless of season, with the exception of P fertilizer in *Yala* 1985 (58%). Use of pesticides was variable, ranging from 23% to 61% of farmers. Use of herbicide was consistently low, varying from zero to 24%, probably because of the

Table 5. Incidence of technical practices under major irrigation in Kurunegala district by season from *Maha* 1983–84 to *Maha* 1985–86 (percentage of farmers).

Practices	*Maha* 1983–84	*Maha* 1984–85	*Maha* 1985–86	*Yala* 1984	*Yala* 1985
Variety					
Bg 34-8	21	20	55	53	63
Bg 276-5	12	17	9	35	11
Bg 400-1	27	26	18	3	16
Village	17	4	0	0	0
Other	23	33	18	9	10
Establishment Method					
Broadcasting	20	8	64	33	14
Row transplanting	27	11	0	12	1
Random transplanting	52	81	36	55	85
Row seeding	1	0	0	0	0
Timing of establishment					
Early	6	0	0	3	1
On time	84	100	100	96	99
Late	9	0	0	1	0
No. of fertilizer dressings					
0	0	0	0	1	3
1	100	100	100	99	97
2	92	99	100	96	82
3	71	76	55	75	46
Use of P fertilizer	91	94	82	84	58
Use of K fertilizer	94	100	100	99	82
Use of pesticides	37	49	23	61	46
Use of herbicides	11	5	0	24	1
Use of manual weeding	72	86	64	48	30
Use of institutional credit	4	1	0	4	0

Note: Totals for seasons may not add to 100 due to rounding.

Table 6 Incidence of technical practices under minor tanks in Kurunegala district by season from *Maha* 1983–84 to *Maha* 1985–86 (percentage of farmers).

Practices	*Maha* 1983–84	*Maha* 1984–85	*Maha* 1985–86	*Yala* 1984	*Yala* 1985
Variety					
Bg 34-8	33	57	70	46	94
Bg 276-5	44	9	17	33	0
Bg 400-1	0	29	13	10	0
Village	13	0	0	0	0
Other	10	5	0	10	6
Establishment Method					
Broadcasting	76	37	27	69	88
Row transplanting	7	0	0	0	0
Random transplanting	17	63	70	31	12
Row seeding	0	0	3	0	0
Timing of establishment					
Early	2	0	0	5	0
On time	65	100	100	95	100
Late	33	0	0	0	0
No. of fertilizer dosages					
0	0	0	0	8	6
1	100	100	100	92	94
2	96	97	97	77	6
3	57	69	50	56	1
Use of P fertilizer	78	91	87	72	19
Use of K fertilizer	96	100	97	100	75
Use of pesticides	46	63	36	77	50
Use of herbicides	74	11	10	36	6
Use of manual weeding	67	80	63	49	25
Use of institutional credits	0	0	0	0	0

Note: Totals for seasons may not add to 100 due to rounding.

use of standing water as a control measure, combined with manual weeding, particularly in *Maha* seasons. Institutional credit was used only exceptionally by these farmers.

Under minor tanks, varietal choice showed a clear pattern of change over time (Table 6). In *Maha* seasons, the main change was from a preference for Bg 276-5 to Bg 34-8, both 3-month varieties. In all but one season, farmers were generally satisfied with their timing of establishment. *Maha* 1983–84 was an unusual season with late rains and a long wet season and one third of farmers reported late plantings. The seasonal rain factor is of course more important under minor tanks than major irrigation.

All farmers used at least one fertilizer dressing in *Maha* seasons and almost all applied two. Only about half applied three. *Yala* seasons showed somewhat lower usages. Proportions of farmers using P and particularly K fertilizer were generally high in *Maha* seasons. In *Yala*, again use of K was high but use of P was less widespread.

Under rainfed conditions, varietal choice patterns were very similar to those under minor tanks (Table 7). Establishment methods in *Maha* seasons were also similar to those under minor tanks.

Almost all farmers applied at least one fertilizer dressing in *Maha* seasons and a large proportion used a second application. Proportions of farmers using three dressings were low in 1983–84, but were variable thereafter. Quite substantial proportions applied no fertilizer in *Yala* seasons; less than half applied two dressings and relatively few used three, especially in 1985.

Under mixed conditions, the varietal use pattern and changes were very similar to those under rainfed conditions and minor tanks (Table 8). This also applied to establishment methods. All farmers used at least one fertilizer dressing in

Table 7. Incidence of technical practices under rainfed conditions in Kurunegala district by season from *Maha* 1983–84 to *Maha* 1985–86 (percentage of farmers).

Practices	*Maha* 1983–84	*Maha* 1984–85	*Maha* 1985–86	*Yala* 1984	*Yala* 1985
Variety					
Bg 34-8	42	69	71	70	75
Bg 276-5	31	15	11	26	22
Bg 400-1	1	7	13	1	0
Village	15	1	1	0	3
Other	11	8	4	3	0
Establishment Method					
Broadcasting	83	37	26	90	75
Row transplanting	2	1	2	1	0
Random transplanting	15	62	72	9	25
Row seeding	0	0	0	0	0
Timing of establishment					
Early	2	0	0	1	6
On time	81	100	100	99	94
Late	17	0	0	0	0
No. of fertilizer dosages					
0	10	2	1	28	22
1	90	98	99	72	78
2	58	88	95	47	41
3	28	63	44	21	4
Use of P fertilizer	46	79	66	61	19
Use of K fertilizer	78	100	97	100	41
Use of pesticides	21	50	21	32	25
Use of herbicides	27	8	5	7	0
Use of manual weeding	45	70	69	47	50
Use of institutional credit	6	0	0	3	0

Note: Totals for seasons may not add to 100 due to rounding.

Table 8. Incidence of technical practices under mixed conditions in Kurunegala district by season from *Yala* 1984 to *Maha* 1985–86 (percentage of farmers).

Practices	*Maha* 1984–85	*Maha* 1985–86	*Yala* 1984	*Yala* 1985
Variety				
Bg 34-8	38	64	45	80
Bg 276-5	16	9	36	8
Bg 400-1	21	15	3	8
Village	22	9	16	5
Other	3	3	0	0
Establishment Method				
Broadcasting	33	36	60	41
Row transplanting	10	15	2	0
Random transplanting	57	49	39	59
Row seeding	0	0	0	0
Timing of establishment				
Early	0	0	2	0
On time	100	97	96	97
Late	0	3	2	3
No. of fertilizer dressings				
0	0	0	4	5
1	100	100	96	95
2	98	94	77	82
3	82	55	59	23
Use of P fertilizer	92	79	72	46
Use of K fertilizer	100	94	100	82
Use of pesticides	48	33	63	33
Use of herbicides	18	6	13	0
Use of manual weeding	74	61	49	41
Use of institutional credit	0	0	0	0

Note: Totals for seasons may not add to 100 due to rounding.
Maha 1983–84 season included in Table 7.

Table 9. Incidence of technical practices under minor tanks in Anuradhapura district by season from *Maha* 1983–84 to *Yala* 1985 (percentage of farmers).

Practices	*Maha* 1983–84	*Yala* 1984	*Yala* 1985
Variety			
Bg 34-8	65	89	74
Bg 276-5	29	8	26
Bg 400-1	4	3	0
Village	0	0	0
Other	2	0	0
Establishment Method			
Broadcasting	86	100	99
Row transplanting	11	0	1
Random transplanting	3	0	0
Row seeding	0	0	0
Timing of establishment			
Early	1	7	0
On time	7	48	74
Late	92	45	26
No. of fertilizer dressings			
0	0	5	3
1	100	95	97
2	67	83	78
3	12	29	39
Use of P fertilizer	47	75	57
Use of K fertilizer	71	86	78
Use of pesticides	89	81	71
Use of herbicides	76	52	71
Use of manual weeding	83	81	86
Use of institutional credit	12	0	0

Note: Totals for seasons may not add to 100 due to rounding.

Maha seasons, almost all a second and a small proportion applied a third. A few used no fertilizer in *Yala*, and a high proportion used two dressings. Very high proportions of farmers used K fertilizer in all seasons. Pesticide use was generally more frequent than under rainfed conditions. There was little use of herbicides. Manual weeding was quite common but less so in *Yala* than in *Maha* seasons. There was no reported use of institutional credit.

In Anuradhapura, details of technical practices were collected for three seasons under minor tanks only (Table 9). Varietal choice centred almost exclusively on 3-month varieties with a predominant preference for Bg 34-8. Almost all paddy was broadcast in this district. In *Maha* seasons, all farmers applied at least one fertilizer dressing, but relatively few applied three. In *Yala* seasons, small proportions of farmers did not apply any fertilizer. Use of P and K fertilizer was less common than under minor tanks in Kurunegala, while use of pesticides was more widespread. Use of both herbicides and manual weeding was also more common.

Human Capital Variables and Farm/Farmer Attributes

In Kurunegala, there was considerable similarity across water regimes in human capital variables such as age and farming experience of household heads, years of schooling (6–8 years) and occupation (Table 10). Notably, only about half had farming as their sole occupation. In terms of farm/farmer attributes, sizes of families were fairly similar (4.3 to 4.9) and ownership of land predominated (mostly sole ownership) with 31% to 42% renting, particularly in rainfed areas. Nonfarm incomes among household heads were highest for minor tank farmers. Only small proportions of other family members earned nonfarm income.

In Anuradhapura, data were available for major irrigation and minor tank farmers (Table 11). Human capital characteristics were similar to

Table 10. Incidence of farm/farmer attributes in Kurunegala district by water regime for *Maha* 1984–85.

Attribute	Major Irrigation	Minor Tanks	Rainfed	Mixed
Household heads				
Mean age	49	51	46	50
Mean years of farming experience	30	21	26	32
Mean years of schooling	6.3	7.7	7.3	5.8
Occupation (% of farmers)				
on farm only	58	46	52	53
nonfarm only	1	—	1	3
farm and nonfarm	39	54	47	44
Total family size	4.7	4.3	4.3	4.7
Tenure (% of farmers)				
Owned solely	47	57	42	53
Owned jointly	14	9	15	10
Rented	39	31	42	38
Nonfarm income				
% of household heads with none	55	60	54	56
Mean for household head earners (Rs)	2753	3842	2763	3139
% of family members with none	78	74	72	82
Mean for family earners (Rs)	4530	4017	5035	5427

Note: Totals for water regimes may not add to 100 due to rounding.

Table 11. Incidence of farm/farmer attributes in Anuradhapura district by water regime for the crop year 1983–84.

Attribute	Major Irrigation	Minor Tanks
Household heads		
Mean age	49	44
Mean years of farming experience	23.6	23.4
Mean years of schooling	6.5	6.5
Occupation (% of farmers)		
on farm only	84	79
nonfarm only	1	—
farm and nonfarm	15	21
Total family size	6.7	6.8
Tenure (% of farmers)		
Owned solely	94	91
Owned jointly	1	3
Rented	4	6
Nonfarm income		
% of household heads with none	79	52
Mean for household head earners (Rs)	3357	1062
% of family members with none	88	71
Mean for family members earners (Rs)	6200	996
Work conflict (% of farmers)		
paddy/highland crop	18	47
own/nonfarm	4	13
Full-time farming (%)	92	86
Part-time farming (%)	8	14

Note: Totals for water regimes may not add to 100 due to rounding.

Kurunegala. There was not much variation in terms of age, farming experience and schooling. However, onfarm work dominated activities with only 12% and 20% respectively combining farm and nonfarm work, reflecting lack of opportunities for the latter in the Dry Zone. Among farm/farmer attributes, family size was greater than in Kurunegala (6.7 to 6.8). Sole ownership was the dominant form of tenure, with only 4% and 6% respectively renting.

CHAPTER THREE

Socioeconomic Analysis

R.T. Shand, G.A.C. De Silva and N.F.C. Ranaweera

Factors affecting productivity and profitability were examined in an attempt to achieve more efficient use of resources and higher farm incomes. As part of the investigation, data from socioeconomic farm surveys were analysed using the stochastic frontier production function approach. Once the relevant variables influencing farm outputs are specified and measured, this approach permits identification of the major factors that contribute to variability in technical and economic performance within a farming community. A detailed description of the methodology and its development can be found in Chapter 4.

The major results obtained by the application of this methodology to data from the farm surveys carried out in Kurunegala and Anuradhapura are summarised and evaluated. Descriptions of the data sets and details of the analysis of each survey are given in Chapter 2 and in the Sri Lankan project working papers.

As can be seen from Chapter 2, among the farms surveyed there were large variations in levels of inputs, outputs, managerial practices, field-level physical characteristics (soils, landscape position etc.) and incomes. In order to determine potential productivity improvements at the individual field level, the frontier production function approach makes use of this variation to delineate factors influencing farm productivity and profitability and thus provides measures of efficiency levels for each production unit. Farm performance is determined by economic efficiency which comprises, in turn, a technical and an allocative component; each of these components can be derived from the frontier production functions once they have been estimated.

The analyses for the two districts, Kurunegala and Anuradhapura, are presented separately.

Kurunegala

Kurunegala comprises four distinct agro-environments: major irrigation, minor tanks, rainfed and mixed irrigated/rainfed. These were described in Chapter 2 and are referred to as water regimes.

Separate frontier production functions of the Cobb-Douglas type (in loglinear form) were specified for each season for each water regime, using paddy output from each field as the dependent variable. Intercept-shifting dummy (0–1) variables were used to account for field-level differences in relevant physical attributes (soil fertility, landscape position, drainage etc.).

Five seasons were surveyed, from *Maha* 1983–84, through to *Maha* 1985–86. In *Maha* 1985–86, the survey was confined to the (most important) rainfed sample, where the same respondents were surveyed as in previous seasons. In addition, a subset of 50 was selected for the Close Monitoring Survey (CMS) and some six visits were made to each farmer after important stages of the crop cycle. The objective was to ascertain whether such an intensive approach would give greater explanatory power than the customary two visits undertaken in the normal surveys.

The sets of variables used in the estimation of each production frontier are detailed in the Sri Lankan project working papers. These included field area, preharvest labour, cost of chemical fertilizer, pest occurrence, drainage, and soil moisture conditions at various times during the season. Unfortunately, due to multicollinearity, separate variables representing actual doses in kg of the three nutrients, nitrogen, phosphorus and potassium, could not be used. There was thus a certain loss of information when these variables were combined in an overall fertilizer cost variable.

Over the five seasons and four water regimes, 17 frontier production functions were estimated and are shown in Tables 1–6. The variables with most consistent significance in the frontier equations were field area, cost of chemical fertilizer and, to a lesser extent, preharvest labour. During the Close Monitoring Survey of the rainfed sample in *Maha* 1985–86, soil moisture conditions were recorded by eliciting farmers' views at crucial times during the establishment, growth and maturity stages of the crop season. Two soil moisture variables were found to be highly significant in the frontier production functions (Table 6).

One of the innovative features of the frontier production function methodology is its ability to decompose the total variance around the frontiers into two distinct and independent components. The first of these represents variation above and below the frontier and is assumed to be due to random factors ('pure error') which affect each field in the same way. The second component of the total variance represents the degree to which a field is **below** the frontier and is associated with its

Table 1. Maximum likelihood estimates of Cobb-Douglas stochastic frontier production functions by water regime for survey farmers in Kurunegala district. *Maha* 1983–84.

Parameter	Variable	Unit of measurement	Estimates		
			Major Irrigation	Minor Tanks	Rainfed
α	Constant	—	6.1290*** (0.4948)	5.0881*** (1.2227)	5.7962*** (0.4994)
β_1	Preharvest labour	Person days	0.2490*** (0.0624)	-0.0057^{ns} (0.1699)	0.1887*** (0.0848)
β_2	Fertilizer cost	Rs	0.1068** (0.06)	0.4325** (0.2122)	0.1768*** (0.0715)
β_3	Field area	ha	0.6078*** (0.0720)	0.4746*** (0.2141)	0.3846*** (0.1105)
No. of cases			144	42	138

Note: Figures in parentheses are asymptotic standard errors of the estimates.
***Significant at the 1% level.
**Significant at the 5% level.
$^{\text{ns}}$ Not significant.

Table 2. Maximum likelihood estimates of Cobb-Douglas stochastic frontier production functions by water regime for survey farmers in Kurunegala district. *Yala* 1984.

Parameter	Variable	Unit of measurement	Estimates			
			Major Irrigation	Minor Tanks	Rainfed	Mixed
α	Constant	—	−1.6930*** (0.6855)	-0.5005^{ns} (0.5187)	−2.1468*** (0.6269)	−2.1550*** (0.8692)
β_1	Preharvest labour	Person days	0.2697*** (0.0724)	0.0589* (0.0387)	0.1465** (0.0765)	0.3906*** (0.1424)
β_2	Fertilizer cost	Rs	0.2591*** (0.1114)	0.1890* (0.1449)	0.5211*** (0.1285)	0.2316* (0.1602)
β_3	Field area	ha	0.5175*** (0.1034)	0.4308*** (0.0975)	0.4301*** (0.1174)	0.4340*** (0.1420)
β_4	Pest occurrence	Dummy	0.1031* (0.0644)	0.1164^{ns} (0.1956)	0.6106*** (0.0917)	0.1429^{ns} (0.1291)
No. of cases			150	34	114	61

Note: Figures in parentheses are asymptotic standard errors of the estimates.
***Significant at the 1% level.
**Significant at the 5% level.
*Significant at the 10% level.
$^{\text{ns}}$ Not significant.

Table 3. Maximum likelihood estimates of Cobb-Douglas stochastic frontier production functions by water regime for survey farmers in Kurunegala district. *Maha* 1984–85.

			Estimates			
Parameter	Variable	Unit of measurement	Major Irrigation	Minor Tanks	Rainfed	Mixed
α	Constant	—	−0.8230***	−1.5079***	−0.9438***	−1.2266***
			(0.3176)	(0.5750)	(0.7369)	(0.6205)
β_1	Preharvest labour	Person days	0.0372^{ns}	0.0892^{ns}	0.1920***	0.1986**
			(0.0608)	(0.1068)	(0.0043)	(0.1109)
β_2	Fertilizer cost	Rs	0.1677***	0.2443***	0.1271***	0.0812^{ns}
			(0.0520)	(0.0911)	(0.0029)	(0.0920)
β_3	Field area	ha	0.7745***	0.6648***	0.7252***	0.7759***
			(0.0548)	(0.0707)	(0.0030)	(0.0877)
β_4	Drainage	Dummy	0.1293^{ns}	0.0300***	0.0214^{ns}	0.1564*
			(0.3596)	(0.0077)	(0.0124)	(0.1109)

Note: Figures in parentheses are asymptotic standard errors of the estimates.
***Significant at the 1% level.
**Significant at the 5% level.
*Significant at the 10% level.
^{ns} Not significant.

Table 4. Maximum likelihood estimates of Cobb-Douglas stochastic frontier production functions by water regime for survey farmers in Kurunegala district. *Yala* 1985.

			Estimates		
Parameter	Variable	Unit of measurement	Major Irrigation	Rainfed	Mixed
α	Constant	—	5.1988***	4.7326***	5.3971***
			(0.4907)	(0.2897)	
β_1	Preharvest labour	Person days	0.0678^{ns}	0.2191***	0.6571***
			(0.1051)	(0.0198)	(0.1161)
β_2	Fertilizer cost	Rs	0.3250***	0.3288***	—
			(0.0671)	(0.0214)	
β_3	Field area	ha	0.3358***	0.3915***	0.4028***
			(0.0687)	(0.0157)	
β_4	Water stress at maturity	Dummy	—	−0.1943***	−0.9198***
				(0.0159)	(0.2434)
No. of cases			126	25	36

Note: Figures in parentheses are asymptotic standard errors of the estimates.
***Significant at the 1% level.
^{ns} Not significant.

Table 5. Maximum likelihood estimates of Cobb-Douglas stochastic frontier production functions by water regime for survey farmers in Kurunegala district. *Maha* 1985–86.

Parameter	Variable	Unit of measurement	Estimates (Rainfed)
α	Constant	—	6.0676***
			(0.4745)
β_1	Preharvest labour	Person days	0.0722^{ns}
			(0.0727)
β_2	Fertilizer cost	Rs	0.2773***
			(0.0766)
β_3	Field area	ha	0.6500***
			(0.0684)
No. of cases			207

Note: Figures in parentheses are asymptotic standard errors of the estimates.
***Significant at the 1% level.
^{ns} Not significant.

Table 6. Maximum likelihood estimates of Cobb-Douglas stochastic frontier production functions by water regime for survey farmers in Kurunegala district for *Maha* 1985–86. Close Monitoring Survey (CMS), with and without soil moisture variables.

			Estimates (Rainfed)	
Parameter	Variable	Unit of measurement	Without moisture variables	With moisture variables
α	Constant	—	3.4916**	5.8993***
			(1.4971)	(0.6601)
β_1	Preharvest labour	Person days	0.5017***	0.6156***
			(0.1625)	(0.1581)
β_2	Fertilizer cost	Rs	0.2100*	—
			(0.1363)	
β_3	Field area	ha	0.3959**	0.6890***
			(0.2046)	(0.1370)
β_4	Preharvest power cost	ha	0.1971†	—
			(0.1834)	
β_5	No. of days of moist soil on visits 5 and 6	Days	—	−0.053***
				(0.0289)
β_6	No. of days of cracked on dry soil on visit 3	Days	—	−0.0201***
				(0.0100)
No. of cases			50	50

Note: Figures in parentheses are asymptotic standard errors of the estimates.
***Significant at the 1% level.
**Significant at the 5% level.
*Significant at the 10% level.
†Significant at the 20% level.
^{ns} Not significant.

level of technical efficiency (TE). A field's position with respect to its frontier is denoted by a percentage, with 100% being equivalent to full technical efficiency or 'best practice' with respect to the management of that particular field.

Apart from the field-specific dummy variables which characterise the physical aspects of the fields in the frontier production function, technical efficiency is the only variable that is field-specific. Hence, if all the information concerning field-specific physical characteristics that influence yield (output) has not been accurately measured and incorporated into the frontier function, then variance due to these field-specific biophysical factors will be captured by the technical efficiency variable. The technical efficiency variable also includes residual effects of past management which can influence the current season's crop yield. Thus, the technical efficiency variable will inevitably contain a bias of unknown sign and magnitude.

Technical efficiency

The frontier production function analyses for specific season/water regime combinations summarised in Table 7 give ratios, denoted by gammas, of the field-specific variance (technical efficiency) to the total variance around the frontier. Fourteen of the 17 ratios were large and statistically significant. This implies that the variance due to random error was small and that the field-specific variance was large. In other words, there was a wide spread of technical efficiencies among the survey farmers. This large spread in efficiencies enabled a statistical investigation of factors which may explain why some farmers were more efficient than others. Particularly relevant in this context are factors which could be used by policy-makers or extension workers to reduce the gaps between most efficient and least efficient farmers by implementing appropriate programs in a cost-effective manner.

Estimation of field-specific technical efficiencies and their mean levels (Table 7) suggests that there is potential for improvement in productivity **without** additional inputs or new technology. The means tended to be high under major irrigation and consistently lower under rainfed conditions, with a wider range of individual field efficiencies. There was considerable seasonal

Table 7. Gamma values, mean technical efficiencies and total variances of frontier production functions by season, year and water regime in Kurunegala district from 1983–84 to 1985–86.

Season	Year	Variable	Major Irrigation	Minor Tanks	Rainfed	Mixed
Maha	1983–84	γ	0.0128[ns]	0.6535***	0.6996***	n.a.[a]
		Mean TE	97.2	50.5	55.6	n.a.
		σ^2	0.0873	0.4036	0.3231	n.a.
Yala	1984	γ	0.7168***	0.9292***	0.5236***	0.5714***
		Mean TE	62.5	64.5	62.5	65.4
		σ^2	0.2342	0.1987	0.2906	0.3266
Maha	1984–85	γ	0.4717***	0.0004[ns]	0.7318***	0.4192***
		Mean TE	88.2	99.7	69.7	89.4
		σ^2	0.0543	0.0300	0.1192	0.0757
Yala	1985	γ	0.4185***	n.a.[b]	0.9253***	0.3289[ns]
		Mean TE	80.5	n.a.	61.5	81.2
		σ^2	0.0813	n.a.	0.1168	0.0678
Maha	1985–86	γ	n.a.[d]	n.a.[d]	0.6953***	n.a.[d]
		Mean TE	n.a.	n.a.	64.7	n.a.
		σ^2	n.a.	n.a.	0.1736	n.a.
Maha (CMS)[c]	1985–86	γ	n.a.[d]	n.a.[d]	0.4771*** 0.5816***	n.a.[d]
		Mean TE	n.a.	n.a.	72.8 67.1	n.a.
		σ^2	n.a.	n.a.	0.1476 0.1533	n.a.
					(without SMVs) (with SMVs)	

n.a. Not available

[a] Included in the rainfed sample.

[b] Observations were too few for analysis.

[c] Close monitoring survey. Frontier estimated with and without soil moisture variables (SMVs).

[d] Not surveyed in this season.

***Significant at the 1% level.

[ns] Not significant.

The ratio γ and the total variance σ^2 and its components are explained in detail in Chapter 4.

variability in the means under minor tanks and mixed conditions. There was no consistent trend over time in any of the four water regimes. By raising a field towards its frontier, particularly those with lower technical efficiency, significant gains in productivity could be achieved. Obviously, not all fields can be fully raised to the frontiers, but if those factors associated with high technical efficiency are determined, improvements in technical efficiency could be achieved through manipulation of those factors. The extent of such improvements would depend on how many determining factors for technical efficiency are amenable to change by appropriate policies or programs. This can be tested by identifying significant determinants of technical efficiency using regression analysis.

Three groups of determinants of technical efficiency can be hypothesised. One includes (a) **management practices** which could be expected to have a direct impact on output from a field or which are likely to be associated with good management. These include, for example, the choice of variety, choice of establishment method, use of particular pest or weed control practices, timing of crop establishment and harvesting, timing, composition and methods of fertilizer applications (e.g. single or multiple applications). A second group comprises (b) **human capital variables** of the farmer such as age, education, farming experience, technical efficiency in previous seasons and various forms of exposure to extension services. The third group comprises (c) **farm/farmer attributes** which could influence a farmer's capacity to apply optimal management practices. These include income level and sources, family size, access to credit, farm size and conflicts in labour allocation between different economic activities.

For the 14 season/water regime combinations for which the gammas were significant (Table 7), variables representing the above three groups were used as explanatory variables in Ordinary Least Squares (OLS) regression models. Technical efficiency, transformed as described in Chapter 4, was the dependent variable. Tables 8–11 show the

Table 8. Significant variables in OLS regressions on technical efficiency by season and year under major irrigation in Kurunegala district from 1984 to 1985.

Season	Year	Variables	Sign	Significance level (%)
Yala	1984 $\bar{R}^2 = 0.17$	Use of pesticides	+	1
Maha	1984–85 $\bar{R}^2 = 0.08$	Use of pesticides	+	1
		Critical harvesting date	+	5
		Conflict between paddy and highland crops	+	5
		Farm work only for household head	+	10
Yala	1985 $\bar{R}^2 = 0.09$	Duration of varieties longer than 3.5 months	−	1
		Third urea application	−	1

Table 9. Significant variables in OLS regressions on technical efficiency by season and year under minor tanks in Kurunegala district from 1983–84 to 1984.

Season	Year	Variables	Sign	Significance level (%)
Maha	1983–84 $\bar{R}^2 = 0.23$	Use of pesticides	+	1
		Farming experience of household head	+	5
Yala	1984 $\bar{R}^2 = 0.26$	Date of harvesting	+	1
		Age of household head	+	5

results of the regressions analysis for each water regime. Sometimes, certain explanatory variables could not be used due to high multicollinearity.

Amongst management practice variables tested in the regressions, the timeliness factor, which relates to crop establishment (timing and method), variety and date of harvesting, was dominant and affected almost all seasons and water regimes. This reflects the importance of the interaction between the physical growth environment, as determined by soil, landscape position and rainfall pattern, and the growth period of the crop which is determined by the various components of the timeliness factor. The most commonly significant component of the timeliness factor was the date of harvesting.

The next most commonly significant management variable was use of pesticides. This had a positive effect in all water regimes and was not season-specific. Other management variables were occasionally significant. These included use of herbicides, use of phosphorus fertilizer, source of seed, and weed levels in the previous season.

Human capital variables exerted only a minor and irregular influence on technical efficiency, with farming experience proving to be the most important.

Farm/farmer attributes were similarly of minor importance. Notably, the conflict between paddy and highland crops for inputs was not evident. The explanatory power of the OLS regressions on technical efficiency was generally not high, leaving well over 50% of the variation unexplained.

The above discussion of technical efficiency refers to the 14 season/water regime combinations where the gamma values were significant (Table 7). The remaining three seasons, *Maha* 1983–84 under major irrigation, *Maha* 1984–85 under minor tanks and *Yala* 1985 under mixed conditions all had non-significant gamma values. This implies that technical efficiency levels were similar within those particular regimes. The lack of variability in technical efficiency meant that no further analysis could be undertaken.

Allocative efficiency

As explained in Chapter 4, the second component of economic efficiency is allocative efficiency, which was also measured using the methodology described in Chapter 4. Allocative efficiency is

Table 10. Significant variables in OLS regressions on technical efficiency by season and year under rainfed conditions in Kurunegala district from 1983–84 to 1985–86.

Season	Year	Variables	Sign	Significance level (%)
Maha	1983–84	Month of planting	−	5
	$\bar{R}^2 = 0.10$	Use of herbicides	+	5
		Duration of crop varieties	+	5
		Full-time farming by household head	+	5
		Farming experience of household head	−	10
Yala	1984	Use of pesticides	+	1
	$\bar{R}^2 = 0.20$	Date of harvesting	+	1
Maha	1984–85	Use of Bg 34–8 variety	−	1
	$\bar{R}^2 = 0.05$	Use of Bg 276–5 variety	−	10
		Schooling of household head	+	10
Yala	1985	Full-time farming by household head	+	10
	$\bar{R}^2 = 0.09$			
Maha	1985–86	Farming only for household head	+	1
	$\bar{R}^2 = 0.12$	More than 5 years of schooling for household head	−	1
		Nonfarm income of household head	+	5
		Date of harvesting	+	10
Maha (CMS without moisture variables)	1985–86	Weed level in previous season	+	1
		Source of seed	+	1
		Effective fertilizer use rating	+	1
	$\bar{R}^2 = 0.25$	Pest damage in periods 2 to 4	−	5
Maha (CMS with moisture variables)	1985–86	Source of seed	+	1
		Weed level in previous season	+	1
		Management of fertilizer rating	+	1
	$\bar{R}^2 = 0.26$	Pest damage in periods 1 and 4	−	5

Table 11. Significant variables in OLS regressions on technical efficiency by season and year under mixed conditions in Kurunegala district from 1984 to 1984–85.

Season	Year	Variables	Sign	Significance level (%)
Yala	1984	Date of harvesting	+	1
	$\bar{R}^2 = 0.35$	Use of P fertilizer	−	1
		Use of pesticides	+	5
		Month of planting	−	10
		Age of household head	−	1
		Schooling of household head	−	5
		Farming experience of household head	+	10
		Full/part land ownership	−	10
		Nonfarm income of household head	+	10
Maha	1984–85	Method of establishment	+	1
	$\bar{R}^2 = 0.37$	Choice of variety	+	1
		Critical harvesting date	+	1
		Use of herbicides	+	10

determined, at any given level of technical efficiency, by the extent to which marginal costs and returns from inputs are equated, i.e., allocative efficiency refers to the appropriateness, for given price levels, of the combination of input levels on a given production function. Analysis of the determinants of allocative efficiency by season and water regime using OLS regression showed the dominance of technical efficiency as an explanatory variable.

The most significant relationship that emerged from the use of the regression models was that between allocative efficiency and technical efficiency. This reflects the fact that a farmer must know the output response to his inputs in order to make accurate allocative decisions. Where technical input-output relationships are known, either because of extension advice and/or experience, allocative efficiency will usually be positively related to technical efficiency. In this case, overall economic efficiency, since it consists of technical and allocative efficiency, will be high. (For an explanation of overall economic efficiency, see Chapter 4).

Anuradhapura

It was originally intended to undertake surveys in Anuradhapura district over the same seasons as in Kurunegala. However, owing to limited staff resources this could not be achieved and the main focus was on Kurunegala. In all, three surveys were carried out in Anuradhapura for two water regimes: under major irrigation and minor tanks. There was no substantial area of rainfed paddy in this district.

As with Kurunegala, separate production frontiers of the Cobb-Douglas type were specified for each of the three seasons (Table 12). In *Maha* 1983–84 they were estimated for major irrigation and minor tanks. In the two later seasons, the major irrigation sample was excluded as the main purpose was to focus on less favourable environments, i.e. on minor tanks. The full analyses of these three seasons are set out in the Sri Lankan project working papers.

As in Kurunegala, the variables with most consistent significance were field area, cost of chemical fertilizer and preharvest labour. The large and statistically significant gammas shown in Table 13 indicate that there was a considerable range in technical efficiency in each surveyed season and water regime. Mean technical efficiencies are also given in Table 13.

The regression analysis of factors determining technical efficiency was based on the same three groups of explanatory variables as in Kurunegala (Table 14). Once again, the composite variable timeliness was most commonly significant although usually only weakly so and not in all seasons and water regimes. In contrast with Kurunegala, use of pesticides was not significant in Anuradhapura. As has been noted in Chapter 2, a higher percentage of survey farmers in Anurad-

Table 12. Maximum likelihood estimates of Cobb-Douglas stochastic frontier production functions by water regime for survey farmers in Anuradhapura district from *Maha* 1983–84 to *Yala* 85.

			Estimates			
			Maha 1983–84		*Yala* 1984	*Yala* 1985
Parameter	Variable	Unit of measurement	Major Irrigation	Minor Tanks	Minor Tanks	Minor Tanks
α	Constant	—	4.1810*** (0.8927)	6.0990*** (0.6267)	7.7380*** (0.6853)	4.9558*** (0.8114)
β_1	Preharvest labour	Person days	0.2778*** (0.1060)	0.1828† (0.1205)	−0.2175† (0.0221)	0.3649*** (0.1501)
β_2	Fertilizer cost	Rs	0.3644*** (0.1290)	0.1323* (0.0727)	0.1674† (0.0124)	0.2795*** (0.0866)
β_3	Field area	ha	0.5312*** (0.1875)	0.6088*** (0.0994)	0.8084*** (0.0172)	0.6014*** (0.1406)
β_4	Soil fertility	Dummy	0.4390*** (0.0944)	—	—	—
No. of cases			128	75	98	72

Note: Figures in parentheses are asymptotic standard errors of the estimates.
***Significant at the 1% level.
*Significant at the 10% level.
†Significant at the 20% level.

Table 13. Gamma values, mean technical efficiencies and total variances of frontier production functions by season, year and water regime in Anuradhapura district from 1983–84 to 1985.

Season	Year	Variable	Major Irrigation	Minor Tanks
Maha	1983–84	γ	0.7193***	0.4890***
		Mean TE	74.4	64.9
		σ^2	0.3529	0.3166
Yala	1984	γ		0.8986***
		Mean TE	na	53.0
		σ^2		0.2392
Yala	1985	γ		0.4202***
		Mean TE	na	76.9
		σ^2		0.1155

na Not surveyed because of a decision to limit surveys to less favourable conditions under minor tanks.
***Significant at the 1% level.
The ratio γ and the total variance σ^2 and its components are explained in detail in Chapter 4.

Table 14. Significant variables in OLS regressions on technical efficiency by water regime, for survey season and years, in Anuradhapura district from 1983–84 to 1985.

Water regime	Season	Year	Variables	Sign	Significance level (%)
Major irrigation	*Maha*	1983–84	Use of herbicides	+	5
	$\bar{R}^2 = 0.10$		Farming as sole occupation of household head	−	10
			Age of household head	+	10
			Full/part land ownership	−	10
Minor tanks	*Maha*	1983–84	Conflict between paddy and highland crops	+	1
	$\bar{R}^2 = 0.19$		Farming as sole occupation of household head	−	1
			Transplanted crop	−	1
			Use of herbicides	+	10
	Yala	1984	Age of household head	+	1
	$\bar{R}^2 = 0.18$		Full/part land ownership	+	1
			Fertilizer score	−	1
	Yala	1985	More than 5 years of schooling and more than 10 years of farming experience	+	1
	$\bar{R}^2 = 0.32$		Timely planting	+	1
			Fertilizer score (with more than one dosage)	−	5
			Farming as sole occupation of household head	+	5
			Longer varietal duration	−	5
			Use of Bg 34-8	−	10

hapura used pesticides than in Kurunegala. The overall explanatory power of the above regressions was low.

The important role of technical efficiency as a determinant of allocative efficiency was similar to Kurunegala.

Conclusions

Having determined the factors responsible for technical and allocative efficiencies, scope exists to influence those factors and thus to raise each or both these components of overall economic efficiency.

In the more favourable environments the technical efficiency means were generally close to 100%. This implies that there were few farmers with low levels of technical efficiency, and thus there is generally little opportunity for improving the technical efficiency of the less efficient farmers. In the less favourable environments technical efficiency means were further from 100%. Thus there is scope in these areas for raising the technical efficiency of those farmers who are currently operating at low levels of technical efficiency.

The two main determinents of technical efficiency which emerged from the analysis were the composite variable timeliness and use of pesticides. Both were less significant in Anuradhapura than in Kurunegala. Agronomic field trials, reported in Chapter 1, showed that significant gains can be achieved by extending better pest control techniques to all farmers. Although recommendations have been worked out for particular pests, practical success depends upon weather and soil moisture conditions and the interaction with timeliness of application, and upon pest recognition.

Despite the significance of the abovementioned variables in determining technical efficiency, much of the variability in technical efficiency remained unexplained. This is consistent with the large field-to-field variability in yields found in the agronomic project (Chapter 1). Even the detailed biophysical measurements carried out during the agronomic trials were unable to explain this variability.

The other component of economic efficiency, allocative efficiency, was shown in the analysis to be dependent upon technical efficiency. Thus knowledge of technical input-output relationships is a key element of overall economic efficiency. Any intervention which raises technical efficiency would have the additional benefit of raising allocative efficiency, and thus have a dual effect on economic efficiency.

CHAPTER FOUR

Methodology for the Socioeconomic Analysis

K.P. Kalirajan and R.T. Shand

The methodologies that have hitherto been utilised for the analysis of the adoption and performance of new technologies for crop production in the Asian region have generally been confined in scope in a number of important respects.

First, they have focused mostly on rice and have thus been monocrop studies.

Second, they have been located in well irrigated environments. Thus, even in the case of rice, according to IRRI, 'The level and causes of yield constraints in the less favourable rainfed wetland and dryland conditions are poorly understood, let alone quantified' (Summary of Organisation Plans for Future Activities — IRRI, January 1982).

Third, the IRRI constraints project assumed that the recommended new technology is the best for a given location. Often, the recommendations have not been fine-tuned for location-specific factors. For example, fertilizer recommendations have often been national or, at best, regional, and have not been tailored to soil types and landscape positions. The agronomic adaptation of such technologies needs to be carefully studied if optimal recommendations are to be developed. This is even more important in nonirrigated environments.

Fourth, even for rice, the approach adopted in assessing the performance of farmers against experiment station and field trial standards has been confined to *average* farm performance and has not explored the *range* of performance within the farm community. Furthermore, the emphasis has been on quantifying the gaps between farmers, experiment station and field trial performances, rather than investigating which factors determine the gaps and quantifying these factors.

Finally, those factors that have been examined were exclusively concerned with single crop decision-making and took no account of the multiplicity of other farm and off-farm activities and associated decision-making. Such a view on contraints to performance can only provide a partial analysis of the factors determining technical and economic performance.

The Production Function Model

While aggregate data on rice production costs and returns would provide broad measures of production efficiency, existing variations in levels of inputs, outputs, management practices and field-level physical characteristics limit their utility for examining the potential for productivity improvements at farm level. Therefore, it is necessary to incorporate these field-specific variables into the analysis, while identifying the factors influencing field-level productivity and efficiencies, and thereby profitability. An approach based on the 'best practice' stochastic frontier production function* has been selected as the core methodology.

It is assumed in this project that farms behave according to a specified decision pattern which is profit maximisation, subject to a production function defined for a particular technology.** The question of interfarm variations in factor produc-

* A conventional production function approach can be used to measure technical efficiency under certain restrictive assumptions. However, the measure so obtained cannot be called a pure measure of technical efficiency as it also contains random variables such as measurement and sampling errors.

** This is in no way a restrictive assumption. As long as the farmers' utility function contains quantities of variables purchased from the market for which there are prices, profit maximisation is sensible. When examining the allocative efficiencies of farmers, the assumption of profit maximisation still proves to be adequate.

tivities can be analysed by determining how successful farms are in following the decision rule when they face different sets of prices. This study follows the pioneering approach of Farrell (1957) in equating farm performance with economic efficiency, which in turn is a combination of technical and allocative efficiencies.

Throughout the project, Technical Efficiency (TE) is defined as the ability to obtain the maximum output at a given level of conventional inputs (or a given level of output with a minimum level of inputs). Allocative Efficiency (AE) is defined as the ability to obtain the maximum profit from the application of conventional inputs with a given set of input and output prices, and a given technology.

Figure 1, showing the input-input space, illustrates Farrell's concepts of allocative and technical efficiencies. Farms A and B lie on the isoquant I_0 which represents minimum input combinations, and no observation lies between the isoquant and the origin. At their respective levels of output, they use no more of the two inputs x_1 and x_2 than required and are said to be technically efficient. Farm C exhibits an input combination to the right of I_0 and is said to be technically inefficient because it could reduce its inputs using techniques available to B. The measure of farm C's inefficiency is given by OB/OC.

Assuming that PP^1 is the relative factor price ratio faced by all three farms, farm B is allocatively efficient as the optimum input combination given by PP^1 lies on B. Although farm A is technically efficient, it is not allocatively efficient as it uses inappropriate factor combinations at market prices. The measure of farm A's allocative inefficiency is calculated as OD/OA. If P_2P_3 is drawn parallel to PP^1, then the optimum input combination given by P_2P_3 (PP^1) lies on C. This means that C is allocatively efficient, even though it is technically inefficient. Thus, farm C's inefficiency stems from inefficient use of an appropriate technology while farm A suffers from efficient employment of inappropriate factor proportions.

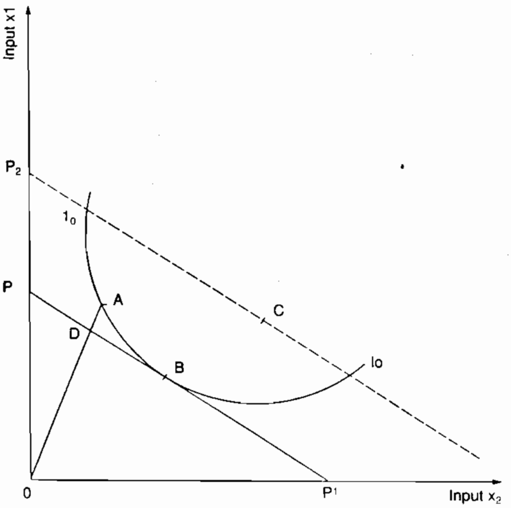


Figure 1. Farrell's concepts of technical and allocative efficiencies.

There are two major problems with Farrell's efficiency measures. One is that the technical efficiencies of various farms are measured from a single frontier. This method of measuring efficiency ignores differences in the socioeconomic and physical environments faced by farms. If these environments vary among farms, then each farm will have different production possibilities, even though they use the same technology. For example, between an educated farmer producing an output using high-yielding variety technology under irrigated conditions with good drainage facilities and an illiterate farmer producing under identical conditions but with poor drainage facilities, apparent differences in efficiency are bound to arise. What is needed is a measure of technical efficiency with respect to each farm's own production possibilities rather than to some common frontier.

The second problem is that Farrell's assumption that all farms face the same relative factor price ratio is unrealistic. Due to various market imperfections in both the factor and product markets, farms do face different price ratios. This implies that the allocative efficiency of a farm should be measured with respect to its own price ratio and not to some common price ratio.

The literature provides a number of different methodologies to measure technical efficiency; of these, the frontier production function approach popularised by Aigner et al. (1977) generally can be considered an appropriate method.* However, this approach only allows the measurement of average technical efficiency of a group of farms and does not provide estimates of technical efficiency

---

* A brief but comprehensive discussion on the evolution of frontier production functions is given in Førsund et al. (1980).

for individual observations. More recently, Jondrow et al. (1982) and Kalirajan and Flinn (1983) independently developed a similar method to measure field-specific technical efficiency for individual sample observations from farms producing a single output with mulitple inputs from a single period cross-section. These individual technical efficiency measures are more useful for policy-makers than the average technical efficiency estimates. An additional major attraction of this procedure over alternatives is that, in the total variation, it distinguishes between influences of technical efficiency and those due to random factors. It also permits statistical testing of the hypothesis that observed deviations from the frontier are merely due to random 'noise'. Generally, stochastic production frontiers are estimated for a single ouput with multiple inputs using cross-section data* and this is the main focus of this analysis. However, in the course of the project, methodology was developed to estimate production frontiers in other more general conditions of production, including methods to measure individual technical efficiency using panel data and to identify factors causing variation in technical efficiency over time. Also developed was a model to measure individual field-specific technical efficiency simultaneously with field-specific allocative efficiency under general conditions of production. Measurement of allocative efficiency was not included in the production frontier method popularised by Aigner et al. (1977). For explanation and discussion of the various models developed during the project, see Kalirajan (1986) Kalirajan and Shand (1985) and project papers (methodology series).

These models were developed in the course of the project, before the survey data became available for analysis, with the objective of providing a range of analytical tools which could assist in answering the complex questions implicit in the analysis of farm performance in terms of technical and allocative efficiencies. The extent to which they could be applied to the farm survey data depended upon the nature of that data, e.g. the extent of multicropping within a season, the availability of panel data, the length of time series, etc.

In practice, the data placed substantial limitations on the application of some of the models. First, the incidence of multicropping (with rice and upland crops) in any one season was unexpectedly rare. Second, the surveys could only be undertaken over five seasons which made the use of panel data analysis impossible. However, even though the use of models generated by the project is restricted here, they do provide the potential for much wider application given the many data sets to which they could be applied to measure and explain farm performance.

As is clear from the analysis presented in Chapter 3, only one of the models could be applied to the survey data, and this was the single period cross-section analysis of randomly selected fields by location and season over several years.

The frontier production function represents the function that yields maximum output from given quantities of a given set of inputs. Observed production levels thus lie on or below the frontier production function. A hypothetical field-specific Cobb-Douglas frontier production function, assuming m inputs, can be written as follows:†

$$y_j^* = \alpha' \prod_{k=1}^{m} (x_{jk})^{\beta_k} \qquad (1)$$

where y_j^* is the maximum possible output of the j^{th} field from the sample of n fields; x_{jk} is the k^{th} input applied to the j^{th} field, α' is the intercept and the β_ks are production parameters to be estimated. The intercept α' is related to the constant α used in Chapter 3 by the formula $ln\ \alpha' = \alpha$.

The above hypothetical frontier production function (1) gives the maximum possible (efficiency) output when the j^{th} field realises its technical efficiency fully. Assuming the j^{th} field does not realise its technical efficiency fully, the hypothetical frontier production function (1) can be written as below:

$$\tilde{y}_j = \alpha' \prod_{k}^{m} (x_{jk})^{\beta_k} e^{U_j} \qquad (2)$$

---

* Schmidt (1985–86) provides a critical analysis of efficiency measures derived from frontier production methodology.

† Alternative functional forms such as translog, quadratic and semilog were tried, but in terms of high R^2 and the number of significant variables, the Cobb-Douglas form was chosen for further analysis. In addition, the Cobb-Douglas technology shows the second stage of production which is more important from the production point of view.

In the above model (2), if the j^{th} field realises its technical efficiency fully, then U_j takes a value zero and if not, U_j takes a value less than zero, depending on the extent of its technical inefficiency. Thus e^{U_j} provides a measure of field-specific technical efficiency. Now, in the production process, the output y is determined not only by the technical efficiency of the field, but also by the exogenous shocks not under the control of any farm, such as weather variation. The introduction of a general statistical random error term V in (2), which is independent of U, captures the exogenous shocks, and also makes (2) stochastic. Therefore, the observed output of the j^{th} field can now be written as follows:

$$y_j = \alpha' \prod_{k}^{m} (x_{jk})^{\beta_k} e^{(U_j + V_j)} \tag{3}$$

A measure of the field-specific technical efficiency of the j^{th} field is defined as follows:

$$e^{U_j} = \frac{y_j}{\alpha' \prod_k x_{jk}^{\beta_k} e^{V_j}} \tag{4}$$

This measure necessarily has values between one and zero, as it is the ratio of actual observed output, given the true level of realisation of technical efficiency, to the maximum possible stochastic output when technical efficiency is fully realised. Further, this measure of technical efficiency is not dependent on the level of the factor inputs for the given field.

Field-specific technical efficiency can be obtained by estimating (4). However, the numerator in (4) is the actual observed production level and it needs no estimation. On the other hand, the denominator is not observable and has to be estimated using (3). For the estimation, it is necessary to specify density functions for U and V. It is assumed the U follows a normal distribution truncated above at the mean, so that U takes the nonpositive values of a $N(O, \sigma_u^2)$ variable and V follows a normal distribution, $N(O, \sigma_v^2)$. U and V are assumed to be independently distributed.

Dropping the subscripts, the density functions of U and V respectively can be written as:

$$f_u(u) = \frac{1}{\sqrt{\pi/2}} \cdot \frac{1}{\sigma_u} \exp\left(-\frac{u^2}{2\sigma_u^2}\right) \qquad u \leq 0 \quad (5)$$

$$f_v(v) = \frac{1}{\sqrt{2\pi}} \cdot \frac{1}{\sigma_v} \exp\left(-\frac{v^2}{2\sigma_v^2}\right) \qquad -\infty < v < \infty \quad (6)$$

The likelihood function of the sample outputs, y, is the product of the density functions of each y_j which in turn is equal to the density function of $(U_j + V_j)$. The density function of $(U_j + V_j)$ can be written as follows (see the convolution formula, Rao 1965):

$$f(u_j + v_j) = \frac{1}{\sqrt{\pi/2\,(\sigma_u^2 + \sigma_v^2)}} \exp\left[\frac{-(u_j + v_j)^2}{2\,(\sigma_u^2 + \sigma_v^2)}\right] \times \left\{1 - \Phi\left[(u_j + v_j)\frac{\sigma_u}{\sigma_v \sqrt{\sigma_u^2 + \sigma_v^2}}\right]\right\} \tag{7}$$

Introducing the following notation,

(i) $\Phi(\bullet)$ is the distribution function of the standard normal random variable,

(ii) $\sigma^2 = \sigma_u^2 + \sigma_v^2$

(iii) $\gamma = \frac{\sigma_u^2}{\sigma_u^2 + \sigma_v^2}$ where γ lies in the interval (0, 1), and

(iv) $u_j + v_j = e_j$

and using this notation in equation (7), the density function of y_j may be written as:

$$f_y(y_j) = \frac{1}{\sigma\sqrt{\pi/2}} \exp\left(-\frac{1}{2}\frac{e_j^2}{\sigma^2}\right) \times \left[1 - \Phi\left(\frac{e_j}{\sigma}\sqrt{\frac{\gamma}{1-\gamma}}\right)\right] \tag{8}$$

The likelihood function of the sample, using (8), will thus be:

$$L^*(y; \Theta) = \prod_{j=1}^{n} \left\{\frac{1}{\sigma\sqrt{\pi/2}} \exp\left(-\frac{1}{2}\frac{e_j^2}{\sigma^2}\right) \times \left[1 - \Phi\left(\frac{e_j}{\sigma}\sqrt{\frac{\gamma}{1-\gamma}}\right)\right]\right\} \tag{9}$$

$$\text{where } e_j = \ln y_j - \sum_{k}^{m} \beta_{jk} \ln x_{jk} - \ln \alpha'$$

and Θ is the parameter to be estimated which contains the production parameters α', the β_ks, σ^2 and γ.

The maximum likelihood (ML) estimators of Θ which maximise the above likelihood function are obtained by setting to zero its first order partial derivatives with respect to the elements of Θ and solving the resulting equations simultaneously.

While it has been assumed that U has a truncated half-normal distribution, ideally, other specifications for the distribution of U should be tested. However, in earlier studies, alternative specifications such as the gamma distribution have not yielded significantly different results (Coelli and Battese 1986; Stevenson 1980; and Waldman 1984). The empirical results, therefore, are subject to the limitations imposed by the assumption of a half-normal specification for U. Maximisation of the relevant likelihood function, by numerical techniques, gives the maximum likelihood estimates of the production function parameters including the intercept, σ^2 and γ. The Newton-Raphson technique (Amemiya 1973) was used with a range of initial values for the parameters, starting with the OLS estimates of the production function given in (3) and different values between 0 and 1 for γ.

Once the frontiers have been estimated, the next step is to estimate the field-specific technical efficiency for each observation in the sample. As the best predictor of an unobservable random variable, conditional on the value of a known random variable, is the conditional expectation of the former random variable, conditional on the value of the latter random variable, estimates of U for individual observations are derived from the conditional distribution of U, given $(U + V)$. Given a normal distribution for V and a half-normal distribution for U, the conditional mean of U given $(U + V)$ is:

$$E(U|U + V) = \int_{-\infty}^{0} u \cdot f_c(u|u + v)\, du$$

where $f_c(u|u + v)$ is the conditional density function of U, given $(U + V)$. Using equations (5) and (7), it is equivalent to:

$$f_c(u|u + v) = \frac{1}{\sqrt{2\pi}} \frac{\sigma}{\sigma_u \sigma_v} \exp \times \left[-\frac{\sigma^2}{2\sigma_u^2 \sigma_v^2} \left(u - e\frac{\sigma_u^2}{\sigma^2} \right)^2 \right] \frac{1}{1 - \Phi\left(\frac{e}{\sigma} \sqrt{\frac{\gamma}{1-\gamma}} \right)} \tag{10}$$

Therefore

$$E(U|U + V) = -\frac{\sigma_u \sigma_v}{\sigma} \times \left\{ \left[\frac{\phi\left(\frac{e}{\sigma} \sqrt{\frac{\gamma}{1-\gamma}} \right)}{1 - \Phi\left(\frac{e}{\sigma} \sqrt{\frac{\gamma}{1-\gamma}} \right)} \right] - \frac{e}{\sigma} \sqrt{\frac{\gamma}{1-\gamma}} \right\} \tag{11}$$

where $\Phi\left(\frac{e}{\sigma} \sqrt{\frac{\gamma}{1-\gamma}} \right)$ is the standard normal distribution function evaluated at $\frac{e}{\sigma} \sqrt{\frac{\gamma}{1-\gamma}}$ and $\phi\left(\frac{e}{\sigma} \sqrt{\frac{\gamma}{1-\gamma}} \right)$ is the standard normal density function evaluated at the same point.

The value of U for each field (observation) is then obtained by substituting the values of σ, σ_u and γ from the ML estimate of equation (9), along with e_j, the residual specific for the j^{th} field, into equation (11) (Kalirajan and Flinn 1983).

The allocative efficiency of a field is the ratio of expected profit to maximum feasible profit and can be measured in two ways. These profits can be based either on the 'best practice' frontier production function or on the fields' own (possibly technically inefficient) 'current practice' production function. To better isolate the 'pure' allocative inefficiency of the field, the latter concept is used. This is computed by obtaining the ratio of the potential maximum profit (using the relevant first order conditions for profit maximisation, given the field-specific production function) and the (expected) profit at the output predicted by the field-specific production function, given its input levels.

Economic efficiency is a combination of technical and allocative efficiency. For a particular field, it is measured as the ratio of the predicted profit at the field's frontier, with the actual levels of inputs, to the maximum feasible profit. The maximum feasible profit is obtained by simul-

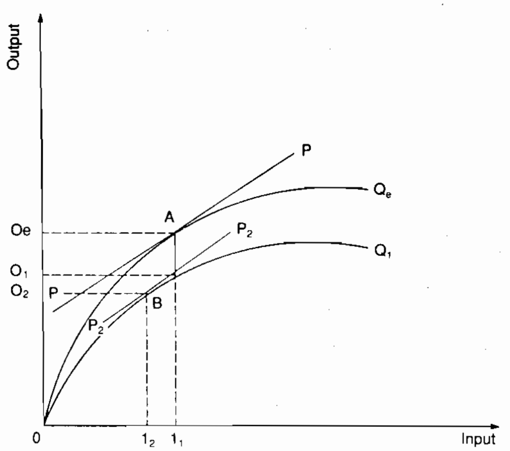


Figure 2. Field-specific technical, allocative and economic efficiencies.

taneously solving the frontier function and the first order conditions for a profit maximum at given input and output prices. Economic and allocative efficiency will coincide only if there is a full technical efficiency.

Figure 2 illustrates the field-specific frontier production function model diagrammatically in an input-output space (Ekanayake 1987). A frontier production function which represents 'best practice' management of the available technology is shown by Q_e. This gives the maximum ouput levels possible at any input levels, e.g. O_e at I_l inputs. Farmers who operate fields which are on this frontier are technically efficient. The line PP gives the market prices ratio for relevant output and inputs. Its point of tangency, at A, is where maximum allocative efficiency is achieved. Since there is also full technical efficiency on this curve, A is also the point of maximum economic efficiency, which is a combination of technical and allocative efficiency, as defined earlier. If a farmer achieves only O_1 output with I_1 inputs on a particular field, he/she is technically inefficient. The extent of the inefficiency is given by the ratio $(O_1/O_e) \times 100$. Analysis of these variations in technical efficiency is presented in Chapter 3.

A farmer may not be aware of the best practice but he/she is aware of the input responses to his/her own management capacities, i.e. the farmer may be on the curve Q_1. It may happen that the farmer optimises input levels and is allocatively efficient, e.g. the farmer produces O_2 with I_2 inputs (where the price line P_2P_2 is tangential) although the farmer is technically inefficient. Allocative efficiency can be calculated for each farmer as the ratio of profits expected at the level of inputs actually used to the potential profit at the level of inputs actually used to the potential profit at the level of inputs which maximises profits at the relevant prices. This can be seen in Fig. 2 as the ratio of profit obtained at input level I_1 and output O_1 on Q_1 to the profit maximising level of inputs I_2 which yield O_2, given the prices P_2P_2. At inputs of I_2, allocative efficiency is 100%. In extreme situations, input costs may exceed output value and negative profits result. Hence allocative efficiency can vary between a negative real number and 100%.

The technical and allocative efficiency measures so obtained are ratios which are not normally distributed. To overcome the problems this presents when they are used as dependent variables in mulitple regression analysis, they can be transformed to obtain variables which vary between $-\infty$ and ∞.

For technical efficiency, a new variable T was defined where $T = ln\left(\frac{TE}{1\text{-}TE}\right)$ and for allocative efficiency a new variable A was defined where $A = ln\left(\frac{1}{1-AE}\right)$. (Note that when no profits are made, $A = 0$.)

In the final step of the economic analysis, each seasonal and locational set of estimates of technical and allocative efficiency, transformed as described above, was subject to OLS regression to identify significant determinants from among sets of variables measured in the farm surveys.

References

Aigner, D.J., Lovell, C.A.K., and Schmidt, P. 1977. Formulation and estimation of stochastic frontier production function models. Journal of Econometrics, 6, 21–37.

Amemiya, T. 1973. Regression analysis when the dependent variable is truncated normal. Econometrica, 41, 997–1016.

Coelli, T.J., and Battese, George E. 1986. A frontier production function for panel data: with application to the Australian dairy industry. A paper contributed to the Thirteenth Annual Conference of the Australian Agricultural Economics Society, Canberra, 3–5 February.

Ekanayake, S.A.B. 1987. Micro level planning, economic performance and human capital. A study of the settler farmers in Mahaweli Project in Sri Lanka. PhD thesis submitted to the Department of Economics, Research School of Pacific Studies, Australian National University.

Farrell, M.J. 1957. The measurement of productive efficiency. Journal of the Royal Statistical Society, Series A (General), 120, 253–290.

Førsund, F.R., Lovell, C.A.K., and Schmidt, P. 1980. A survey of frontier production functions and of their relationship to efficiency measurement. Journal of Econometrics, 13, 5–25.

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, 19, 233–238.

Kalirajan, K. 1986. Measuring absolute technical efficiencies from interdependent multiple outputs frontiers. Journal of Quantitative Economics, 2, 263–274.

Kalirajan, K., and Flinn, J.C. 1983. The measurement of farm specific technical efficiency. Pakistan Journal of Applied Economics, 2, 167–180.

Kalirajan, K., and Shand, R.T. 1985. Types of education and agricultural productivity: A quantitative analysis of Tamil Nadu rice farming. Journal of Development Studies, 21(2), 232–243.

Rao, C.R. 1965. Linear Statistical Inference and Its Applications, New York, Wiley.

Schmidt, P. 1985–86. Frontier production functions. Econometric Reviews, 4(2), 289–328.

Stevenson, R.E. 1980. Likelihood functions for generalized stochastic frontier estimation. Journal of Econometrics, 13(1), 58–66.

Waldman, D.M. 1984. Properties of technical efficiency estimators in stochastic frontier models. Journal of Econometrics, 25, 353–393.

CHAPTER FIVE

Water Balance of Rice Fields

B.M.K. Perera

A major environmental determinant of crop production in rainfed systems is the water balance, that is, the supply of water over the life cycle of field crops. This balance can be calculated from a daily budget of the rainfall, and the various losses as evapotranspiration, seepage, percolation and overflow. The components of the water balance of a flooded rainfed field are shown in Fig. 1 and are connected by the equation:

$$SW_i = SW_{i-1} + R_i - ET_i - S_i - P_i - RO_i - LP_i \qquad (1)$$

where i is the daily counter, SW is the level of soil water, R is rainfall, ET is evapotranspiration, S is seepage, P is percolation and O is overflow. Recently, Walker and Rushton (1984) suggested that a previously unsuspected loss of water from rice fields, called lateral percolation (LP), occurred beneath bunds at a rate much greater than normal rates of percolation because the soil beneath bunds, in contrast to cultivated land, is not puddled, thus avoiding the creation of a compacted layer underneath the bunds (Fig. 1). It is necessary to keep separate account of the various losses because seepage and runoff can be contributors of water to adjacent fields, while percolation and lateral percolation are flows to the groundwater.

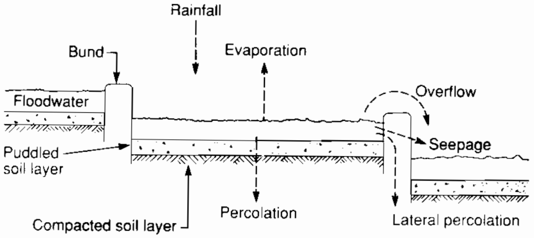


Fig. 1. Components of the water balance in rainfed rice fields.

Of the components of the water balance, rainfall is measured routinely. Evapotranspiration, or in the absence of plants, evaporation, can be estimated from the loss of water from an evaporation pan or from calculations based on net radiation, temperature and humidity. Overflow can be inferred from the spillway level in a field. The other components of the water balance, seepage, percolation and lateral percolation, have not been widely measured in rainfed fields. This chapter describes a simple method for measuring these three components and reports the results obtained in farm fields.

Measurements were made for eleven locations in Kurunegala district, of which six were irrigated by minor tanks and five were rainfed. In Anuradhapura district, all seven locations where measurements were made were rainfed.

Using these results, the daily water balance for each location was calculated. In addition, the rice grain yields, at the locations in which the water balance measurements were made, were related to the total evapotranspiration for the season for each location.

Methods

Seepage, percolation and lateral percolation were measured using two concentric plastic cylinders embedded in the soil of flooded fields (Fig. 2). The procedure for making the observations was first to push a narrow cylinder (150 mm inside diameter, 6 mm wall thickness) vertically into flooded soil as far as possible, and then to place a specially constructed anvil onto the upper rim and hammer it a further 5–10 mm into compacted soil. The wider cylinder (250 mm inside diameter, 6 mm wall thickness) was then installed around the narrow cylinder in the same way. The depth of penetration of the cylinders into the soil was typically

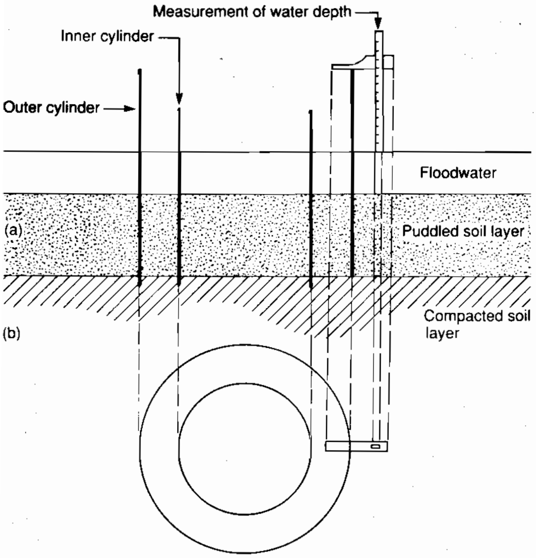


Fig. 2. Measurements of water loss using concentric infiltration rings.

80–100 mm. A cover was placed over the cylinders to exclude rainfall and evaporation. All measurements were made when the fields were flooded so as to obtain values representative of the rainy season. Three replicate sets of cylinders were used on each field.

The system of measurement consisted of observations of water depth at intervals of 24 or 48 hours. The components of water loss were measured as follows:

Percolation:	Water loss from inner cylinder				
Evapotranspiration:	Net pan evaporation				
Seepage and lateral percolation:	Water loss from field	−	Water loss from inner cylinder	−	Net pan Evaporation

The reason for using concentric cylinders was to provide a buffer of relatively constant water depth around the inner cylinder so that fluctuations in the depth of water in the field did not interfere with the percolation measurements (Bouwer 1963). The related measure of pan evaporation was used as an estimate of evaporation and evapotranspiration for the days when the measurements with the cylinders were made (Tomar and O'Toole 1980).

The daily water balance for each location was calculated using a computer program. Rainfall data for each location were measured at the nearest gauge, generally located within 2 km of the field. Pan evaporation data from the Central Rice Breeding Station were used for locations in Kurunegala district and from the Agricultural Research Station at Maha Illuppallama for those in Anuradhapura district. Measurements of evaporation were made within 20 km of the experimental fields. Location-specific values for percolation, and combined seepage and lateral percolation were those measured with the cylinders.

The evapotranspiration summed over the growing season of each rice crop, was then related to the grain yield measured in researcher-managed trials (Chapter1) conducted at each location.

Results and Discussion

Measurements of water loss from experimental fields are presented in Table 1. The rates of percolation are in the range of 1–3 mm/day, which is similar to the range of 3–4 mm/day reported for irrigated rice fields in the Philippines by Wickham (1973) and in Sri Lanka by Pannabokke and Walgama (1974). There is little difference between percolation in rainfed and irrigated fields.

Table 1. Measurements of the water balance of rice fields in the two districts. Standard deviations of the mean are in parentheses.

Location and season	Number of observations	Total water loss	Percolation	Pan evaporation	Seepage and lateral percolation
		mm/day			
Anuradhapura *Maha* 1985–86	7	14.0 (11.3)	3.3 (2.1)	4.3 (0.9)	6.4
Anuradhapura *Yala* 1986	5	30.2 (10.8)	3.6 (0.5)	5.3 (0.8)	21.3
Kurunegala *Maha* 1985–86	11	n.a.*	1.3 (1.4)	n.a.	n.a.

*Not available.

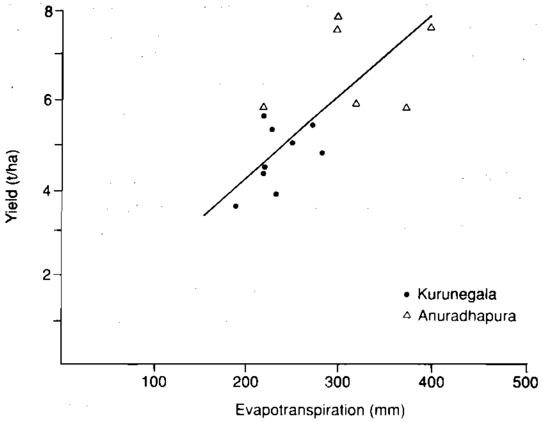


Fig. 3. Relationship between yield and cumulative evapotranspiration calculated from a water balance and rice yield.

The largest loss of water was due to a combination of seepage and lateral percolation. It is not possible from the measurements used in this study to separate these components. Of the two, seepage is the more visible, and in these fields the large banks between rice fields probably restricted the rate of seepage. Presumably, much of the very large rate of water loss was from lateral percolation, as it was in the irrigated systems studied by Walker and Rushton (1984). The possibility of reducing this loss should be the subject of further research. It is not unlikely that burrowing in the bunds by rats increases the rate of lateral percolation. A reduction in this water loss path, e.g. through proper rat control, would benefit the water supply of the field itself. It may also lead to a significant reduction of regional water tables and reduced flooding at the tails of irrigation systems.

The relationship between yield and estimated evapotranspiration is shown in Fig. 3. The separation of data between Kurunegala and Anuradhapura reflects the generally higher evaporation rates in the latter district; there is also evidenc of an association between yield and evapotranspiration in both districts. The closeness of the relationship ($r = 0.75$) suggests that water supply is an important limitation to yield in both environments. The slope of the line in Fig. 3 is a measure of the water-use efficiency; its value, 18.4 kg/ha of grain per mm of water used, is similar to that found for rice by Angus et al. (1983).

The yield data on which this association was determined were from researcher-managed treatments in which nutrient stress and pests were eliminated. The conclusion that water supply limits productivity may apply only under these conditions, and the conclusions of Chapter 1 about the importance of pest control are more relevant to the productivity of farmers' crops. Nevertheless, the estimate of water-use efficiency found here provides a basis for estimating the benefit to be gained by conserving water within rice fields.

References

Angus, J.F., Hasegawa, S., Haiao, T.C., Liboon, S.P., and Zandstra, H.G. 1983. The water balance of post-monsoonal dryland crops. Journal of Agricultural Science 101, 699–710.

Bouwer, H. 1963. Theoretical effect of unequal water levels on the infiltration rate determined with buffered cylinder infiltrometers. Journal of Hydrology 1, 29–34.

Pannabokke, C.R. and Walgama, A., 1974. The application of rainfall confidence limits to crop water requirements in dry zone agriculture in Sri Lanka. Journal of the National Science Council of Sri Lanka 2, 95–113.

Tomar, V.S. and O'Toole, J.C., 1980. Water use in lowland rice cultivation in Asia: a review of evapotranspiration. Agricultural Water Management. 3, 335–351.

Walker, S.H. and Rushton, K.R., 1984. Verification of lateral percolation losses from irrigated fields by a numerical model. Journal of Hydrology 71, 335–351.

Wickham, T., 1973, Predicting yield benefits in lowland rice through a water balance model. In: Water Management in Philippine Irrigation Systems: Research and Operations. Los Baños, IRRI, 155–181.

CHAPTER SIX

Summary and Conclusions

The two projects focused on the identification of the agronomic and socioeconomic reasons for the gap between farmers' rice yields and the potential production as represented by researchers' yield in the farmers' environment and the reasons for variable technical and economic performance among farmers. This was achieved by means of socioeconomic farm surveys and agronomic field experiments carried out over six consecutive rice-growing seasons in Anuradhapura district in the Dry Zone and in Kurunegala district in the Intermediate Zone. Both zones had major irrigation schemes and minor tank irrigation but only the latter had partly irrigated and rainfed cropping systems in addition.

Analysis of the farm-survey data showed that rice farm size was typically small: between 0.5 and 1.0 ha. In the rainfed areas most farms were less than 0.5 ha. Mean yields in Kurunegala varied over seasons from 2.9 to 3.6 t/ha under major irrigation. Under minor tanks and mixed irrigated/ rainfed conditions yields were slightly lower. Yields were lowest under rainfed conditions and showed the greatest variability in the fewer seasons surveyed. In Anuradhapura yields did not vary greatly and ranged from 2.1 to 2.5 t/ha. In both districts, fertilizer application was widespread and most farmers used multiple applications irrespective of water regime. Less fertilizer was used in the *Yala* season than in the *Maha* season.

Total labour inputs per hectare in Kurunegala were highest under irrigation from major tanks, lower under minor tanks and mixed conditions, and lowest under rainfed conditions. In all four water regimes there was a consistent negative relation between rice-farm size and the level of labour input per hectare.

In both districts ownership of land predominated. Across the four water regimes in Kurunegala only about half of the household heads had farming as their sole occupation; income from non-rice sources was generally greater than from rice. The consistency and magnitude of the contribution of non-farm income in this district is particularly striking. Such a trend was also evident in Anuradhapura although off-farm work was less prevalent due to lack of opportunities.

Economic efficiency of a farm was assessed by analysing its two components: technical efficiency and allocative efficiency. This allows intervention to raise each or both components. For the analysis of the performance within individual cropping seasons a stochastic frontier production approach was used to estimate technical and allocative efficiencies at individual field level. The range in performance was measured in terms of the closeness of individual efficiencies to the frontier or 'best practice' performance. Estimation of technical efficiency revealed wide variation in each of the seasons, water regimes and districts.

In general, the levels of technical efficiency were higher in the more favourable environments. The range of technical efficiencies in the less favourable environments was greater; thus, there may be more scope in such areas for assisting farmers who are currently operating at low levels of technical efficiency.

The two main determinants of technical efficiency that emerged from the analysis were timeliness and use of pesticides. Timeliness was a composite variable which included such decisions as the date and method of establishment and the choice of variety. Timeliness of management practices affected technical efficiency significantly in both districts in almost all seasons and water regimes.

It was shown that allocative efficiency was dependent upon technical efficiency. Therefore raising technical efficiency may have both a direct and indirect positive influence on economic efficiency.

In comparing the agronomic and socioeconomic projects, it was found in both analyses that a considerable proportion of the variation in field trial and farm survey yields remained unexplained. The estimates of variability measured in the socioeconomic farm surveys differ from those obtained from the field trials. In the former, variability in yields comprises the influences of both environmental factors and management practices whereas in the latter, the management factor is relatively constant. Estimates of variability from the trials thus provide an indication of the contribution of environmental factors. Yield variability between field trial sites was substantial. This was attributed to unmeasured environmental factors and to past or present management practices associated with individual farmer's fields.

The agronomic field experiments confirmed the importance of an adequate water supply as a determinant of yield by means of an associated water balance study in which a close relationship was found between yield and total evapotranspiration during the growing season. In addition, the experiments showed that plant water stress lowered the efficiency of plant N to produce grain. When water is not a limiting factor the environment of the two districts combined with the rice varieties used is conducive to a high plant-N efficiency. There seems little scope for using irrigation water more efficiently other than by investigating methods to decrease lateral percolation.

The onfarm experiments conducted over six consecutive seasons in the two districts indicated that there was an average yield gap between collaborating farmers and researchers of at least 1.2 t/ha. The amount of fertilizer N applied by the farmers was generally adequate, but its management could be improved. An attempt to predict the amount and timing of fertilizer N required per crop for a specific farm, based on models containing several soil parameters, indicated that at present there is little scope for improvement of the current official recommendations.

Of the three main inputs recommended by the Department of Agriculture, viz. fertilizers, weed control, and insect pest control, incorrect use of the last was the major and most consistent factor contributing to the yield gap. When insect pest control was not applied according to the official recommendations, there was an average loss of 0.5 t/ha of grain per crop. Although the farm surveys showed that most farmers used insect pest control the results of both the agronomic and socioeconomic projects pointed strongly to the need for improved pest control in order to increase yields and economic efficiency. Pest control may be the management variable most amenable to intervention. A more intensive extension on insect pest recognition is warranted and the possibility of controlling insect pests on a regional scale could be investigated.

ACIAR Technical Reports

No. 1. ACIAR Grain Storage Research Program: research report 1983–84, 63p., 1985.
No. 2. Pastures in Vanuatu, D. Macfarlane and M. Shelton, 32p., 1986.
No. 3. ACIAR Grain Storage Research Program: research report 1984–85, 85p., 1986.
No. 4. Coconut germplasm in the South Pacific Islands, M.A. Foale, 23p., 1987.
No. 5. South Pacific agriculture: challenges and opportunities for ACIAR and its research partners, G.J. Persley and P. Ferrar, 87p., 1987.
No. 6. ACIAR Grain Storage Research Program: research report 1985–86, 96p., 1987.
No. 7. Building on success: agricultural research, technology, and policy for development: report of a symposium held at Canberra, 14 May 1987, J.G. Ryan, 39p., 1987.
No. 8. New technologies for rainfed rice-based farming systems in the Philippines and Sri Lanka: report of a workshop held at Iloilo, Philippines, 20–24 July 1987, 39p., 1988.
No. 9. Gaseous nitrogen loss from urea fertilizers in Asian cropping systems, J.R. Freney, J.R. Simpson, Zhu Zhao-liang and Aziz Bidin, 16p., 1989.
No. 10. Bulk handling of paddy and rice in Malaysia: an economic analysis, G.J. Ryland and K.M. Menz, 32p., 1989.
No. 11. Economic prospects for vanilla in the South Pacific, K.M. Menz and E.M. Fleming, 14p., 1989.
No. 12. Biological control of *Salvinia molesta* in Sri Lanka: an assessment of costs and benefits, J.A. Doeleman, 14p., 1989.
No. 13. Rainfed Rice Production in the Philippines: a combined agronomic/economic study of Antique Province, K.M. Menz, 90p., 1989.
No. 14. Transport and storage of fruit and vegetables in Papua New Guinea, K.J. Scott and G. Atkinson, 22p., 1989.
No. 15. Marketing perspectives on a potential Pacific spice industry, Grant Vinning, 59p., 1990.
No. 16. Mineral nutrition of food legumes in Thailand with particular reference to micronutrients, R.W. Bell et al., 52p., 1990.