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.

Where trade names are used this constitutes neither endorsement of nor discrimination against any product by the Centre.

ACIAR TECHNICAL REPORT SERIES

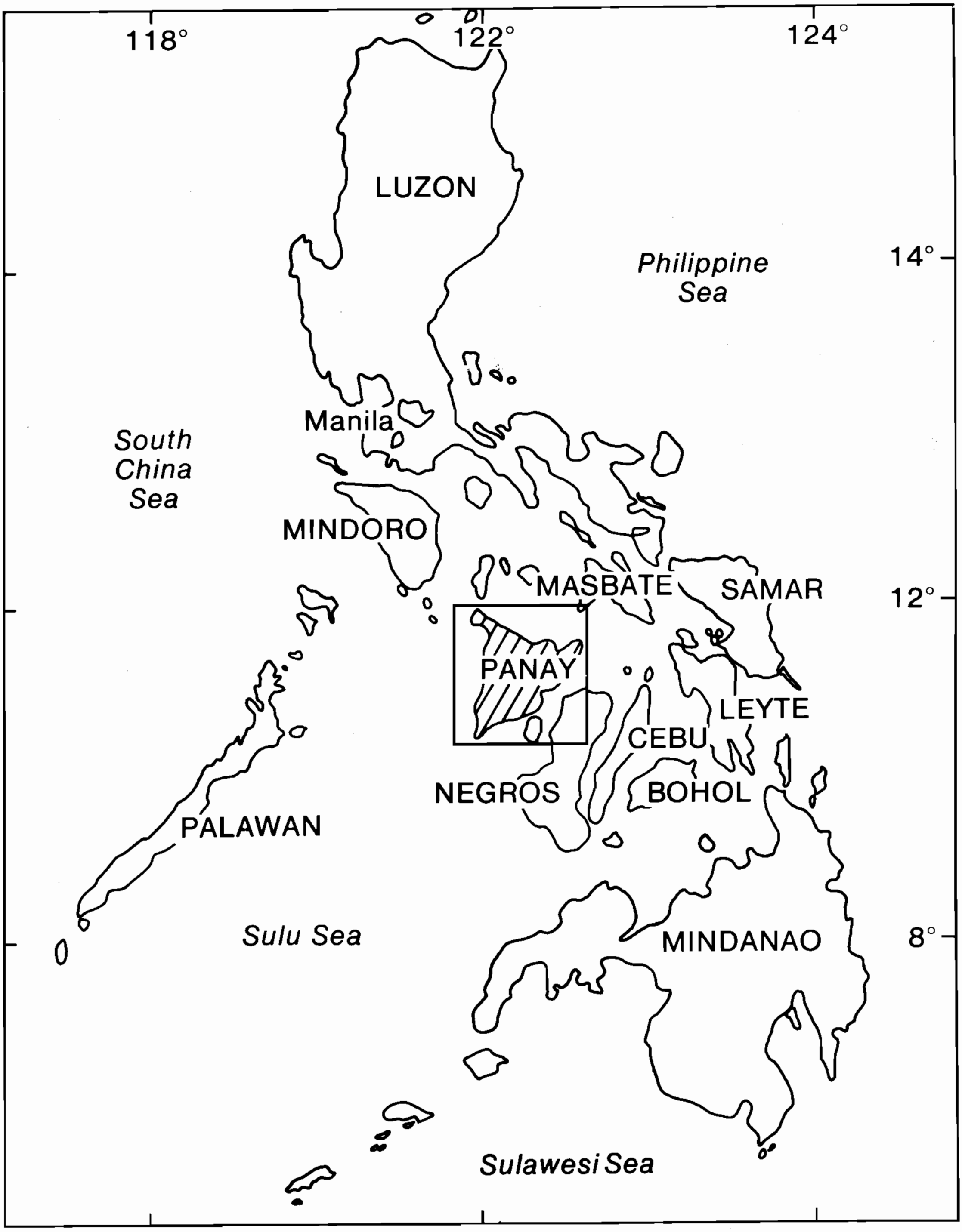
This series of publications contains technical information resulting from ACIAR-supported programs, projects, and workshops (for which proceedings are not being published), reports on Centre-supported fact-finding studies, or reports on other useful topics resulting from ACIAR activities. Publications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

Menz, K.M. (ed.) 1989. Rainfed Rice Production in the Philippines: A Combined Agronomic/Economic Study in Antique Province. ACIAR Technical Report No. 13, 90p.

ISBN 0 949511 73 0

Typeset and laid out by: Ocean Graphics, Gold Coast.
Printed by: Roden Print, Silverwater, NSW.
Photos: cover, Brian Lee; p.12, John Angus.

Rainfed Rice Production in the Philippines



General location map. Antique Province is located on the west coast of Panay Island (see Fig. 2, Chapter 1 for detailed map).

Rainfed Rice Production in the Philippines:

A Combined Agronomic/Economic Study in Antique Province

Kenneth M. Menz, Editor

Australian Centre for International Agricultural Research
Canberra 1989

Contributors

J.F. Angus	CSIRO Division of Water and Land Resources, GPO Box 1666, Canberra ACT 2601; present address: CSIRO Division of Plant Industry, GPO Box 1600, Canberra ACT 2601, Australia
A.B. de Lima	Department of Agriculture, San José, Antique, Philippines
G.T. Estomata	Department of Agriculture, San José, Antique, Philippines
C. Fazekas de St.Groth	CSIRO Division of Water and Land Resources, GPO Box 1666, Canberra ACT 2601, Australia
A.G. Garcia	Agronomy Department, University of the Philippines at Los Baños, Laguna, Philippines
S.K. Jayasuriya	Research School of Pacific Studies, Australian National University, GPO Box 4, Canberra ACT 2601; present address: Economics Department, La Trobe University, Bundoora Vic 3083, Australia
K.P. Kalirajan	National University of Singapore; present address: Research School of Pacific Studies, Australian National University, GPO Box 4, Canberra ACT 2601, Australia
D.S. Magbanua	Department of Agriculture, San José, Antique, Philippines
M.C. Mangabat	Agricultural Research Office, Department of Agriculture Metro Manila, Philippines
D.A. Marquez	Department of Agriculture, San José, Antique, Philippines
R.T. Shand	Research School of Pacific Studies, Australian National University, GPO Box 4, Canberra ACT 2601, Australia
R.C. Tasic	Department of Agriculture, San José, Antique, Philippines

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, 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 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 Report 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 Philippines component of the project. The Sri Lankan component will be the subject of a separate report.

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 Reg MacIntyre and Camilla Fazekas de St.Groth in producing this publication. The projects on which this publication is based were originally developed by the Australian and Philippine project leaders, whose names are listed in this publication, and who wrote the various papers. The 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, the projects described in this report were sponsored by ACIAR, focusing on the less favoured rainfed rice areas of the Philippines and Sri Lanka.

There were two projects — one agronomic and one economic — each collaborative between Australian and developing country institutions and with each other. Both projects were based in the target countries (Philippines and Sri Lanka), but the results have broad relevance for rainfed rice production in Asia.

G.H.L. Rothschild
Director, ACIAR

Project Personnel

AUSTRALIA

ACIAR 8330: Regional Analysis of the Transfer and Performance of New Technologies in Rice-Based Farming Systems in Sri Lanka and the Philippines

Dr Richard T. Shand — Australian National University (ANU)
Dr Sisira K. Jayasuriya — ANU (now at La Trobe University)
Dr K.P. Kalirajan — National University of Singapore (now at Australian National University)

ACIAR 8369: Environmental Constraints to Increased Productivity of Rainfed Rice-Based Farming in the Philippines

Dr John Angus — Commonwealth Scientific and Industrial Research Organisation (CSIRO)
Ms Camilla Fazekas de St.Groth — CSIRO

PHILIPPINES

Dr Edgardo C. Quisumbing — Director, Agricultural Research Office (ARO), Department of Agriculture (DA)
Dr Arturo Gomez — Consultant, ARO, DA
Dr Dennis Wood — International Rice Research Institute (IRRI)
Ms Jindra L. Demeterio — ARO, DA
Ms Minda C. Mangabat — ARO, DA
Mr Rolando Labios — ARO, DA

Project Staff, ACIAR Project 8369

Administrative:
Mr Honorato Jereza — DA, Region VI, Iloilo City
Mr Diosdado Magbanua — DA, Antique Province

Research:
Mr Rafael C. Tasic
Mr Gaspar Estomata
Mr Dominador Marquez
Mr Angelo de Lima
Mr Henry Venegas
Mr Romulo Villodres
Mr Roger Zacarias
Miss Jocelyn Durana
Mr Ramon Alonsabe
Miss Thelma Fetiza

Introduction

The great improvements experienced in cereal production and food self-sufficiency in Asia since the 1950s have been based upon irrigated farming systems. However, given the high and increasing cost of expanding the irrigated rice area in Asia, the importance of rainfed lowland and upland rice must increase if future rice output per head of population, and current levels of regional self-sufficiency, are to be maintained.

In contrast to irrigated rice-based farming systems, little research has been carried out on how to raise the productivity of rainfed rice-based systems. Consequently, little data exist on the yield potential in rainfed agriculture. Similarly, knowledge of constraints on rainfed multiple cropping strategies is scant compared to that for irrigated farming.

In many areas in which rainfed rice is grown, it is possible that more than one crop can be grown in a year. Annual crop production is made up of the yield per crop and the number of crops grown each year. These projects were concerned with both aspects of production. Each is studied from both agronomic and socioeconomic viewpoints, as reported in the chapters contained in this report. The principal research methods used in studying the constraints to higher productivity were: in the agronomic project — field trials and simulations for yield per crop and number of crops respectively; and in the socioeconomic project — farm surveys and frontier production functions, and discriminant functions.

Socioeconomic Project

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 from 1983 to 1986. 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 agroenvironmental 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.

Agronomic Project

The agronomic study of yield per crop was based on field trials located on farmers' land. These trials indicated the yields obtainable with recommended technology, and the yield responses to changes in the levels of major inputs of fertilisers and herbicides. The trials highlighted gaps between yields with farmer-technology and those with researcher-technology, and the reasons for such gaps. Associated with the field trials was a program of crop-cuts on farmer-managed rice crops growing on land which was as close as possible to that used for the field trials. The field trials were concerned not only with rice, but also with upland crops and, where possible, mungbean and cowpea were grown as a second or in some cases a third crop. The agronomic project in the Philippines, called PHARLAP (Philippine-Australian Rainfed Lowland Antique Project) has been described in detail by Tasic et al. (1987). A condensed version is presented in Chapter 3.

In areas which are marginal for multiple cropping, the number of crops which it is possible to grow per year cannot be reliably determined from field trials conducted over a few seasons. Successful multiple cropping under rainfed conditions largely depends on seasonal conditions. Trials conducted over a series of atypical seasons will give a misleading indication of the potential for multiple cropping. The key to promoting an increased number of crops grown in a season lies in better understanding of how crops respond to the environment, particularly the water balance. Research experience over a number of seasons is needed to provide a confident recommendation on feasible cropping patterns.

A computer model based on water balance concepts was used to estimate the potential number of crops at specified landscape positions during long sequences of seasons. The yields measured in the agronomic trials were used to validate the simulation model for particular landscape positions and seasons.

The simulation model is a development of an earlier version produced at the International Rice Research Institute (IRRI). During model development, it became clear that a simplified version, suitable for use on microcomputers, was needed both for analysing the results of particular experiments and for studying the adaptation of new cropping patterns in different environments. An interactive and user-friendly version has been released for use in the Philippine Department of Agriculture and is available for interested users.

Interaction

The agronomic and socioeconomic projects were linked through their estimation of actual and potential productivity.

The two disciplines utilise different methods of estimating productivity, the socioeconomic analysis being based on interviews with hundreds of farmers. It was not feasible to conduct field trials in such numbers, but generally there were sufficient numbers of trials to reliably sample productivity of the same environments where farmers were surveyed by social scientists.

Since the major emphasis of the socioeconomic project was on explaining the variation in farmers' economic performance, an attempt was made to measure the yield variability of rice crops when supplied with recommended inputs. This is an important departure from typical agronomic studies in which the emphasis is on mean productivity and responses. Some of the variation in production between farms is due to natural variability of soil and landscape and some is due to farmers' management and inputs. One aspect of the interaction between the agronomic and socioeconomic projects was the examination of estimates, made by different methods, of the variation of crop yield.

Location of Study Areas

The study areas selected were three municipalities in the central Philippine province of Antique. The reason for selecting Antique was its relatively undeveloped economy and the lack of previous research. The three municipalities were chosen to represent widely differing durations of growing season, as described in Chapter 1.

All rice crops included in the PHARLAP field trials were fully rainfed and there were no significant irrigation systems nearby. In this important respect the study areas differ from other Philippine rainfed areas where cropping systems have been studied previously, for example by IRRI in Iloilo, Pangasinan and the Cagayan Valley. All of these areas are close to irrigation land. One consequence of the isolation of Antique rainfed rice from intensive irrigated agriculture was that inputs such as fertiliser and pesticides, and services such as credit and extension advice, were poorly supplied. Another consequence was that there was no consistent supply of seedlings for transplanting of second crops, although transplanted rice has a shorter growth duration which is recognised as an advantage in rainfed areas. Nor was there an active market in renting hand-tractors from farmers in irrigated areas or good access to spare parts or repair services. On the positive side, the pests and diseases which can persist from season to season under irrigation and spread into rainfed areas during the rainy season are largely eliminated during the reliably dry season.

A more detailed description of the evolution of cropping systems in Antique is given in Chapter 1. This is followed by a description of the farming systems, as determined from the socioeconomic surveys, in Chapter 2. The agronomic project and results are summarised in Chapter 3. The economic analysis is presented in Chapter 4 with the methodology underlying it in Chapter 5. The simulation model used to estimate the feasibility of double cropping is presented in Chapter 6. Chapters 7 and 8 are concerned in various ways with the relationship between agronomic and socioeconomic aspects of improving productivity. The final Chapter 9 contains the conclusions.

Reference

Tasic, R.C., Fazekas de St.Groth, C., and Angus, J.F. 1987. PHARLAP: a cropping systems study on rainfed rice farms in Antique Province, Philippines. Natural Resources Series No. 7. Canberra: CSIRO Division of Water and Land Resources.


PHARLAP project
LOCATION: CLAM-ISAN, PANDAN, AN
CROPPING PATTERN: WSR-WSR-
VARIETY: IR 60
DATE OF ESTAB.: NOV. 18, 1984
FARMER COOP.: M. BARRIENTOS
RESEARCHERS: G. ESTOMATA
R. ALONSABE JR.

CHAPTER ONE

Rainfed Lowland Cropping Systems and Environment in Antique

D.S. Magbanua

The objective of this chapter is to describe the recent evolution of rainfed lowland cropping systems and the environment of Antique.

Cropping Systems

Rainfed lowland cropping systems in Antique have evolved rapidly since the 1950s, with changes in rice varieties, establishment methods, cropping intensities, weed control and fertiliser usage. The historical development of these aspects is shown in Fig. 1.

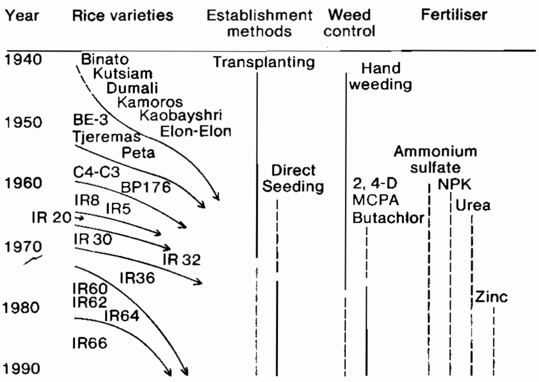


Fig. 1. Evolution of the cropping systems of rainfed rice farms of Antique.

Rice Varieties

Up to the late 1950s, all rice farmers in the region used traditional varieties such as Binato, Kutsiam, Dumali, Kamoros, Kaobayshri and Elon-elon. Several of these varieties came from other regions, the more popular ones being photoperiod-sensitive and therefore seasonal. Mostly, they were planted during the rainy months of June or July, and matured in December.

In the late 1950s, the Philippine Seedboard of the Bureau of Plant Industry introduced rice varieties, such as BE-3, Peta and Tjeremas, from Burma, Indonesia and China, respectively, because of their higher-yielding potential and better eating qualities. These varieties were still very susceptible to lodging, especially during typhoons, due to their long stems.

The Philippine College of Agriculture at Los Baños, being aware of this vulnerability, started a rice-breeding program, through which varieties such as C4-63, C18 and C4-54 were introduced. At the same time, the Bureau of Plant Industry developed its own BPI series, of which BPI-76 was released in Antique. Through irradiation, the Philippine Atomic Energy Commission converted the variety BE-3 from a seasonal into a nonphotoperiodic variety.

The International Rice Research Institute (IRRI), established in 1960, realised the importance of short-stemmed, stiff-straw varieties with erect leaves, and started a vigorous breeding program that emphasised these characteristics. This resulted in the variety IR8 or 'miracle rice' that had the potential to outyield the traditional varieties by a factor of four.

Unfortunately, the popularity of IR8 did not last long due to the unexpected incidence of bacterial diseases and its inferior eating quality. However, IRRI has continued to develop a long series of new varieties with built-in characteristics to counter pest and disease problems as well as adverse soil conditions. The IRRI varieties are now the predominant ones in almost all rice-growing areas of the province; at present, the very successful IR36 still has not been replaced completely by the latest varieties, although IR60, 62, 64 and 66 are now popular.

Establishment Methods

During the 1950s, rice crops on virtually all rainfed farms in the province were established by the transplanting method (TPR). This required the raising of seedlings in a nursery bed during the onset of the rainy season. Depending on the availability of water in the main field, the seedlings were transplanted 20–30 days after sowing, but in some rainfed areas, seedlings older than 30 days had to be used on some occasions. The growth duration of TPR is shorter than rice established by other means, but the reduction is less than the time spent in the nursery because of a shock to development caused by the stress of transplanting.

This method of establishment continued even during the introduction of the IRRI varieties, but, due to increasing labour costs and better herbicides, direct-seeding, which may be done under wet or dry conditions, is now practiced on about 80% of irrigated and rainfed farms. Wet-seeded rice (WSR) is established by broadcasting pregerminated seeds into a seedbed of mud or shallow water in the main field. Dry-seeded rice (DSR) is established by placing ungerminated seeds into unsaturated soil, either by broadcasting and subsequent harrowing, or by dibbling seeds into a shallow furrow opened by a plough. Most DSR crops included in the PHARLAP field trials were established by the latter method.

Cropping Intensity

Prior to the introduction of the IRRI varieties, farmers in the province grew only one crop of rice per year. Where the soil was friable enough, a rice crop of BE-3 could be followed by an upland crop such as mungbean or cowpea. Until the early 1970s, about 90% of the rainfed area of the province grew only one rice crop per year, and for about 20%, this crop was followed by an upland crop. However, due to the early-maturing characteristics of the IRRI varieties, about 50% of the rainfed area can now be double-cropped with rice.

Weed Control

Until the high-yielding varieties were introduced, hand-weeding was the standard method of weed control in the province. Thereafter, chemical weed control became popular, especially in view of the increasing labour costs associated with hand-weeding. After the first selective herbicides such as 2,4-D, MCPAs were introduced, followed by preemergence types such as Butachlor. However, hand-weeding is still practiced in some areas, even where the IRRI varieties are grown.

Fertiliser Usage

The use of inorganic fertilisers began in Antique during the mid 1950s with the establishment of the then Fertiliser Administration, at a time when the more traditional *indica* rice varieties were grown. As these had long-stem characteristics, they were very susceptible to lodging, especially when high doses of nitrogen fertilisers (mainly in the form of ammonium sulfate) were applied. This often led to negative yield responses.

Soon after, the 'complete' (NPK) fertilisers such as 12-24-12 and 12-12-12 were introduced and their rates of application were recommended by the Regional Soil Laboratory after a soil test had been carried out.

With the introduction of rice varieties that were resistant to lodging, higher rates of N could be applied. At that time, urea became a popular nitrogen fertiliser in view of its high N concentration and consequent low transportation costs per unit of N. Its use was further stimulated by the Government Food Production Program, Masagana 99, which also encouraged the adoption of modern rice varieties, herbicides and insecticides.

Further research on fertiliser requirements has pointed to the need for additives such as zinc, particularly under high pH and submerged soil conditions. Zinc sulfate is now available in the capital city of the province, San José, and an application of 5–10 kg/ha of this chemical is normally sufficient to overcome the zinc deficiencies in the province.

Rice yields in Antique during the 1980s have averaged 2.2 t/ha which is relatively high by national standards. However, in recent years, Antique yields have been static while national yields have continued to rise.

Environment

The environment of the lowland areas of Antique has similarities and differences when compared with other Philippine provinces. As in most lowland parts of the Philippines, temperatures are warm throughout the year, with little day-night range or between-season range. The water balance is controlled by the southeast monsoon, which brings rain during April–May until November–February. Figure 2, taken from Tasic et al. (1987), shows the pattern of mean rainfall and growing-season duration throughout the province, with the southern parts having lower rainfall and a shorter growing season than the northern parts.

There are a large number of distinctive soil types in the province which have been described by Calimbas et al. (1963). In general, the soils on which rice is grown are of coarser texture than in many parts

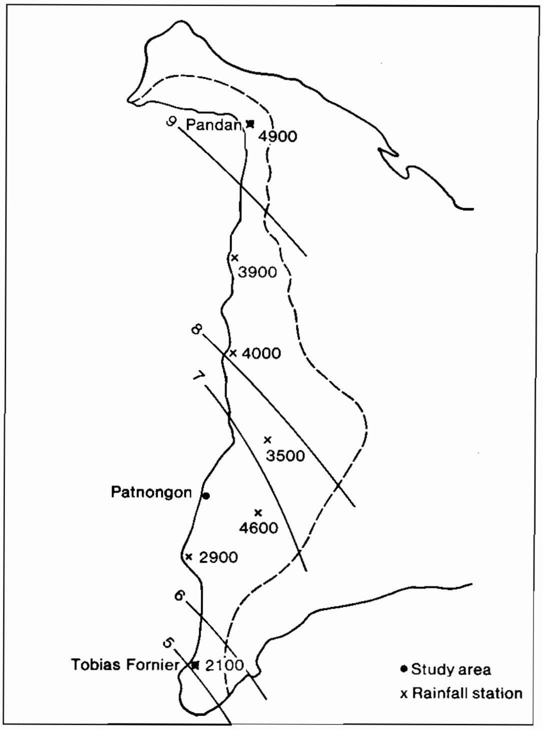


Fig. 2. Map of Antique showing mean annual rainfall (in mm) (crosses) and duration of the flooded growing season (lines), based on months of rainfall greater than 200mm.

of the Philippines. A distinctive feature is the narrow plain lying between the coast and the rugged hills and mountains which form the inland boundary of the province. Figure 3 is a schematic cross-section of the

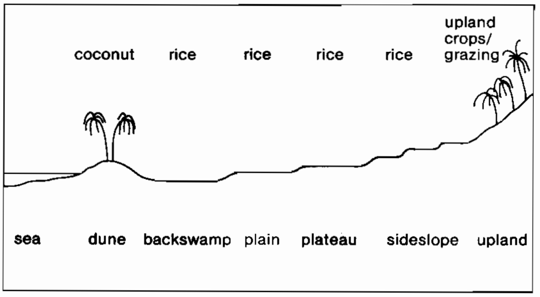


Fig. 3. Schematic cross-section of the lowlands of Antique.

lowlands showing the pattern of riceland in relation to topography and landform, based on the definitions of Raymundo (1979). The plain and plateau are the most closely settled and productive areas of rainfed land and have the advantage of relatively good transport. The more remote sideslope and upland areas are generally less well served with transport and other infrastructure than the plains and plateaus near the coast.

References

Calimbas, F., Lopez, F.B., and Tingzon, J. 1963. Soil survey of Antique Province. Soil Report 30, Bureau of Soils, Manila.

Raymundo, M.E. 1979. Rice Soils of the Philippines. In: Soils and Rice. Los Baños, IRRI. 115–133.

Tasic, R.C., Fazekas de St.Groth, C., and Angus, J.F. 1987. PHARLAP: A cropping systems study on rainfed rice farms in Antique Province, Philippines. Natural Resources Series No. 7. Canberra: CSIRO Division of Water and Land Resources.

CHAPTER TWO

Description of the Farming Systems in Antique

S.K. Jayasuriya, M.C. Mangabat and R.T. Shand

Antique is one of the five provinces comprising the Western Visayas, known as Region VI. It is a narrow strip of land, only 35 km wide at the widest point and 155 km long, with an area of 251 757 ha, located on the western coast of Panay Island. The mountains of Central Panay divide it from the east and over 80% of the land area is classified as mountainous. From the coastal plain which is narrow, and in places almost nonexistent, the land rises steeply to the mountains. The population distribution is strongly biased towards the plains and over 60% of the population live on these coastal plains.

The climate is typically monsoonal with a unimodal rainfall distribution. The rainy season becomes progressively longer towards the north. The municipalities at the northern tip of the province get some rain for 10 months of the year, on average, compared with 6 months in the southernmost areas (for more details on the physical environment, see Tasic et al. 1987).

Rice cultivation is the major agricultural activity. Some of the rice area on the coastal plain is irrigated but there are considerable nonirrigated areas where rainfed lowland rice cultivation is carried out. The major irrigated area is found in the basin formed by the Sibalom River. While Antique is considered one of the 'depressed' regions of the Philippines, it is a small net rice exporter. Other important crops are corn, sugar cane and coconuts.

There is also an important fishing industry. In 1982, nearly one-fifth of the households were engaged in fishing as their major occupation while one-third of the households depended mainly on farming. Livestock raising is usually a small-scale activity. Water buffaloes ('carabaos') and other cattle, hogs and poultry are raised by many farm households as an important, although subsidiary, activity. Raising of work animals is strongly linked to rice cultivation.

Study Areas

Selection of the study areas within Antique was primarily governed by the opportunity presented for studying rainfed rice-based farming systems in three different rainfall regimes, which represent conditions often found elsewhere. In addition, it enabled the major rainfed rice-growing areas in the province to be covered by the study. Three municipalities were selected for the study, representing three distinct rainfall regimes. Tobias Fornier (formerly Dao) in the south had the shortest rainy season. Pandan, in the north, had the longest season, while Patnongon was intermediate. Cropping intensity on lowland areas varied according to the length of the rainy season. Cultivation of two rice crops per year was common in Pandan, while double cropping of any kind was rare in Tobias Fornier. Patnongon typically had a significant proportion of such land under two crops each year.

Even within these three municipalities, the study areas showed considerable heterogeneity, for example, in landscape positions; such differences were most pronounced in Patnongon. This heterogeneity was not confined to physical and climatic aspects. There were also differences in road infrastructure and access to markets. Again, such differences were most clearly seen in Patnongon. Reflecting these differences in biophysical and socioeconomic aspects, there were significant differences in the farming systems both within and between the three municipalities.

Farm Surveys

A series of farm household surveys was conducted to obtain information from a sample of households which cultivated rainfed rice. These sample farmers were selected in 1984 by taking a systematic random sample of 603 from existing lists of a total of 1450 rainfed lowland farmers from the three municipalities, in consultation with the Department of Agriculture in Antique Province. In addition, information was collected from the farmers who participated in the agronomic field trials and farmers who had fields adjacent to those trial fields. Some farmers had to be excluded from the original sample for various reasons, such as leasing or mortgaging of their farms and lack of cooperation in providing reliable data. The sample size for each municipality was proportional to the population of rainfed rice farmers, giving very much larger samples for Patnongon than for Tobias Fornier or Pandan (Table 1). For each semester during the cropping years 1984–85 and 1985–86, two surveys were conducted, immediately after crop establishment and harvest. Three sets of precoded questionnaires were prepared. One questionnaire was used to gather field-level data for rainfed lowland fields. A map of each farm was prepared in the first survey and was used in subsequent surveys to gather field-level data when subdivision occurred. Detailed information on the physical characteristics of the field, and the agronomic and cultural practices followed with each crop, including dates and levels of input applications and output levels, were recorded.

A second questionnaire was used to obtain farm-level data such as crop production from all fields, crop disposal and consumption, sales, payments to landlord, etc. and noncrop farm incomes. The third questionnaire was used to gather detailed household data including demographic characteristics and human capital attributes, levels and sources of income, farm assets and community linkages relevant to farming information, and inputs such as credit.

Table 1. Sample sizes for the PHARLAP farm surveys.

		Municipality		
Year	Crop	Tobias Fornier	Patnongon	Pandan
1984–85	First	199	566	176
	Second	210	554	175
1985–86	First	244	568	190
	Second	206	580	186
1986–87	First	90	81	87

Note: Some farmers were excluded from the final analyses due to data deficiencies in the questionnaire.

Thus data were obtained on the overall farming systems, household attributes and activities and (in great detail) on the rice-based cropping component of the farming systems. These surveys provided data on five successive crop seasons beginning with the 1984–85 first crop season.

The survey for the fifth season (1986–87 first crop season), referred to as the 'Close Monitoring Survey' (CMS), intensively covered a subsample of the farmers who had been surveyed in the previous four seasons. This survey was carried out for two main reasons. Firstly, in the previous four surveys, information on the physical attributes of the fields had come from farmer interviews. Thus there was no uniformity and possibly subjective bias in the physical characterisation of individual fields. Since it is important for the analytical methods used in this study to have accurate information on the relevant field level physical factors, an agronomist visited each field and provided a description of its physical attributes. For practical reasons, this survey had to be carried out on a random subsample of the original sample, with approximately equal numbers from each municipality. The second concern addressed by this more intensive survey was the accuracy of data obtained at the end of the crop season. In the Close Monitoring Survey, the farmers were visited a number of times during the crop season.

Farm Household Characteristics

From the farm surveys it was found that, throughout the study areas, the farms were typically very small, averaging about 1 ha. None of the farms was above 5 ha, while about 90% of the farms were below 2 ha (Table 2). Typically, these farms had only lowland paddy lands; over 90% of the farmers in

Table 2. Mean farm size, composition and distribution.

Municipality	Mean lowland area (ha)	Mean upland area (ha)	Mean of total farm area (ha)	Percentage of farms ≤ 2 ha
Tobias Fornier	0.98	0.44 (9%)[a]	1.02	94
Patnongon	0.98	0.95 (22%)[a]	1.19	90
Pandan	1.10	0.57 (5%)[a]	1.13	88

[a]Percentage of farms with upland fields. Only these farms were included in the upland means.
Source: PHARLAP farm household survey: 1985–86.

Table 3. Livestock ownership (percentage of farms).

Municipality	Carabaos 1	Carabaos >1	Other cattle	Goats	Hogs	Poultry
Tobias Fornier	41	26	18	17	72	67
Patnongon	48	18	2	26	67	83
Pandan	46	39	6	8	81	80

Source: PHARLAP farm household survey: 1985–86.

Tobias Fornier and Pandan had no upland areas at all. In Patnongon, however, about 20% of the farms had some upland fields and 13% of the farms had more than 0.5 ha of such land. Thus, the rainfed farms on the coastal plains are somewhat different from the 'upland' farmers in the hilly areas of the province who typically have larger farms (about 4 ha), of which only about 25% is terraced and over half is under permanent grass or tree crops (Bouchet et al. 1982). As most farmers have only their lowland paddy lands to cultivate, clearly research for improved cropping systems must concentrate on attaining higher productivity in these areas. Nonrice crops, therefore, can be considered only as subsidiary crops in these rice-based systems.

As is the case for most rural parts of the Philippines, the majority of farms engaged in some small-scale raising of livestock (Table 3). Farms typically had one or more carabaos, some poultry and one or more hogs. Raising of livestock was an important economic activity and contributed a significant proportion of the cash income of the farms (Table 4).

Farmers owned few other assets. Ownership of agricultural machinery (tractors, threshers, etc.) was almost nonexistent. In Tobias Fornier and Pandan, around 30% of the farms did not own even a plough; in Patnongon, 15%.

Share tenancy was widespread in Patnongon and Pandan (each 37%), although it was much less common in Tobias Fornier (10%). Some temporary renting of land occurred in all locations, the extent varying from season to season. Full ownership was recorded for 82% of fields in Tobias Fornier and 51% in Patnongon but only 31% in Pandan.

The surveys recorded information on the major occupations of the household members. While varying slightly from year to year, the importance of nonfarm occupations, even among the household heads, was striking. In the 1985–86 crop year, the respective percentages of household heads reporting farming as their fulltime occupation were 56% in Tobias Fornier, 68% in Patnongon and only 22% in Pandan. Few if any of the other household members were engaged in farming as a fulltime occupation. Therefore, it is not surprising that incomes from sources outside the farm were of major importance in total household earnings (Table 4). The figures given in this table are for the crop year 1985–86; the basic pattern was similar in other years. Across almost all income groups, by far the major proportion of cash incomes came from nonfarm sources. These included earnings from nonfarm occupations as well as contributions made to the household by nonresident family members. Many of the households with the highest incomes had family members working overseas. Even when the implicit value of the rice consumed in the household (net of paid out costs on hired labour and material inputs) was taken into account, the role of such nonfarm incomes remained quite substantial (Table 5). Thus, for these rainfed, rice-based farms of Antique, rice production was an essentially subsistence-orientated activity, generating only a small marketable surplus. In fact, given the cost of purchased inputs and hired labour, it appeared that, sometimes, rice sales were inadequate even to pay for the cash costs of rice cultivation.

Overall, the distributions of farm incomes were rather similar in Tobias Fornier and Pandan. In Patnongon, however, the mean incomes were much lower and the distributions skewed towards lower incomes (Tables 6 and 7). It should be noted that in Patnongon, the sample included farmers from a number of relatively remote villages. Over the two complete crop years for which data were available from the farm surveys, no significant change in these patterns was observed.

The mean age of household heads was roughly similar in the three locations (50–53 years), as was the mean number of years of formal schooling (6–8 years). The average number of years that fields had been farmed varied from 15 and 16 years for Pandan and Tobias Fornier to 20 years for Patnongon, all indicating long experience.

Table 4. Sources of cash income[a] by income group and municipality for crop year 1985-86 (percentage of total income from each source).

Total cash income (pesos)	Percentage of farmers in each group			Source of income: Rice sales			Other crop sales[b]			Livestock sales			Nonfarm		
	Tobias Fornier	Patnongon	Pandan	Tobias Fornier	Patnongon	Pandan	Tobias Fornier	Patnongon	Pandan	Tobias Fornier	Patnongon	Pandan	Tobias Fornier	Patnongon	Pandan
≤999	11	24	5	0	17	20	6	10	0	61	25	10	33	48	70
1000- 1999	5	12	9	6	17	10	0	6	0	43	26	33	51	52	57
2000- 2999	8	9	8	12	23	14	0	4	0	26	32	18	61	40	68
3000- 3999	5	10	10	16	15	29	0	2	0	11	30	22	73	52	50
4000- 4999	8	6	5	20	27	11	2	3	0	32	12	24	47	58	66
5000- 5999	4	6	1	6	23	0	1	1	0	25	18	0	69	58	100
6000- 6999	5	6	4	33	17	31	0	1	0	19	25	20	48	57	50
7000- 7999	6	3	5	12	9	23	0	13	0	28	17	12	60	62	65
8000- 8999	5	2	4	3	7	9	1	2	0	18	24	32	78	67	59
9000- 9999	2	3	7	5	14	3	0	3	0	14	12	6	82	71	91
10000-14999	14	5	11	9	6	14	1	2	0	19	6	9	71	87	77
15000-29999	11	9	12	10	17	4	1	0	0	15	6	5	74	77	92
30000-49999	11	5	15	13	11	6	0	3	0	8	4	4	80	82	90
≥50000	6	2	5	5	13	14	0	18	0	7	3	2	88	66	85

[a]Cash income includes income from sales of crops and livestock, wages from off- and nonfarm employment and remittances from nonresident family members.
Note: Municipality totals may not add to 100 due to rounding. Source: PHARLAP farm surveys: 1985-86. [b]Includes corn, mungbean, peanut, etc.

Table 5. Sources of net income[a] by income group and municipality for crop year 1985-86 (percentage of total income from each source).

Total net income (pesos)	Percentage of farmers in each group			Source of income: Value of rice			Other crop sales[b]			Livestock sales			Nonfarm		
	Tobias Fornier	Patnongon	Pandan	Tobias Fornier	Patnongon	Pandan	Tobias Fornier	Patnongon	Pandan	Tobias Fornier	Patnongon	Pandan	Tobias Fornier	Patnongon	Pandan
≤999	1	4	1	100	27	37	0	4	0	0	1	0	0	68	63
1000- 1999	2	7	2	61	85	75	0	1	0	9	4	8	30	10	17
2000- 2999	5	7	4	56	77	42	3	2	0	20	9	22	22	12	36
3000- 3999	5	7	1	72	76	22	0	2	0	14	9	1	14	14	77
4000- 4999	5	7	6	67	64	60	0	11	0	14	7	3	21	18	36
5000- 5999	5	7	7	44	67	63	0	2	0	24	9	10	32	22	26
6000- 6999	7	6	5	50	59	71	2	0	0	17	13	6	31	28	24
7000- 7999	3	9	3	21	61	64	1	2	0	18	8	14	60	30	22
8000- 8999	8	4	2	47	63	71	0	1	0	16	10	8	37	26	22
9000- 9999	4	6	5	36	58	34	0	5	0	28	9	9	37	28	56
10000-14999	18	15	20	34	44	50	0	1	0	25	11	10	42	44	40
15000-29999	17	11	25	31	37	32	1	1	0	12	6	5	57	57	63
30000-49999	12	6	12	21	22	23	0	3	0	7	4	3	72	72	74
≥50000	8	2	8	14	22	23	0	16	0	6	3	2	80	59	75

[a]Net Income = (gross value of rice production — paid out costs on hired labour and material inputs) plus all other cash incomes.
Note: Municipality totals may not add to 100 due to rounding. Source: PHARLAP farm surveys: 1985-86. [b]Includes corn, mungbean, peanut, etc.

Table 6. Distribution of farms by cash income[a] for crop years 1984–85 and 1985–86 (percentages in each income class).

Cash income (pesos)	Tobias Fornier		Patnongon		Pandan	
	84–85	85–86	84–85	85–86	84–85	85–86
≤1999	24	17	50	36	9	14
2000– 3999	11	12	14	18	17	19
4000– 5999	7	11	8	12	15	6
6000– 7999	8	11	4	9	10	8
8000– 9999	9	6	6	5	14	10
10000–14999	12	14	9	5	9	11
15000–29999	17	11	7	8	12	12
30000–49999	5	11	1	5	7	15
≥50000	6	6	1	2	6	5
Mean income (pesos)	14346	15790	5644	7550	14986	15319

[a]Cash income includes income from sales of crops and livestock, wages from off- and nonfarm employment and remittances from nonresident family members.

Note: Columns may not add to 100 due to rounding.

Source: PHARLAP farm surveys: 1984–85 and 1985–86.

Table 7. Distribution of farms by net income[a] for crop years 1984–85 and 1985–86 (percentages in each income class).

Net income (pesos)	Tobias Fornier		Patnongon		Pandan	
	84–85	85–86	84–85	85–86	84–85	85–86
≤1999	11	3	21	11	1	3
2000– 3999	11	10	22	15	6	5
4000– 5999	8	10	16	15	13	13
6000– 7999	8	10	10	15	7	7
8000– 9999	6	11	5	9	11	7
10000–14999	15	18	12	15	27	20
15000–29999	26	17	10	12	18	25
30000–49999	8	12	2	6	10	12
≥50000	7	8	1	2	8	8
Mean income (pesos)	17944	19318	8009	11029	19574	20554

[a]Net Income = (gross value of rice production — paid out costs on hired labour and material inputs) plus all other cash incomes.

Note: Columns may not add to 100 due to rounding.

Source: PHARLAP farm surveys: 1984–85 and 1985–86.

Farming Practices

Modern rice varieties were cultivated by nearly all farmers included in the surveys. While IR36 remained a most popular variety, other more recently released varieties were gradually becoming popular, especially in Pandan. In the 1985–86 first crop season for example, over 70% of farmers in Tobias Fornier and Patnongon grew IR36; in Pandan, fewer farmers (57%) grew it, the rest preferring newer varieties from the IR60 series. In Antique, adoption of modern varieties by rainfed lowland rice farmers is not a new phenomenon. Even a decade ago, use of modern (IR) varieties and considerable adoption of chemical fertiliser (particularly nitrogen) were quite common (NEDA/PCARRD/SEARCA/UPLB 1976).

Land preparation relied almost exclusively on the use of animal (carabao) power and mechanisation (use of tractors or power tillers) was rare. This contrasts with the situation in Iloilo Province, on the eastern side of Panay Island, where mechanical land preparation has become widespread even in rainfed areas. During the survey period, there was no sign of any tendency towards greater mechanisation of land preparation in Antique. Mechanical threshing, using small portable threshers, was common and, in Patnongon, most farmers had adopted it. This was a relatively recent development; less than a decade ago, there was hardly any mechanical threshing in the area. The rapid mechanisation of threshing in Antique parallels changes elsewhere in the

Philippines, including in other parts of Panay, such as in Iloilo Province.

Crop establishment methods (see Chapter 1) showed considerable differences across the three locations and between seasons (Table 8). Over the study period, there was a marked decline in labour-intensive transplanting (TPR) as a method of crop establishment. In Pandan, the method of wet-seeding (WSR) was almost universally practiced for both first and second rice crop establishment. While wet-seeding as well as dry-seeding (DSR) were used for first crop establishment in Tobias Fornier and Patnongon, only wet-seeding was used when a second rice crop was established, since at this time, during the wet season, DSR cannot be practiced. Wet-seeded rice, on the other hand, cannot survive submergence for an extended period; hence, in those fields where water accumulation is high and drainage difficult, transplanting is preferred. For second crop establishment, it has the further advantage that the field duration of the crop is somewhat shorter than a direct-seeded crop, reducing the risk of exposure to drought when the rainy season is relatively short. On the other hand, early establishment of the first crop facilitates double cropping. The direct-seeding methods (DSR and WSR) enable earlier crop establishment than TPR and have the added advantage that they use less labour. However, weed problems are more serious with direct-seeding, particularly with DSR. Uneven germination, too, is sometimes a problem with DSR (Barlow et al. 1983).

Table 8. Rice crop establishment method (percentage of fields).

	Establishment method		
	WSR	DSR	TPR
Tobias Fornier			
First crop			
84–85	40	25	35
85–86	64	21	15
86–87	62	25	13
Second crop			
84–85	83	—	17
85–86	94	—	6
Patnongon			
First crop			
84–85	31	40	29
85–86	53	24	23
86–87	48	32	20
Second crop			
84–85	82	—	18
85–86	80	—	20
Pandan			
First crop			
84–85	98	2	—
85–86	98	2	1
86–87	99	—	1
Second crop			
84–85	100	—	—
85–86	100	—	—

Note: Columns may not add to 100 due to rounding.
Source: PHARLAP farm surveys.

Pandan, with its long wet season, naturally had the highest cropping intensity while Tobias Fornier had the lowest (Table 9). Percentage of area (rather than fields or farms) is used in Table 9 because the level of multiple cropping in a municipality is better reflected by the proportion of the total area under multiple cropping. The same farm may have only some fields or even parts of fields that are used to grow a second crop. Double rice cropping was the major multiple cropping system. Farmers grew no post-rice upland crops as second crops in Pandan while a very small proportion did so in Patnongon and Tobias Fornier. In Table 10, a more detailed picture of cropping patterns by establishment method is shown. The determinants of cropping patterns are examined in more detail in Chapter 7.

As with the cultivation of modern varieties, chemical fertiliser was almost universally applied (Table 11). Nitrogen (N), in the form of urea, was the most widely used fertiliser, although ammonium sulfate was sometimes used. With the exception of Pandan, dosage levels of N were quite high, although

Table 9. Cropping intensity: 1984-85 and 1985-86 crop years (percentage area under each cropping pattern).

	Tobias Fornier		Patnongon		Pandan	
Cropping pattern	84–85	85–86	84–85	85–86	84–85	85–86
Rice-Rice	30	35	39	46	95	98
Rice-Upland	4	1	8	2	—	—
Rice-Fallow	66	64	53	52	5	2
Multiple cropping index[a]	134	136	188	198	147	148

[a]Multiple cropping index = total area cultivated during the crop year as a percentage of the total physical area.
Source: PHARLAP farm surveys: 1984–85 and 1985–86.

Table 10. Cropping patterns: 1984–85 and 1985–86 crop years (percentage area under each cropping pattern).

Cropping pattern	Tobias Fornier 84–85	Tobias Fornier 85–86	Patnongon 84–85	Patnongon 85–86	Pandan 84–85	Pandan 85–86
WSR-WSR	8	19	9	21	93	96
WSR-TPR	—	1	1	3	—	—
DSR-WSR	9	7	15	10	2	2
DSR-TPR	1	—	4	2	—	—
TPR-WSR	8	7	8	5	—	1
TPR-TPR	4	1	2	4	—	—
WSR-Fallow	30	43	19	28	5	2
DSR-Fallow	14	13	19	12	—	—
TPR-Fallow	22	8	15	13	—	—
Rice-Corn	1	—	1	1	—	—
Rice-Mungbean	3	1	5	1	—	—
Rice-Peanut	—	—	2	1	—	—

Note: Columns may not add to 100 due to rounding.

Table 11. Use of chemical inputs (percentage of farmers using input).

Input	Nitrogen (N)	Phosphorus (P)	Potassium (K)	Herbicides	Pesticides
Tobias Fornier					
First crop					
84–85	90	23	15	22	48
85–86	94	31	19	25	61
86–87	99	35	17	27	64
Second crop					
84–85	91	24	21	9	40
85–86	92	18	14	30	65
Patnongon					
First crop					
84–85	96	50	28	38	56
85–86	98	50	22	43	62
86–87	100	53	18	30	44
Second crop					
84–85	92	35	13	19	66
85–86	99	44	16	33	65
Pandan					
First crop					
84–85	88	51	10	75	81
85–86	89	57	9	73	57
86–87	95	41	15	67	37
Second crop					
84–85	90	56	1	66	61
85–86	96	53	12	83	69

on average they were below the recommendation. A small proportion of farmers supplemented their nitrogen fertiliser applications with mixed fertilisers containing both phosphorus (P) and potassium (K), but average levels of applied P and especially K were low even though both are included in the current recommendation.

Many farmers used pesticides. Herbicides were also widely used although less commonly than pesticides. Application of herbicides was lowest in Tobias Fornier and highest in Pandan.

Despite the small farm sizes, hired labour was extensively used. Average figures over the study period showed that in Tobias Fornier and Pandan, hired labour accounted for about 60% of total labour. In Patnongon, this proportion was markedly lower, being less than 40%. As overall labour use in Patnongon was similar, this clearly represented a

Table 12. Distribution of rice yields 1984–86 (percentage of fields in each class).

Yield (t/ha)	Tobias Fornier					Patnongon					Pandan				
	First crop			Second crop		First crop			Second crop		First crop			Second crop	
	84–85	85–86	86–87	84–85	85–86	84–85	85–86	86–87	84–85	85–86	84–85	85–86	86–87	84–85	85–86
≤0.4	3	1	1	5	8	6	2	—	8	4	—	—	—	2	—
0.5–0.9	7	4	5	10	6	15	4	11	20	8	6	6	—	10	3
1.0–1.4	16	8	8	13	20	25	15	17	23	20	16	9	4	15	9
1.5–1.9	14	12	14	22	12	22	21	17	16	22	22	17	21	20	21
2.0–2.4	17	18	19	15	14	11	17	29	11	15	22	23	25	25	23
2.5–2.9	16	19	17	20	15	8	19	9	9	15	15	22	25	13	27
3.0–3.4	8	14	12	8	9	5	10	11	5	8	10	15	11	5	10
3.5–3.9	10	9	7	3	9	3	5	3	3	5	5	3	9	4	3
4.0–4.4	5	7	2	2	5	2	3	3	3	2	1	4	1	2	1
4.5–4.9	1	3	2	—	1	1	2	—	1	0.5	2	1	3	2	1
4.0–5.4	1.5	3	6	2	1	0.5	2	—	—	—	0.5	—	—	1	1
5.5–5.9	0.5	1	3	—	—	0.5	—	—	1	0.5	0	1	—	1	—
≥6.0	2	1	3	—	—	1	1	—	—	—	0.5	—	1	—	1
Mean yield	2.4	2.8	2.8	2.1	2.2	1.8	2.4	2.1	1.6	2.1	2.2	2.4	2.7	2.1	2.4
Coefficient of variation	53	43	51	47	49	63	36	42	66	47	42	45	33	48	30

Note: Columns may not add to 100 due to rounding.
Source: PHARLAP farm surveys.

greater utilisation of family labour. When the lower average income levels of the households in Patnongon are taken into account, this suggests that the scope for remunerative nonfarm employment was generally more limited there. As noted earlier, the Patnongon sample included farmers from some remote villages. This finding is consistent with the conclusions of other studies about the income levels and employment opportunities of farm households in the more remote villages (see, for example, Bouchet et al. 1982).

Rice Yields

Mean rice yields and their distributions are presented in Table 12. The means are in the range generally observed in rainfed systems in other similar locations where farmers have adopted modern varieties and chemical fertilisers. Yields varied between the first and second crop as well as from year to year, with mean yields somewhat lower in Patnongon. The most striking feature of these figures is the wide field-to-field variability in yields within each location and season, as indicated by the large coefficients of variation shown in Table 12. Second crop yields, when a crop was successfully grown, were generally somewhat lower than first crop yields except in Pandan. Inflation rates in the Philippines were very high in the 1984–85 period, and it is likely that average real profitability of rice production declined somewhat during the study period. It is noteworthy that the nominal price of raw rice in the study area at the end of the 1986 first crop was lower than that in 1984.

Conclusions

In this study, the major aim was to assess the potential for improved crop productivity and incomes in the rainfed, rice-based farming systems of Antique province.

The series of farm household surveys conducted over five cropping seasons enabled the development of a profile of the farming system, including the role and importance of crop production activities within the farm households. A striking feature of these households was the degree of diversification they exhibited in terms of income sources. In general, these households had few assets, and operated small rainfed rice farms whose income potential was limited and variable. For the typical farm, the rice cultivation activity was mainly a means of securing subsistence rice requirements while depending on noncrop and nonfarm sources for the bulk of cash incomes.

Within the cropping component, rice was not only dominant but often the only crop of any significance. As most landowners and tenants farmed no land except the lowland rice land, potential for upland crop cultivation was confined to subsidiary crops before or after rice. Currently available technology seems to be inadequate to enable farmers to successfully grow profitable rice-upland crop systems. The agronomic research (Chapter 3) indicated some limited potential for growing upland crops in certain soil types but it is unlikely that a major boost to farm incomes will come in the forseeable future from extensive cultivation of upland crops in a rice-based cropping pattern.

From a rural development perspective, these surveys show quite clearly that productivity improvements in rice cultivation cannot substitute for other policy measures to achieve higher rural employment and incomes, given the dependence of the farming households on outside sources of income and the limited potential for large income gains from small farms.

References

Barlow, C., Jayasuriya, S., and Price, E.C. 1983. Evaluating technology for new farming systems: case studies from Philippine rice farms. Los Baños, Philippines, International Rice Research Institute.

Bouchet, Genevieve, Heemskerk, Willem, Lopez, Ester, Mettrick, H., Mollah, M.M.H., and Parshad, R. 1982. The farming system in the uplands of the south of Antique Province, Panay Island, Philippines. Wageningen, The Netherlands, ICRA Bulletin 4.

NEDA/PCARRD/SEARCA/UPLB. 1976. Analysis of the Agricultural Benchmark Survey: Western Visayas, Region VI. Los Baños/Iloilo, Philippines, Working Paper No. 3.

Tasic, R.C., Fazekas de St.Groth, C., and Angus, J.F. 1987. PHARLAP: A Cropping Systems Study on Rainfed Rice Farms in Antique Province, Philippines. Natural Resources Series No. 7. Canberra: CSIRO Division of Water and Land Resources.

CHAPTER THREE

Agronomic Results and Their Implications

R.C. Tasic, G.T. Estomata, D.A. Marquez, A.B. de Lima and J.F. Angus

Extensive field trials with irrigated rice conducted in many parts of Southeast Asia have demonstrated the existence of a 'farm-level yield gap,' that is, a significant difference between yields obtained with farmers' inputs and practices, and those obtained with recommended inputs and practices (IRRI 1979). Despite the existence of this gap, Herdt (1979) found in an international study that it was generally unprofitable for farmers to change existing practices to those recommended. The yield gap of rainfed lowland rice has not been widely studied but extensive research has been conducted to determine the most appropriate cropping systems, methods of cultivation and crop establishment, and timing and rates of nitrogen fertiliser for this system of rice culture (Zandstra et al. 1981; Morris et al. 1982).

As part of the studies described in this monograph, the PHARLAP field experiments were conducted over two growing seasons: 1984–85 and 1985–86. Three municipalities in Antique were selected for field experiments: Tobias Fornier (formerly Dao) where the mean duration of the flooded growing season is less than 6 months, Patnongon where the duration is about 7 months, and Pandan where the duration is greater than 9 months.

The objectives of the agronomic project were to measure the yield gap, to find the most appropriate technology for the rainfed rice industry of the province, to measure productivity in relation to the environment so as to validate a simulation model of crop growth, and to use experimental productivity data to test the frontier production functions described in Chapters 4 and 5.

The detailed results of the project have been described by Tasic et al. (1987). The results presented here are confined to rice yield gaps and rice yield responses to inputs which provide background to the implications discussed later in this chapter, and to the interaction with the frontier production function analysis (Chapter 8).

Materials and Methods

Experiments were established on farmers' fields in the three municipalities during the 1984–85 and 1985–86 growing seasons. The fields were selected from among those operated by progressive and cooperative farmers who indicated an intention of growing two rice crops during the season, although no firm commitment to double cropping was sought by project agronomists. Farmers were requested to provide draught power for all tillage operations for the experimental cropping patterns, while the project provided seed, fertiliser and pesticides. A guarantee was offered to compensate farmers if any researcher-managed field produced less net income than a comparable farmer-managed field. Additional selection criteria for experimental fields were that the soil types be representative of the municipality, and that the field should not be irrigated, nor adjacent to a road, waterway or trees.

In each rice experiment, yield was sampled from areas managed according to the following system:

1. A field managed by researchers according to current recommendations, with inputs supplied by the project.
2. Within each researcher-managed field, a replicated component-technology trial to test components of recommendations.
3. A field, managed entirely by a farmer, adjacent to each researcher-managed field and with similar soil and at a similar landscape position. Where possible, the selected field was one operated by the farmer who normally operated the researcher-managed field. No advice on the management of this field was provided by project agronomists.

A schematic layout of an experimental field is shown in Fig. 1. Replicated trials to test components of the recommended technology were established within each crop of a cropping pattern. The experimental design thus combined elements of the methodologies of cropping-pattern testing and evaluation of constraints (De Datta et al. 1978; Zandstra et al. 1981; Gomez and Gomez 1983). The recommended technology for rice crops was taken to be a modern variety, either IR36 or IR60, fertilised with NPK fertiliser at a rate of 70/30/30 kg/ha, together with a herbicide to control weeds and insecticides applied in relation to threshold levels of pests. It was recognised that pest control could not be tested on small plots because of transfer of pests from unsprayed to sprayed areas. Each component-technology experiment and its surrounding researcher-managed field was sprayed with insecticide if pests built up to threshold levels.

At the start of the project, a standard seven-treatment experiment was designed to test both existing recommendations and some additional practices which were not widely adopted but suspected of being justified. The original experimental design tested the interaction of the practices generally adopted, nitrogen and herbicide (treatments 1–4):

1	−Herbicide	N0			
2	−Herbicide	N35			
3	+Herbicide	N0			
4	+Herbicide	N35			
4a	+Herbicide	N35	S40		
5	+Herbicide	N70			
6	+Herbicide	N70	P30		
7	+Herbicide	N70	P30	K30	
8	+Herbicide	N70		K30	
9	+Herbicide	N105	P30	K30	
10	+Herbicide	N105	P30	K30	Zn5

The recommended inputs which were not widely adopted, phosphorus and potassium fertilisers, were not tested as main effects but, only in the presence of recommended levels of nitrogen and herbicide. The reason for this simplification, apart from the fewer resources required, was that deficiencies of phosphorus and potassium were expected to be more pronounced at the higher level of nitrogen. In addition, if these inputs were to be adopted by farmers, they would probably be applied along with nitrogen fertiliser at the existing rates.

In the first series of experiments in 1984–85, the potassium response was tested only in the presence of phosphorus but, in later series, the interaction of phosphorus and potassium was tested with an additional treatment (8) in the experimental design. Responses to zinc were tested on selected fields after the first crop of 1984–85. Most tests of zinc response were at a level of nitrogen in addition to that used in the standard experimental design; all tests of sulfur were at the lowest level of applied nitrogen. Not all experimental fields included the additional treatments using zinc and sulfur because of financial constraints on the project.

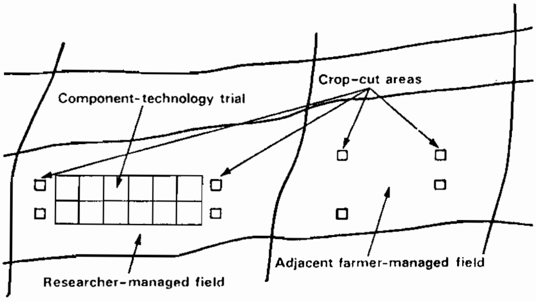


Fig. 1. A schematic layout of a component-technology trial within a researcher-managed field and the adjacent farmer-managed field.

Results and Discussion

Yield Gap

The difference in yield between one crop managed by a farmer and another crop grown in a similar environment with recommended practices is called the farm-level yield gap (Herdt 1979). When comparing yields, it is important that the areas of sampled fields are similar so that any apparent advantage from researchers' management is not due to the greater time and attention being available for researchers' small plots (Davidson 1962). The comparisons in this study were all made on fields of average size for the area, generally between 500 and 1500 m^2. In each comparison, the field sizes were similar.

Averaged over 130 comparisons for all locations and seasons, the mean yield gap was 0.55 t/ha, with a standard error of 0.09 t/ha. The comparison of paired farmer-managed and researcher-managed fields is shown in Fig. 2, and the mean yield gaps for each series of rice experiments in each municipality are given in Table 1. This shows that in most cases, yields under farmer management were

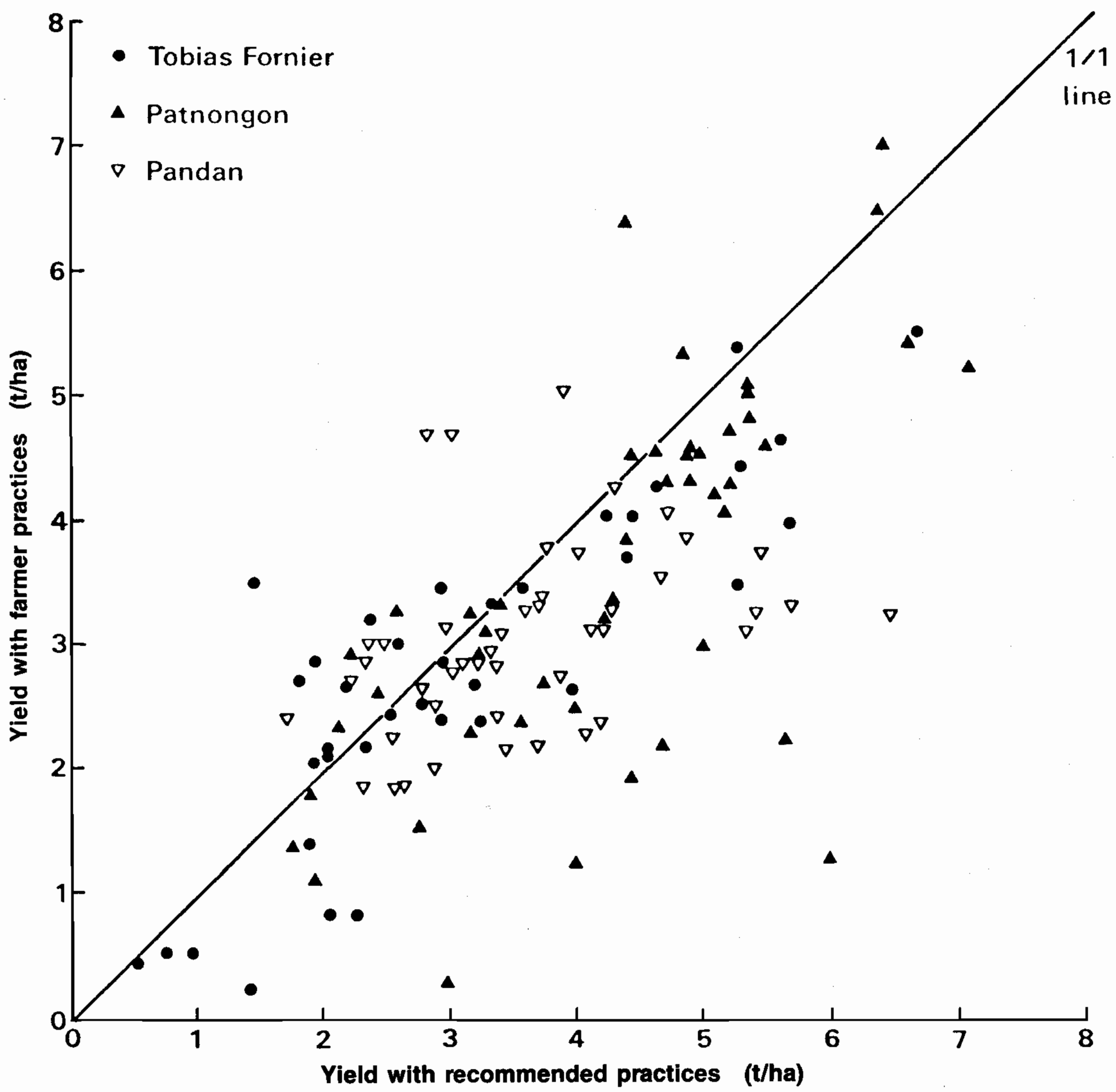


Fig. 2. Comparison of rice yields in adjacent fields, one of which was managed by a farmer and the other by researchers using recommended practices.

Table 1. Mean rice yield gap (t/ha) between researcher-managed fields and adjacent fields managed by farmers. The negative values indicate that farmers' fields outyielded researchers'. Standard errors are in parentheses.

Crop	Tobias Fornier	Patnongon	Pandan
		1984–85	
First	-0.28 (0.20)	0.62 (0.21)	-0.07 (0.28)
Second	1.08 (0.46)	3.08 (0.24)	0.12 (0.25)
		1985–86	
First	0.73 (0.23)	0.37 (0.18)	1.09 (0.29)
Second	0.07 (0.19)	0.28 (0.16)	0.92 (0.19)

lower than under researcher management, but there were a number of cases in which farmer-managed crops outyielded researcher-managed crops.

The lower mean yields of farmer-managed crops are consistent with many previous studies. However, as is to be expected, some fields managed by farmers outyielded those managed by researchers, possibly because of differences in soil and landscape favouring the farmer-managed field, or because of measurement errors, or because some farmers applied higher than recommended levels of inputs, e.g. chemicals and labour.

Many of the negative yield gaps were observed among the first crops of 1984–85 when farmers mostly grew the older-established variety IR36, while researchers grew the then new IR60 which was introduced because of its resistance to recent biotypes of tungro virus which had infested irrigated areas in central Antique and nearby provinces. No tungro symptoms were noticed on or near project fields so the advantage of IR60 was not expressed during the project. In the absence of the virus, IR36 appeared to have a yield advantage on the project fields although, in general, IR36 and IR60 have comparable yields. After the first crop of 1984–85, IR60 was enthusiastically adopted by farmers, using seed originating from project experiments. The later comparisons of farmer and researcher management were mostly between IR60 crops.

Two of the larger mean yield gaps were evident in the second rice crop for 1984–85 in Tobias Fornier and Patnongon. The reason appeared to be that farmers applied little fertiliser or other inputs because they believed that the seasonal prospects were unpromising; in fact, the end of the rainy season was relatively favourable so that there were high yields associated with the recommended inputs on researcher-managed fields.

In Pandan, the yield gaps found in both crops in 1985–86 were greater than for 1984–85 because of a shift in location of experimental fields from relatively low landscape positions to higher and less fertile positions, where the level of farmers' inputs was particularly low.

Time of Rice Establishment

The yields of researcher-managed fields are shown in Fig. 3 in relation to the date and method of establishment (see Chapter 1). A large between-field variation is apparent, and there is evidence for an effect of date of establishment on the yield of early-established dry-seeded rice (DSR) crops in 1984–85 which experienced water deficit prior to anthesis. Later-established crops were vegetative at the time of the drought and were less affected. Other evidence for an effect of establishment date was at the end of both growing seasons when yields of late-established crops were reduced by water deficit.

Rice Component Technology

The results of superimposed trials are presented here on the basis of yield responses to individual inputs, averaged over experiments within one municipality in one cropping season. Where there were important differences between the responses for different landscapes or soil types, these are discussed separately.

Response to Herbicide

The experimental comparison of herbicide and hand weeding is hampered by the difficulty of realistically hand weeding small plots. In this project, a specified time was allocated for hand weeding each plot so as to avoid bias favouring the hand weeding treatment. Data on the yield advantage of herbicide-treated over hand weeded rice, averaged over the N0 and N35 treatments, are presented in Table 2.

The results show that for most locations and seasons, the use of herbicides was effective in increasing yields. Herbicide treatment was generally more effective in Tobias Fornier and Patnongon than in the more consistently wet environment of Pandan, presumably because weeds grew faster on soils which were occasionally unsaturated. Similarly, herbicide was more effective in the generally drier 1984–85 season than in 1985–86.

For many of the experiments listed in appendix 1 of Tasic et al. (1987), there was no effect of herbicide on yield, and in some cases, a lower yield was noted on herbicide-treated plots. A possible reason for lack of herbicide effect was its application to a dry soil when the efficiency of the herbicide is reduced. A possible reason for yield reduction was herbicide toxicity associated with localised overdoses.

In some experiments, individual treatments supplied with phosphorus, potassium, zinc or sulfur yielded less than their corresponding controls. In all these experiments, weed control was by means of herbicide, and it is possible that localised herbicide toxicity also caused these yield reductions.

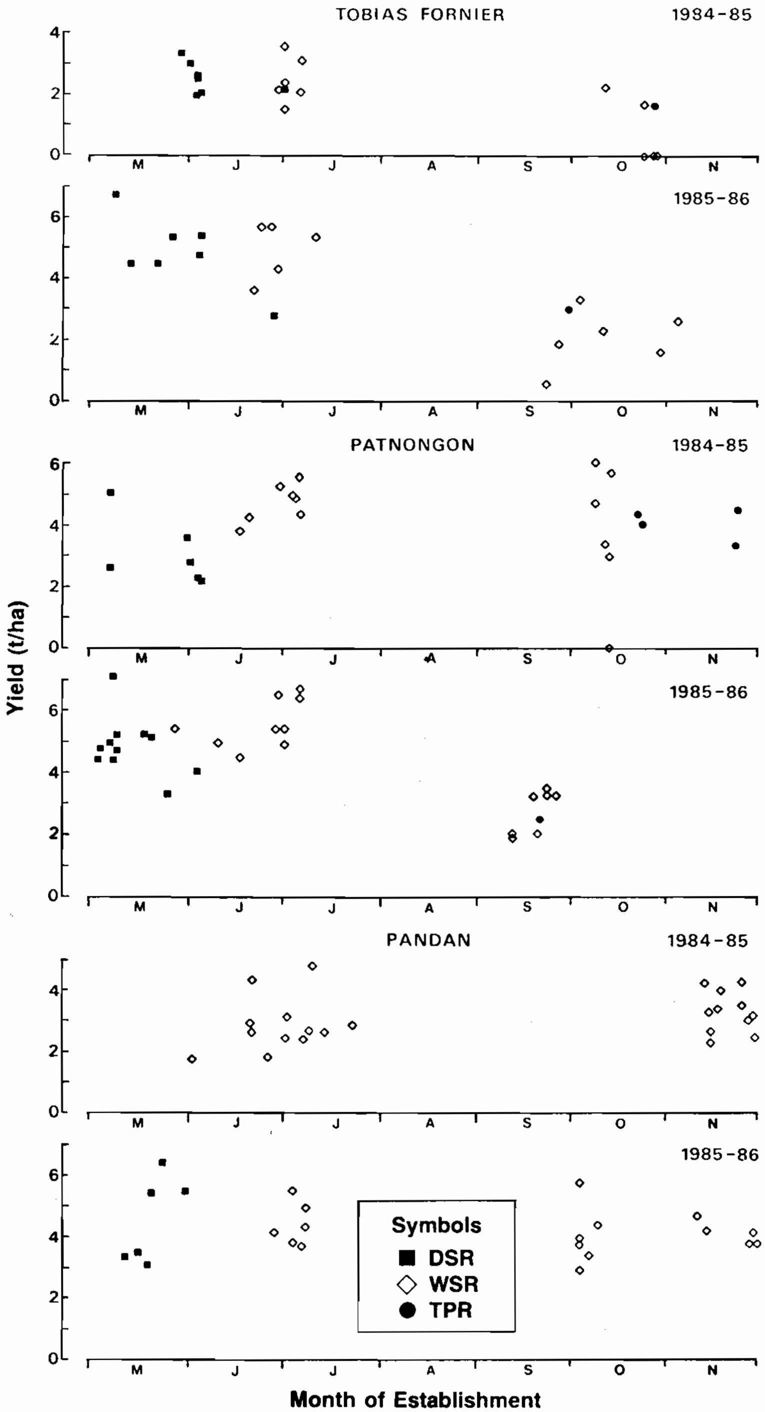


Fig. 3. Yield of researcher-managed rice crops in relation to date of establishment for the three methods of establishment: dry-seeding (DSR), wet-seeding (WSR) and transplanting (TPR).

Table 2. Mean rice yield increase (t/ha) in response to the use of herbicide in component-technology trials. Standard errors are in parentheses.

Crop	Tobias Fornier	Patnongon	Pandan
	1984–85		
First	0.35 (0.06)	0.20 (0.07)	0.15 (0.07)
Second	0.29 (0.14)	0.39 (0.12)	0.47 (0.07)
	1985–86		
First	0.32 (0.10)	0.19 (0.08)	0.01 (0.10)
Second	0.06 (0.08)	0.22 (0.07)	0.13 (0.06)

Table 3. Mean rice yield increase (t/ha) in response to two rates of nitrogen application in component-technology trials. Both responses refer to treatments supplied with herbicide but with no added phosphorus or potassium. Standard errors are in parentheses.

Crop	Tobias Fornier	Patnongon	Pandan
N rates (kg/ha)	0–35 35–70	0–35 35–70	0–35 35–70
	1984–85		
First	0.46 0.30	0.54 0.35	0.43 0.20
	(0.09)	(0.10)	(0.10)
Second	0.18 0.13	0.42 0.16	0.05 0.55
	(0.20)	(0.17)	(0.10)
	1985–86		
First	0.79 0.65	0.67 0.21	0.88 0.48
	(0.14)	(0.11)	(0.14)
Second	0.23 -0.01	0.17 -0.04	0.78 0.43
	(0.12)	(0.10)	(0.09)

Table 4. Mean rice yield increase (t/ha) in response to an increase in nitrogen application from 70 to 105 kg N/ha in component-technology trials. The response applies to treatments supplied with herbicide, phosphorus and potassium. Standard errors are in parentheses.

Crop	Tobias Fornier	Patnongon	Pandan
	1984–85		
Second	0.76	0.56	—
	(0.44)	(0.31)	
	1985–86		
First	-0.25	0.32	0.09
	(0.27)	(0.19)	(0.19)
Second	0.00	-0.03	0.54
	(0.19)	(0.16)	(0.14)

Table 5. Mean rice yield increase (t/ha) in response to phosphorus (30 kg P_2O_5/ha) in component-technology trials. The results for the second crops of 1985–86, the only series in which there was significant interaction between phosphorus and potassium, are presented for both levels of potassium. Standard errors are in parentheses.

Crop	Tobias Fornier	Patnongon	Pandan
	1984–85		
First	0.12 (0.09)	0.54 (0.10)	0.36 (0.10)
Second	0.14 (0.14)	0.51 (0.12)	0.12 (0.07)
	1985–86		
First	0.28 (0.10)	0.36 (0.08)	0.24 (0.10)
Second			
(at K0)	0.14	0.33	0.24
	(0.12)	(0.10)	(0.09)
(at K30)	0.20	-0.12	0.32

Nitrogen Response

Mean yield responses to nitrogen are shown in Tables 3 and 4. The largest municipal-level responses were generally obtained during the first crop of 1985–86 when growth was unconstrained by water stress. The first crop of 1984–85 did not respond so well because of the brief drought in July 1984 which restricted growth and may have led to losses of fertiliser nitrogen. The yield responses of the second crops, particularly in Tobias Fornier and Patnongon, were lower than responses of the first crops because of the poorer water supply at the end of the rainy season.

The generally low or negative yield responses to rates of application above 70 kg N/ha (Table 4), even with recommended rates of phosphorus and potassium, suggest that the optimum rate of nitrogen for crops growing in good conditions lies somewhere near the national recommendation of 60 kg N/ha.

Phosphorus Response

Mean yield responses to phosphorus were positive in all locations and cropping seasons, although not all were statistically significant (Table 5); responses quoted are for 30 kg P_2O_5/ha in the presence of 70 kg N/ha and herbicide.

However for the 1985–86 second crop, there were significantly different yield responses to phosphorus in the presence of potassium from those in its absence. Both sets of data are therefore presented.

Responses for first crops were generally greater than for second crops, probably because water stress reduced the yield potential of second crops. Responses differed between municipalities, with farms in Tobias Fornier generally showing small responses and those in Patnongon large responses. Yield responses within municipalities were also variable. For example, in barangay Pandang within Patnongon municipality, the following variation was found in 12 tests of phosphorus response on five farms, all within 1 km of each other:

No. of fields	Yield response to 30 kg P_2O_5/ha (t/ha)
2	$\geq$2.0
2	1.0–1.9
7	0.0–0.9
1	$\leq$0.0

There was no obvious cause of this variation such as differences in landscape position or soil texture between fields. It is possible that variations in the previous land use and management of individual fields were responsible.

Potassium Response

Yield responses to potassium were tested in all rice experiments (Table 6). In the first cropping season of 1984–85, the potassium response was tested only in the presence of herbicide, 70 kg N/ha and 30 kg P_2O_5/ha, but when large responses were detected in that season, all subsequent tests of potassium response were in factorial combination with 0 and 30 kg P_2O_5/ha.

On average, farms in Patnongon showed no significant yield response to potassium in three of the four cropping seasons. In the one season when there appeared to be a response, the sample of farms was small. In Tobias Fornier and Pandan mean responses were significant in almost all seasons.

As with phosphorus, the response to potassium consisted of large responses on relatively few farms, and many farms on which the responses were relatively small. These farms can be identified in appendix 1 of Tasic et al. (1987).

Potassium deficiency of the extent and severity indicated by the results is unusual in lowland rice in the Philippines because of the generally young soils (Bunoan et al. 1970). The Antique soils are mainly coarse textured and may lack the exchange capacity to supply sufficient potassium for maximum yield. The underlying rock in Antique, although geologically young, is formed from parent material which is readily leached (Mitchell et al. 1986). Some Antique soils appear to be particularly prone to potassium deficiency. The most obvious are the red earths of Duyong and the yellow earths of Clabanog, both in Pandan municipality. The next most obvious are the red earths in Opsan in Tobias Fornier municipality. Other cases of potassium deficiency are more scattered. Possible reasons for the patchiness of the deficiencies are the removal of potassium from some fields in previously harvested sugarcane, and that grazing animals are normally tethered near houses at night and on more remote fields during the day, leading to transfer of potassium towards the houses.

Zinc Responses

The first tests of zinc response were conducted in experiments on the second crop of 1984–85. This was after a visual examination of the first crops, as they approached maturity, suggested that maximum yields would be less than expected, and nitrogen responses less than potential. Zinc deficiency was suspected,

Table 6. Mean rice yield increase (t/ha) in response to potassium (30 kg K_2O/ha) in component-technology trials. The results for the second crops of 1985–86, the only series in which there was significant interaction between phosphorus and potassium, are presented for both levels of phosphorus. Standard errors are in parentheses.

Crop	Tobias Fornier	Patnongon	Pandan
	1984–85		
First	0.34 (0.09)	0.01 (0.10)	0.39 (0.10)
Second	0.44 (0.14)	0.48 (0.12)	0.39 (0.07)
	1985–86		
First	0.24 (0.10)	0.14 (0.08)	0.49 (0.10)
Second			
(at P0)	−0.05	0.34	0.49
	(0.12)	(0.10)	(0.09)
(at P30)	0.01	−0.11	0.56

Table 7. Mean rice yield increase (t/ha) in response to zinc (5 kg $ZnSO_4.7H_2O$/ha), in the presence of 105/30/30 NPK, except where indicated otherwise. Standard errors are in parentheses.

Crop	Tobias Fornier	Patnongon	Pandan
	1984–85		
Second	−0.37 (0.44)	0.53 (0.31)	na
with 70/30/0	0.78 (0.39)	0.46 (0.28)	na
with 70/0/0	0.40 (0.72)	0.66 (0.51)	na
	1985–86		
First	0.47 (0.27)	0.26 (0.19)	0.27 (0.19)
Second	0.01 (0.19)	0.20 (0.17)	0.10 (0.14)

and all subsequent experimental series, involving a total of 26 experiments on 16 farms, included a test for zinc response. Fields selected for the first tests of zinc response were mostly those in low-lying or especially wet locations, or those with a history of heavy inputs of nitrogen fertiliser. Later tests were conducted on higher landscape positions and on those fields which did not have a history of heavy fertiliser use.

Mean yield responses to zinc are presented in Table 7. There were significant yield responses found on a few farms in each municipality for the first crop of 1985–86. However, for the experimental series on the second crop of 1984–85 in which zinc was applied with 70/30/0 NPK, there was an overall yield response to zinc but no interaction with municipality or with farms within municipalities. There was a weak interaction between the zinc response and municipality for the main experimental series on the second crop of 1984–85. The magnitude of the yield responses shows a general decline from the earlier to the later experimental series, probably reflecting the less responsive fields chosen for later experiments.

Standard errors of yield responses to zinc are mostly greater than those for other treatments, mainly because zinc was tested in fewer trials. Nevertheless, there were several farms within each municipality, as shown in appendix 1 of Tasic et al. (1987), on which very large zinc responses were obtained. As with yield responses to phosphorus and potassium, there was a large between-farm variability.

The zinc responses throughout Antique are part of a pattern of large rice-yield responses to zinc which have been detected across extensive areas of Asia (Randhawa et al. 1978). One of the reasons is presumably greater withdrawals of zinc by high-yielding crops. Another important factor is the growth of rice on alkaline soil types such as Vertisols; zinc is relatively unavailable above pH 8. The latter factor is unimportant in Antique where the sampled soils were neutral to acid. The important factors in the zinc deficiency of Antique soils are probably leaching and depletion by crops.

Sulfur Response

In both the first and second series of component-technology trials in 1984–85, yields of plots supplied with recommended inputs were greater than yields of researcher-managed fields nominally supplied with the same inputs. A possible explanation for this difference was that the level of management was better on the small plots than on the fields, a finding consistent with that of Davidson (1962). Another possible explanation, which occurred belatedly to the

Table 8. Mean rice yield increase (t/ha) in response to sulfur supplied at a rate of 40 kg S/ha in ammonium sulfate. The control treatment was supplied with nitrogen as urea. Standard errors are in parentheses.

Crop	Tobias Fornier	Patnongon	Pandan
		1985–86	
First	0.32 (0.15)	-0.36 (0.23)	0.16 (0.33)
Second	-0.15 (0.16)	0.59 (0.29)	0.03 (0.16)

researchers, was that the source of phosphorus used for the plots, single superphosphate, contained more sulfur than was supplied to researcher-managed fields from Triple-14.

After sulfur deficiency was suspected, tests for yield response were conducted by replacing urea with ammonium sulfate as a source of nitrogen in treatment 4 (+Herbicide N35). There were 24 tests conducted over two experimental series (Table 8). There was a significant yield response for the first crop of 1985–86 in Tobias Fornier, but no overall significance across either experimental series. However, there was a large response on the one farm tested in Patnongon in the second crop of 1985–86.

As the comparison of ammonium sulfate with urea is not a definitive test for sulfur response because of the different forms of nitrogen release, the apparent responses reported here should be retested with unconfounded inputs, such as a comparison of KCl and K_2SO_4.

Notwithstanding the uncertainties of the method, there were strong visible responses to sulfur, particularly on the red earth soils of barangay Opsan in Tobias Fornier, where plots supplied with 35 kg N/ha as ammonium sulfate were much greener than plots supplied with either 35 or 70 kg N/ha as urea.

Economic Aspects

In previous sections of this chapter, yield responses to inputs have been discussed mainly in terms of all experiments in a municipality. A farmer seeking advice is more concerned with the likelihood of a response on a particular field and the profitability of the response. An attempt is made here to analyse the experimental data in terms of profitability of inputs on individual farms.

As prices of rice and crop inputs fluctuated during the progress of the project, a precise definition of profitability is impossible and, as an approximation, the prices and costs applying in mid 1985 were used as the basis for calculation. At that time, the price of rice paid to farmers was ₱3/kg and the costs of inputs were as shown in Table 9. A common and reasonable assumption about the profitability of recommended practices is that returns to a recommendation should be twice the cost of inputs so as to allow for risk and the costs of application and interest on borrowed funds. In the following analyses (Tables 10 and 11), twice the cash costs of the component technology tested in the field experiments were compared with returns from the extra rice produced. All profitabilities were calculated for main effects of the treatments, that is, for the response to the input averaged over the levels of other inputs tested in factorial combination. For example, the profitability of the response to 35 kg N/ha was averaged over the treatments with and without herbicide.

For the first crops, the full recommendation (defined as recommended herbicide + 70/30/30 NPK) was consistently profitable for about 75% of farms. The first 35 kg N/ha was the most reliably profitable component of the recommendation in all municipalities, and herbicide was generally the least reliably profitable. Returns to phosphorus were relatively unreliable in all areas, while returns to potassium were unreliable in Patnongon, but relatively reliable in Tobias Fornier and Pandan. Zinc and sulfur were not explicitly recommended but the returns to both were nevertheless analysed by this method. The returns to zinc were generally reliable in both seasons but the returns to sulfur were less reliable.

The reliability of input responses was generally lower for second crops than for first crops, mostly because water stress reduced the responses to inputs on some fields (Table 11). In Tobias Fornier and Patnongon, the profitability of all inputs was low on all but the most favoured fields. The frequency of profitable responses to nitrogen fertiliser was reduced more than those to other inputs, probably because of losses of fertiliser nitrogen from the soil during the frequent periods of wetting and drying.

The reliability of responses presented in Tables 10 and 11 is of course dependent on the assumptions of the rice price and the assumptions listed in Table 9. The effect on reliability of changes or local variations in price can be tested using the data for individual farms presented in appendix 1 of Tasic et al. (1987).

Table 9. Costs and availability of inputs in Antique during 1985.

Input	Price of commercial product	Price per unit	Availability
Butachlor	₱220/litre bottle + application costs	₱500/ha	Freely available
Nitrogen	₱250/50 kg sack of urea (46%N)	₱11/kg N	Freely available
Phosphorus	₱200/50 kg sack of triple-14	₱12/kg P_2O_5	Phosphorus available only in compound fertiliser
Potassium	₱150/50 kg sack of KCl (60% K_2O)	₱5/kg K_2O	Potassium available only in compound fertiliser and only in south Antique
Zinc	₱20/kg zinc sulfate	₱20/kg zinc sulfate	Unavailable in rainfed areas
Sulfur	₱150/50 kg sack ammonium sulfate	₱2.9/kg S	Freely available

Table 10. Percentage of farms showing profitable responses to inputs (i.e. additional returns > twice additional costs), during first crops of 1984–85 and 1985–86. Numbers of observations are in parentheses.

	Tobias Fornier (28)	Patnongon (33)	Pandan (24)	Combined (85)
Recommended (70/30/30)	89	64	78	76
Herbicide	46	30	13	31
First N35	96	76	91	87
Second N35	57	58	57	57
Phosphorus	43	61	50	52
Potassium	75	45	88	67
Zinc (1985–86)	50 (2)	75 (4)	75 (4)	70 (10)
Sulfur (1985–86)	67 (9)	25 (4)	50 (2)	53 (15)

Table 11. Percentage of farms showing profitable responses to inputs (i.e. additional returns > twice additional costs), for second crops of 1984–85 and 1985–86. Numbers of observations are in parentheses.

	Tobias Fornier (10)	Patnongon (13)	Pandan (24)	Combined (47)
Recommended (70/30/30)	10	46	92	62
Herbicide	20	46	38	36
First N35	40	62	54	53
Second N35	10	38	75	51
Phosphorus	30	46	46	43
Potassium	50	54	92	72
Zinc	71 (7)	85 (13)	100 (4)	83 (24)
Sulfur (1985–86)	25 (4)	100 (1)	50 (4)	44 (9)

Predicting Fertiliser Requirements

Because of the variability of fertiliser responses, it would be desirable to predict the likely response to a particular fertiliser on a particular field, without the delay and cost of conducting field experiments. Two possibilities were examined, soil tests and a survey of recent fertiliser application on each farm.

Soil Tests

Soil samples were taken from each experimental farm and analysed in an attempt to identify those which would respond to fertiliser. The soil test data were related to the yield responses to inputs during the first cropping season of 1985–86. This was the most favourable season during the project when water supply was least likely to be limiting. Relationships between yield responses to nitrogen, phosphorus and potassium and the test data on soil organic matter, available soil phosphate and potassium respectively are presented for individual farms in Fig. 4a. The wide scatter for each relationship offers little promise for identifying responsive farms. The only conclusion that can be drawn from these relationships is that there is unlikely to be a large response to phosphorus on farms for which tests indicate a high level of available soil phosphate.

The soil test results averaged over all farms within a municipality are presented in Table 12, together with the mean yield responses to nitrogen, phosphorus and potassium. There was no evidence of a relationship between yield responses and soil tests on a municipal scale.

The probable reason for the lack of success of soil tests, either for individual farms or for averaged results, was the great diversity of soil types within and between the municipalities. The prevalence of multiple soil deficiencies also suggests that chemical analysis for a single nutrient is unlikely to identify the major problem.

Particle-size distribution data were also tested as predictors of nutrient responses (Fig. 4b). There was no evidence of any relationship between clay content and responses to nitrogen or phosphorus, but there was evidence of smaller responses to potassium on soils with a high clay content.

Fertiliser History

In view of residual effects of fertiliser that were observed during the course of the project, an attempt was made to identify responsive fields on the basis of the amount of fertiliser previously applied. Farmers were questioned about their previous fertiliser inputs over the period 1980–85. Their replies related to the whole farm because their recollections were of the total number of sacks of fertiliser purchased but not the allocation of fertiliser between fields. The reported fertiliser use was converted into weight of N, P_2O_5 and K_2O per hectare (Table 13). The adequate or even excessive use of nitrogen fertiliser contrasts with the inadequate use of phosphorus and the almost total neglect of potassium.

The reported nutrient use per farm was related to the yield responses to fertilisers obtained for the first rice crop of 1985–86, the season with no water stress. No significant relationships were found. This conflicts with visual evidence of residual effects of phosphorus and potassium, suggesting that analyses based on reported applications over whole farms and over several years are an insensitive means of identifying responsive fields.

Because of the variable responses reported in Tables 10 and 11, the lack of phosphorus and potassium application is not surprising for Patnongon. However, the lack of potassium application in Pandan appears to reflect a general absence of prior knowledge by farmers, advisers and suppliers, of the general deficiency of potassium throughout this municipality.

Another possible reason for the unbalanced fertiliser usage is the immediate response which farmers can observe with nitrogen, compared with the responses to phosphorus, potassium and zinc which are less dramatic on all but the most deficient soils. In addition, phosphorus, potassium and zinc need to be applied at or before the time of crop establishment, when farmers have no certainty of getting an acceptable crop stand or favourable weather conditions. Most of the nitrogen fertiliser is applied midway through growth when crop stands and weather conditions can be assessed.

Conclusions

Rice Management

Farmers in the study areas applied, on average, close to the recommended rate of nitrogen fertiliser, and also commonly applied the recommended herbicide. The experimental results confirmed that nitrogen fertiliser was a profitable and reliable input to the first crops, but was a less reliable or profitable input to second crops.

Use of the herbicide Butachlor, while on average profitable, was unnecessary on many of the

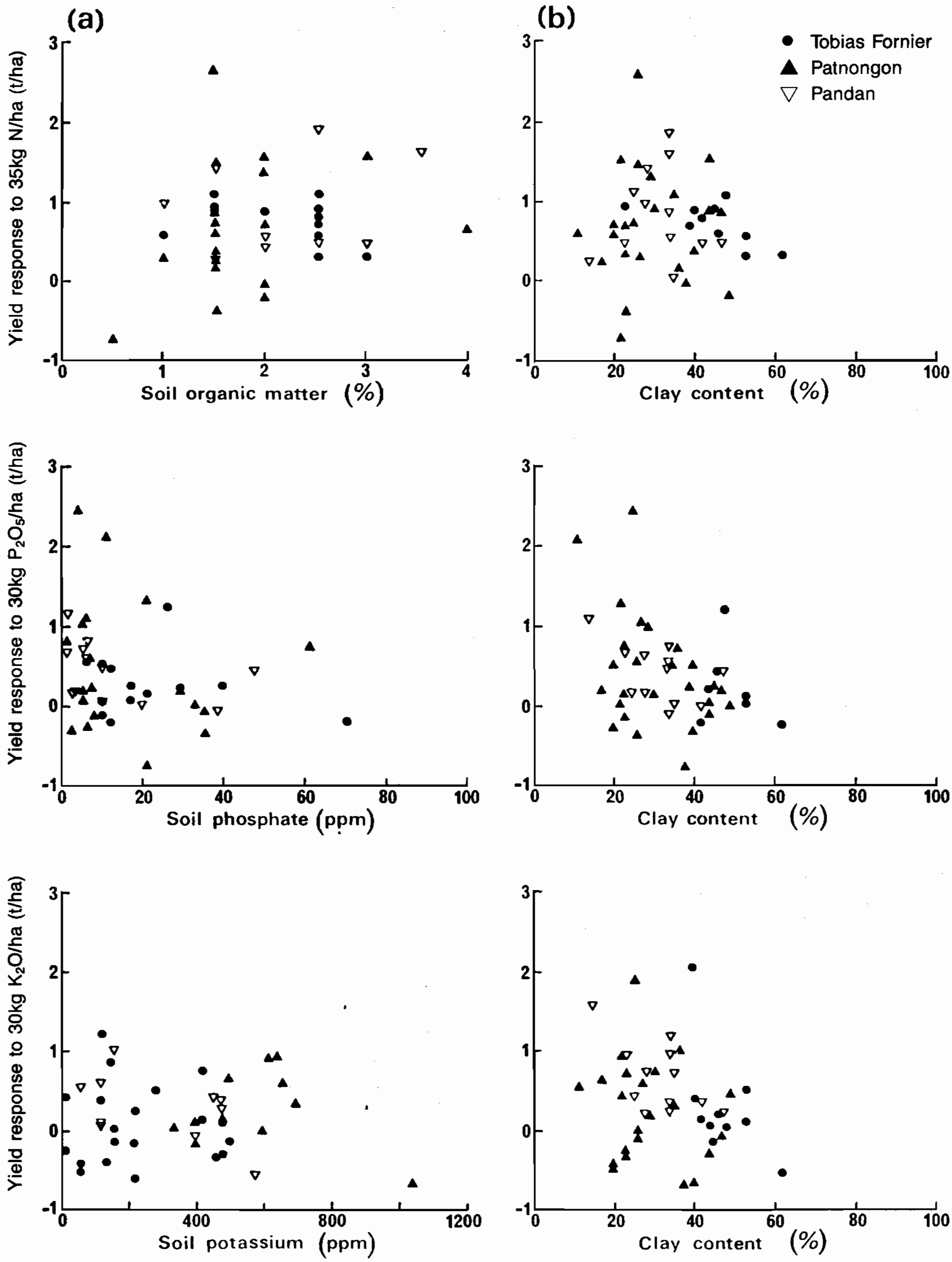


Fig. 4. Rice yield responses expressed in relation to soil tests: (a) responses to N, P and K fertilisers in relation to the levels of soil organic matter, available phosphate and potassium of the researcher-managed fields; (b) responses to N, P and K fertilisers in relation to clay content of the researcher-managed fields.

Table 12. Mean soil test results for farms in the three municipalities, in comparison with mean yield responses (t/ha) to nitrogen, phosphorus and potassium for first crops of 1985–86.

	Tobias Fornier	Patnongon	Pandan
Soil organic matter (%)	2.1	1.7	2.0
Yield response to N35	0.8	0.6	0.9
Soil available P (ppm)	21	15	13
Yield response to P30	0.3	0.4	0.2
Soil potassium (ppm)	580	223	298
Yield response to K30	0.2	0.1	0.5

Table 13. Mean fertiliser usage per crop (kg/ha) for the years 1980–85 on experimental cooperators' farms.

	Tobias Fornier	Patnongon	Pandan
Nitrogen	51	71	81
Phosphorus (P_2O_5)	9	15	17
Potassium (K_2O)	5	3	0

experimental fields for both first and second crops. This result alone should not be a basis for rejecting herbicides because farmers who observe weed growth in crops are in a position to identify fields likely to require chemical weed control for future crops. However, it does suggest that more detailed research is needed to identify fields and seasons in which the use of herbicide is justified.

Few farmers applied fertilisers containing phosphorus or potassium. In Tobias Fornier, this decision was justified for many farmers because of the unprofitable yield responses on most fields for both first and second crops. In Patnongon, the decision was less likely to be justified and in Pandan it was unjustified for potassium but justified for phosphorus on some farms. Fertilisers containing phosphorus and potassium were difficult or impossible to obtain through normal commercial channels in rainfed areas of the province during 1984–85. It was not clear whether the unavailability was basically due to lack of supply by retailers, or lack of farmers' awareness of the need for these fertilisers and hence lack of demand.

Two other nutrients were found to be deficient in parts of the study areas. Large and relatively reliable responses were obtained with small applications of zinc. Smaller and less reliable responses were obtained with sulfur.

Yield Gap

The mean gaps in rice yield between fields managed by farmers and adjacent fields managed by researchers using recommended technology are shown in Fig. 5. Most of the yield gap was due to insufficient application of phosphorus and potassium fertiliser on deficient fields. An increase above the yield with recommended inputs was obtained by applying zinc and there was some evidence of sulfur response. These gaps were due more to the lack of supplies and advice than to farmers' inefficient use of resources.

Implications for Agricultural Development in Antique

The potential impact of the agronomic findings on production within the province is estimated by multiplying the mean yield responses to inputs by the area of land over which the responses are assumed to apply. This method of extrapolation, called 'transfer by analogy' (Angus et al. 1974), is a common basis for extending research findings from experiments in one environment to farms in similar environments. The estimates of land area are the reported area of rainfed rice in the province (AIADP 1985), and the areas of different soil types (Calimbas et al. 1963).

Of the 24 000 ha of rainfed lowland in Antique, it is assumed that 5000 ha resemble the land in Pandan which reliably grows two rice crops each year, and where large and reliable yield responses to potassium were found. The basis for this estimate is the area of rainfed riceland in the municipalities of Libertad, Pandan, Sebaste and Culasi, which share the same soil type, the Umingan clay loam, as that on which many of the experiments in Pandan were conducted.

The remaining 19 000 ha of rainfed lowland is assumed to share the climatic characteristics and the diverse soils on which the PHARLAP field trials were conducted in Patnongon and Tobias Fornier, namely a second crop grown on about 40% of the land area, and patchy yield responses to P and K.

Table 14. Estimated farm-level returns to policy options for promoting production of rainfed lowland rice in Antique.

Policy	Farm costs (₱/ha)	Gross returns (₱/ha)	Net[a] benefit/ cost ratio
1 Apply K to both crops in northern Antique	150	1320	8
2 Apply Zn to first crops throughout Antique	100	900	8
3 Apply S to first crops on red soils	120	1200	9
4 In central and southern Antique:			
(a) apply P+K to first crops on all fields	510	1530	2
OR			
(b) apply P to first crops on the most responsive 50% of fields	360	1940	4
and			
apply K to first crops on the most responsive 50% of fields	150	1660	10
5 Do not apply N to second crops in central and southern Antique	-308	-672	-1

[a]Net benefit/cost ratio = $(GP.\ \Delta Y\text{-}C)/C$, where GP = rice price, C = input costs, ΔY = yield response.

Table 15. Policy options for promoting production of rainfed lowland rice in Antique.

Policy	Relevant rice area (ha)	Production (t/year)	Annual net return to province (million ₱)
1 Apply K to both crops in northern Antique	10000	+4400	+12
2 Apply Zn to first crops throughout Antique	24000	+7200	+19
3 Apply S to first crops on red soils	5000	+2000	+5
4 In central and southern Antique:			
(a) apply P+K to first crops on all fields	19000	+10000	+19
OR			
(b) apply P to first crops on the most responsive 50% of fields	9500	+6600	+15
and			
apply K to first crops on the most responsive 50% of fields	9500	+4500	+14
5 Do not apply N to second crops in central and southern Antique	7600	-1700	-3

Tables 14 and 15 indicate the potential outcomes of various policy options derived from the results of the agronomic project. The assumptions involved in estimating benefits from the findings have been made deliberately conservative because of the uncertainties involved in estimating both the yield responses and the land areas over which these responses apply. For example, it is assumed that potassium should be applied to the first rice crop of each year in some areas. The residual effects would then increase the yields of second rice crops.

It is not known if the potential yield improvements listed in Tables 14 and 15 are additive, that is, the experiments from which they were derived do not enable us to determine if, for example, it is possible to add the yield increases due to zinc and sulfur. The reliability with which each finding could be translated from experiments to farm practice is also unknown and likely to vary with the policy. These problems are discussed for each policy listed in Tables 14 and 15.

Policy 1: Apply potassium fertiliser to both rice

crops in northern Antique. The results of the project clearly support a blanket recommendation to apply potassium to all rice crops in the Pandan environment. Virtually all experimental rice crops in Pandan responded significantly and profitably to K. Mean yield response to 30 kg K_2O/ha was 0.4 t/ha for both first and second crops. It is reasonable to assume that similar responses would apply on similar soils (Umingan clay loam) in neighbouring municipalities.

Policy 2: Apply zinc to first rice crops throughout Antique. Zinc gave less reliable yield responses than potassium, but the mean yield response of 0.3 t/ha and the relatively low cost of the recommended dose suggest that zinc application would be useful on most crops. The most responsive fields are likely to be those with a history of high cropping intensity and heavy application of other fertilisers.

Policy 3: Apply sulfur to first rice crops growing on red soils. Sulfur responses were generally patchy throughout Antique, but of the 12 experiments on soils classified as Alimodian sandy clay, nine gave positive responses to 40 kg S/ha, with a mean yield response of 0.2 t/ha. The area over which this response is likely to be obtainable is uncertain and the conservative estimate of 5000 ha is based on 5% of the reported area of this soil type throughout the province.

Policy 4: Apply phosphorus and potassium to first rice crops in central and southern Antique. Two alternative policy approaches are suggested for the application of P and K because of the variability of the yield responses. The first and more conventional approach is to promote the current national recommendation of 30P+30K on all rice fields. In the PHARLAP trials, the mean yield response to this treatment was 0.5 t/ha.

The alternative approach is to apply P and/or K only to the fields giving the largest responses. For the purpose of this calculation, it is assumed that the 50% of fields which showed greatest yield responses are chosen. The consequence of such a policy would be to produce a similar amount of additional rice as if all fields were supplied with P and K, but there would be greater net income to the province because of a lower cost.

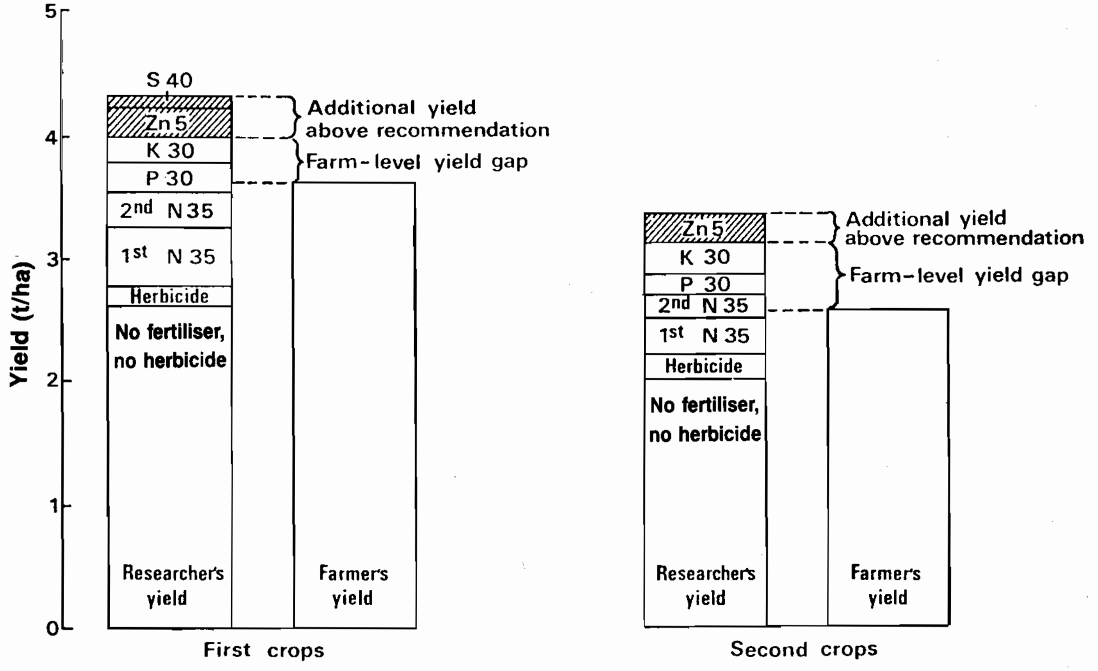


Fig. 5. Mean yields of rice fields managed by farmers in comparison with adjacent fields managed by researchers using recommended practices. The researcher-managed yields also show the contribution to yield of the components of the recommendations. The hatched parts of the histograms show the mean additional yield obtained with inputs which were not specifically recommended.

Unfortunately the PHARLAP project found no reliable way in which to predict from soil tests which fields would be the most responsive, but it did suggest that it is possible to identify responsive fields from an extensive series of strip trials in which extension advisers, or farmers themselves, lay out large numbers of simple field trials so that farmers can judge for themselves if their fields respond to particular nutrients. In practice, the yield responses of such trials could generally be detected visually. For example, there was a mean yield response of 0.6 t/ha to P and 0.5 t/ha to K for the 50% of most responsive first crops. The smallest yield responses to be detected visually would be about 0.2 t/ha.

The calculations in Table 15 suggest that there is a potential benefit of ₱10 million (over a blanket application of P+K) if the most severe deficiencies could be corrected in this way.

The potential benefit from this approach over that of a blanket recommendation suggests that research and extension is warranted to identify the most responsive fields and areas.

Policy 5: Do not apply N to second rice crops in central and southern Antique. This apparently heretical conclusion is based on the low physical efficiency of nitrogen fertiliser found in experiments on second crops (8 kg grain/kg N applied), compared with the efficiency for first crops of 21 kg grain/kg N applied.

Although the second crop yield responses were sufficient to cover the costs of nitrogen fertiliser, they were much lower than the responses to many other inputs, so the opportunity cost of nitrogen fertiliser was unjustified. The actual amounts of nitrogen fertiliser (in kg N/ha) applied to second crops, as determined from the socioeconomic farm surveys (Chapter 2), were as follows:

	1984–85	1985–86
Tobias Fornier	29	31
Patnongon	23	27

Assuming that 28 kg N/ha was not applied to second crops, it is estimated that there would be a reduction in mean yield of 0.2 t/ha. Over the whole province, this lost production is estimated in Table 15 to be 1700 t which is only 1.6% of current annual production.

National Implications

The national significance of the deficiencies of P, K, Zn, and S in Antique is that there may be other areas with undiagnosed deficiencies of the nutrients studied here and possibly also other nutrients. The significance of the patchy deficiencies is that it may not be possible to identify such deficiencies from a small number of field experiments.

It is possible that the nutrient deficiencies found in Antique are unique to soils derived from the ultrabasic rocks in the area, or it may be that other areas with high rainfall and coarse-textured and readily leachable soils may be subject to similar deficiencies. The increased production associated with both relatively high inputs of nitrogen fertiliser and increased intensification of cropping may be placing demands on the supply of nutrients from the soil which cannot be sustained. The deficiencies found in the Antique soils may be a warning of deficiencies which may arise in other regions which currently appear fertile.

One solution, albeit expensive, is for farmers to follow the national recommendation for fertiliser application to rainfed rice:

60 kg N/ha
30 kg P_2O_5/ha
30 kg K_2O/ha

National statistics (NEDA 1985) indicate that the recent fertiliser utilisation is:

178 000 t N
45 400 t P_2O_5
38 600 t K_2O

These figures, converted to percentages of nutrients, are presented in Fig. 6. The percentage composition of nutrients supplied to rice in Antique, derived from the farm surveys, is also shown.

Figure 6 indicates discrepancies between the national recommendation and actual supply of N, P and K. The nutrient supply to Antique rice crops is particularly unbalanced, and leads to the speculation that there may be other Philippine locations with previously undiagnosed areas of nutrient deficiency, and that the area of deficient soils may increase with any intensification of cropping systems.

An implication of widespread deficiencies of the sort found in Antique is that larger amounts of fertiliser containing nutrients other than nitrogen may be needed to maintain rice production, with an inevitable increase in the cost of rice production.

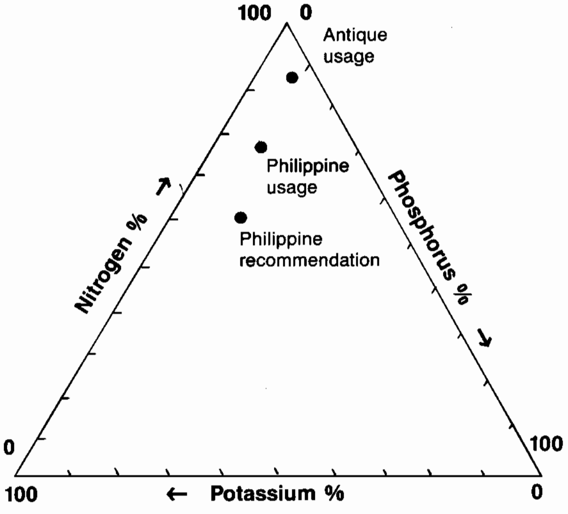


Fig. 6. Percentages of N, P and K fertiliser recommended and actually applied in the Philippines.

Implications for Future Research

A fruitful line of future investigation would be to search for other areas with similar patterns of deficiencies. Possible candidates are areas with intensive cropping practices, or locations remote from sources of fertiliser and those with coarse-textured or heavily leached soils.

The patchiness of the deficiencies also deserves further research. There appears to be little published data on the magnitude of between-field variability in responses to nutrients, and there is no convincing explanation for the variability. One speculation is that much of the land has marginal levels of available nutrients, and variability has been exaggerated by withdrawals of nutrients by different cropping intensities and application of varying amounts of nitrogen fertiliser. Another speculation for the variability is a transfer of nutrients from field to field by the day-night system of animal tethering.

The system of supplying blanket extension advice is called into question by the patchy responses. Although the nitrogen responses were reliable and the blanket recommendation for nitrogen fertiliser is justified, the responses to the other nutrients were probably not sufficiently reliable to justify blanket recommendations. It is not known what level of reliability is needed for a blanket recommendation to be generally accepted by farmers.

Strategic research aimed at understanding the patchy nutritional status of these soils may eventually lead to methods of predicting which fields will be most deficient. Meanwhile, it is suggested that extension workers cooperate with farmers to establish systems of strip trials, that is, small portions of many farm fields on which suspected deficiencies are tested, so that farmers can see for themselves whether a particular nutrient is justified. Strip trials can be more or less elaborate, and can be based on either the addition of nutrients to an existing system, as was done in the PHARLAP trials, on the subtraction of nutrients from a complete nutrient mixture (Middleton and Toxopeus 1973), or on a combination of addition and subtraction methods (Cotter 1979).

The change in local extension methods implied by this suggestion will require that farmers develop greater understanding of the factors affecting production on the land they cultivate and in their immediate district. Byerlee (1987) has suggested that such changes are needed generally in post-Green Revolution agriculture.

References

AIADP. 1985. Antique Integrated Area Development Project, Volume 3, Appendix 2. Manila, National Council on Integrated Area Development.

Angus, J.F., Basinski, J.J., and Nix, H.A. 1974. Weather analysis and its application to production strategy in areas of climatic instability. Proceedings International Expert Consultation on the Use of Improved Technology for Food Production in Rainfed Areas. Rome, FAO.

Bunoan, J.C. Jr., Eugenio, T., Villegas, L.M., Fueur, R., and De Datta, S.K. 1970. Responses of rice to fertilization. The Philippines recommends for rice. Manila. Ministry of Agriculture.

Byerlee, D. 1987. Maintaining the momentum of post-green revolution agriculture: a micro-level perspective from Asia. Department of Agricultural Economics, Michigan State University, 57 p.

Calimbas, F., Lopez, F.B., and Tingzon, J. 1963. Soil survey of Antique Province, Philippines. Soil Report 30. Manila, Bureau of Soils.

Cotter, Sarah C. 1979. A screening design for factorial experiments with interactions. Biometrika, 66, 317–329.

Davidson, Bruce. 1962. Crop yields in experiments and on farms. Nature, 194, 458–459.

De Datta, S.K., Gomez, K.A., Herdt, R.W., and Barker, R. 1978. A Handbook on the Methodology for an Integrated Experiment-Survey on Rice Yield Constraints. Los Baños, IRRI.

Gomez, A.A., and Gomez, K.A. 1983. Multiple Cropping in the Humid Tropics of Asia. Ottawa, IDRC.

Herdt, R.W. 1979. An overview of the Constraints Project Results. In: Farm-level Constraints to High Rice Yields in Asia 1974–77, 395–411. Los Baños, IRRI.

IRRI. 1979. Farm-level Constraints to High Rice Yields in Asia: 1974–77. Los Baños, IRRI.

Middleton, K.R., and Toxopeus, M.J.R. 1973. Diagnosis and measurement of multiple soil deficiencies by a subtraction technique. Plant Soil, 38, 219–226.

Mitchell, A.H.G., Hernandez, F., and Dela Cruz, A.P. 1986. Cenozoic evolution of the Philippine archipelago. Journal of Southeast Asian Earth Science, 1, 3–22.

Morris, R.A., Gines, H.C., Magbanua, R.D., Torralba, R.I., and Sumido, A. 1982. The IRRI-BPI cropping systems research project in Pangasinan and Iloilo. In: Cropping Systems Research in Asia, 279–293. Los Baños, IRRI.

NEDA. 1985. Philippine Statistical Yearbook. Manila, National Economic and Development Authority.

Randhawa, N.S., Sinha, M.K., and Takker, P.N. 1978. Micro-nutrients. In: 'Soils and Rice' 581–603. Los Baños, IRRI.

Tasic, R.C., Fazekas de St.Groth, C., and Angus, J.F. 1987. PHARLAP: A cropping systems study on rainfed rice farms in Antique Province, Philippines. Natural Resources Series No. 7. Canberra: CSIRO Division of Water and Land Resources.

Zandstra, H.G., Price, E.C., Litsinger, J.A., and Morris, R.A. 1981. A Methodology for On-farm Cropping System Research. Los Baños, IRRI.

Socioeconomic Analysis of the Farm Surveys

R.T. Shand, M.C. Mangabat and S.K. Jayasuriya

A major objective of the socioeconomic component of this research project was to determine the degree to which farmers in rainfed areas were utilising the currently available rice production technology. A second objective was to identify farming practices and socioeconomic factors which could provide a basis for more efficient use of resources and higher farm incomes. In this sense the project extended to rainfed areas the 'constraints' project conducted by IRRI and national research institutes in the mid 1970s to study similar issues in irrigated rice cultivation (Herdt and Mandac 1981). However, there were important differences in the methodology and overall philosophy between these projects which have been elaborated elsewhere.

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 which 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 5.

In this chapter, the major results obtained by the application of this methodology to data from the five socioeconomic surveys carried out in Antique Province from 1984 to 1986 are summarised and evaluated. Descriptions of the data sets and details of the analysis of each survey are given in Chapter 2 and the six project working papers (PHARLAP P/1 to P/6; Mangabat et al. 1987a, b, c, 1988; Mangabat and Shand 1987; Shand et al. 1988).

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 use such data 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.

Given the relatively large survey sample sizes in each municipality, the distinct municipal climates (principally due to rainfall regimes) and the differences between the first (wet) and second (dry) crop seasons, it was decided to estimate separate production functions for each municipality and each season. Otherwise, detailed climatic and other biophysical variables would have been necessary to characterise each location/season in an overall production function. This approach was not considered feasible.

Thus, separate frontier production functions of the Cobb-Douglas type (in log-linear form) were specified for each season in each municipality, using palay (unhusked rice) 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, etc.). Where other village-level factors were thought to be important, dummy variables for barangay (a village and the surrounding area) were included. These were usually a measure of 'remoteness.'

The sets of variables used in the estimation of each production frontier are detailed in the five project working papers of the PHARLAP series, P/1 to P/5. These included field area, preharvest labour, cost of chemical fertiliser, pesticide cost, herbicide cost and dummy variables for soil fertility, soil type and landscape position of the field, and barangay. Unfortunately, due to multicollinearity, separate

Table 1. Maximum likelihood estimates of Cobb-Douglas stochastic frontier production functions for survey farmers by location. First crop season 1984–85.

Parameter	Variable	Unit of measurement	Estimates		
			Tobias Fornier	Patnongon	Pandan
α	Constant	–	4.4020***	4.2912***	4.5218***
			(0.8287)	(0.4564)	(0.4612)
β_1	Preharvest labour	Personhours	0.2716***	0.2584***	0.2655***
			(0.0662)	(0.0789)	(0.0816)
β_2	Fertiliser cost	₱	0.2180***	0.2307***	0.2421***
			(0.0518)	(0.0489)	(0.0879)
β_3	Other expenses	₱	0.0703**	0.0593***	0.0410***
			(0.0289)	(0.0126)	(0.0208)
β_4	Field area	ha	0.5312***	0.5062***	0.4902***
			(0.0816)	(0.0689)	(0.0786)
β_5	Soil fertility	Dummy	0.0875^{ns}	0.1197***	0.1218***
			(0.1682)	(0.0305)	(0.0482)
β_6	Barangay	Dummy	–0.1203**	–0.3006***	–0.2096***
			(0.0482)	(0.0689)	(0.0624)
No. of cases			125	475	135

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

Table 2. Maximum likelihood estimates of Cobb-Douglas stochastic frontier production functions for survey farmers by location. Second crop season 1984–85.

Parameter	Variable	Unit of measurement	Estimates		
			Tobias Fornier	Patnongon	Pandan
α	Constant	–	4.9060***	4.5822***	4.4100***
			(0.7189)	(0.6006)	(0.4819)
β_1	Preharvest labour	Personhours	0.2400***	0.2201***	0.2606***
			(0.0587)	(0.0692)	(0.1089)
β_2	Fertiliser cost	₱	0.1912***	0.2500***	0.2602***
			(0.0512)	(0.0598)	(0.0912)
β_3	Other expenses	₱	0.0656***	0.0492**	0.0506***
			(0.0212)	(0.0209)	(0.0202)
β_4	Field area	ha	0.5010***	0.4896***	0.4762***
			(0.0616)	(0.0719)	(0.0816)
β_5	Soil fertility	Dummy	0.0812^{ns}	0.1202***	0.1312***
			(0.1789)	(0.0389)	(0.0398)
β_6	Barangay	Dummy	–0.0812***	–0.2912***	–0.2147***
			(0.0198)	(0.0598)	(0.0501)
No. of cases			54	196	152

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

variables representing actual doses (in kilograms) of the three distinct chemical fertilisers (nitrogen, phosphorus and potassium) could not be used. There was thus a certain loss of information when these variables were combined in an overall fertiliser cost variable.

The 15 estimated frontier production functions are given in Tables 1–5. Over the five seasons and three locations, the six variables with most consistent significance were field area, cost of chemical fertiliser, preharvest labour, other expenses, soil fertility and barangay. The soil fertility variable, which was based upon farmers' subjective opinions, was found to be significant approximately half of the time. The barangay variable was generally significant. This was understandably so for Patnongon, where the number

Table 3. Maximum likelihood estimates of Cobb-Douglas stochastic frontier production functions for survey farmers by location. First crop season 1985–86.

Parameter	Variable	Unit of measurement	Estimates		
			Tobias Fornier	Patnongon	Pandan
α	Constant	-	3.2864***	5.4423***	4.4256***
			(0.7000)	(0.4068)	(0.4769)
β_1	Preharvest labour	Personhours	0.5933***	0.1859***	0.2844***
			(0.1296)	(0.0608)	(0.0823)
β_2	Fertiliser cost	₱	0.2880***	0.2583***	0.2852***
			(0.0581)	(0.0490)	(0.0515)
β_3	Field area	ha	0.2737***	0.4576***	0.4171***
			(0.1042)	(0.0640)	(0.0718)
β_4	Soil fertility	Dummy	—	0.0674*	0.1270**
				(0.0490)	(0.0582)
β_5	Barangay	Dummy	-0.1237**	-0.1268***	-0.1873***
			(0.0750)	(0.0539)	(0.0589)
No. of cases			221	541	166

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.

of barangays sampled was large and covered a range of subenvironments. The significance was less in Pandan and Tobias Fornier, which were smaller, more homogeneous areas.

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 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 in 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 seasonal and locational frontier production function analyses summarised in Table 6 give ratios, denoted by gammas, of the field-specific variance (technical efficiency) to the total variance around the frontier. All these ratios are large (with the exception of Pandan for the 1985–86 first crop) and statistically significant. This implies that the variance due to random error is small and that the field-specific variance is large. In other words, there is a wide range of technical efficiencies among the survey farmers. This large spread in efficiencies enables a statistical investigation of factors which may explain why some farmers are more efficient than others. Particularly relevant in this context are policy-related factors which could be used by policymakers or extension workers to reduce such gaps (due to low TE) by implementing appropriate programs in a cost-effective manner.

In the exceptional season (Pandan for the 1985–86 first crop), farmers behaved in a homogeneous fashion, giving a high mean technical efficiency with a very small range. Since this method of analysis always gives the best farmer a technical efficiency of 100%, the mean value here does not imply that the farmers were uniformly highly efficient. Similarly, in

Table 4. Maximum likelihood estimates of Cobb-Douglas stochastic frontier production functions for survey farmers by location. Second crop season 1985-86.

Parameter	Variable	Unit of measurement	Estimates		
			Tobias Fornier	Patnongon	Pandan
α	Constant	-	5.6613***	4.0273***	5.3629***
			(1.3549)	(0.4636)	(0.6357)
β_1	Preharvest labour	Personhours	0.1487^{ns}	0.2859***	0.1718*
			(0.2134)	(0.0760)	(0.1089)
β_2	Fertiliser cost	₱	0.1635^{ns}	0.3803***	0.2708***
			(0.1677)	(0.0575)	(0.0770)
β_3	Field area	ha	0.7185***	0.4034***	0.5913***
			(0.2234)	(0.0776)	(0.0878)
β_4	Soil fertility	Dummy	0.7331**	—	0.1253**
			(0.3198)		(0.0650)
β_5	Barangay	Dummy	—	-0.2977***	-0.1782***
				(0.0964)	(0.0659)
No. of cases			59	228	162

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 5. Maximum likelihood estimates of Cobb-Douglas stochastic frontier production functions for survey farmers by location. First crop season 1986-87, Close Monitoring Survey (CMS).

Parameter	Variable	Unit of measurement	Estimates		
			Tobias Fornier	Patnongon	Pandan
α	Constant	-	4.4982***	5.4469***	4.4663***
			(0.7994)	(0.6355)	(0.6530)
β_1	Preharvest labour	Personhours	0.1326^{ns}	—	0.3608***
			(0.1101)		(0.1269)
β_2	Fertiliser cost	₱	0.4444***	0.3491***	0.3107***
			(0.1168)	(0.1019)	(0.0738)
β_3	Field area	ha	0.5058***	0.4668***	0.4728***
			(0.1334)	(0.1519)	(0.1116)
β_4	Soil fertility	Dummy	0.2536^{ns}	—	0.2221*
			(0.1895)		(0.1177)
β_5	Barangay	Dummy	—	0.2407*	-0.1252^{ns}
				(0.1316)	(0.0954)
β_6	Yield affected by unusual occurrence	Dummy	-0.2483**	—	—
			(0.1377)		
No. of cases			86	65	81

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.

different locations, farmers with the same technical efficiency are not necessarily comparable since the 100% level is based on the local 'best practice' (or most efficient farmer) which may differ from frontier to frontier since these are location- and season-specific.

Estimation of field-specific technical efficiencies and their mean levels (Table 6) suggests that there is considerable potential for improvement in productivity *without* additional inputs or new technology. By raising a field towards its frontier, particularly those with lower technical efficiency,

Table 6. Gamma values, mean technical efficiencies and total variances of frontier production functions by crop season, year and location from 1984–85 to 1986–87.

Crop season	Year	Variable	Tobias Fornier	Patnongon	Pandan
First	1984–85	γ	0.80**	0.82**	0.78***
		Mean TE	49.2	43.4	77.3
		σ^2	0.28	0.42	0.31
Second	1984–85	γ	0.72***	0.80***	0.76***
		Mean TE	58.3	51.4	75.2
		σ^2	0.31	0.48	0.35
First	1985–86	γ	0.72***	0.76***	0.04^{ns}
		Mean TE	50.6	48.1	94.4
		σ^2	0.39	0.51	0.11
Second	1985–86	γ	0.78***	0.65***	0.75***
		Mean TE	76.2	53.2	63.1
		σ^2	0.64	0.34	0.20
First	1986–87	γ	0.58***	0.71***	0.85***
		Mean TE	67.0	65.4	72.0
		σ^2	0.37	0.30	0.18

Note: ***Significant at the 1% level.
**Significant at the 5% level.
ns = Not significant.
The ratio γ and the total variance σ^2 and its components are explained in detail in Chapter 5.

significant gains in productivity could be achieved. Obviously, not all fields could be fully raised to the frontiers, but if those factors associated with high technical efficiency can be determined, improvements in technical practices could be achieved. 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 to the extent that significant determinants of technical efficiency can be identified using regression analysis.

Three groups of determinants of technical efficiency can be hypothesised. One includes (a) particular *management practices* which could be expected to have a direct impact on output from a field or which are likely to be correlated 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 and methods of input applications (e.g. single or multiple applications of fertiliser). 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, access to credit, farm size and conflicts in labour allocation between different economic activities.

Variables representing these three groups were used as explanatory variables in Ordinary Least Squares (OLS) regression models with technical efficiency (transformed as described in Chapter 5) as the dependent variable (Tables 7–9). 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 all locations. This reflects the importance of the interaction between the physical growth environment, as determined by soil, landscape position and rainfall pattern, with the growth period of the crop which is determined by the various components of the timeliness factor.

The importance of the contribution of most other management practices varied widely from season to season within the same location and across locations. The responses to use of herbicides and pesticides (insecticides) were frequently significant and, with one exception, positive. Significant responses to both

Table 7. Significant variables in OLS regressions on technical efficiency in Tobias Fornier by crop season and year, 1984–85 to 1986–87.

Crop season	Year	Variables	Sign	Significance level (%)
First	1984–85	Timing of crop establishment	+	5
		Establishment method	+	5
$\bar{R}^2 = 0.49$		Use of herbicides	+	5
		Age of household head	+	5
		Motivation in farming	+	5
Second	1984–85	Timing of crop establishment	–	5
		Establishment method	+	5
$\bar{R}^2 = 0.50$		Age of household head	+	5
		Motivation in farming	+	5
		Use of pesticides	+	5
First	1985–86	Date of harvesting	+	1
$\bar{R}^2 = 0.32$		Use of herbicides	+	1
Second	1985–86	Age of household head	+	1
$\bar{R}^2 = 0.29$		Technical efficiency in previous season	+	5
First	1986–87	Years of formal schooling	+	5
		Number of buffaloes	+	1
$\bar{R}^2 = 0.18$		Use of herbicides on WSR	+	1
		Use of P fertiliser	–	1

these pest control measures were most common in Pandan. This location has extensive double cropping during a long wet season and so experiences pest and weed buildup. Many farmers have responded to this buildup with relatively high doses of pesticides.

Amongst human capital variables (or their proxies), the two most important were age of household head and a composite variable, motivation in farming. Both were positive and significant. In contrast, years of formal schooling for the household head was significant (and positively related) only once. Overall, human capital variables did not play a major and consistent role in explaining variations in technical efficiency. This is a contrary finding to that obtained in other studies. In these areas of the Philippines, basic literacy is almost universal and this basic level may be sufficient for the technologies involved. Farmers have already adopted the major components of the new rice technology package. Consequently, additional exposure to extension services does not appear to be having any further positive impact on technical efficiency. In an area demonstrated to be highly location-specific in the factors influencing technical efficiency, a move away from broad brush extension advice may be desirable.

Among farm/farmer attributes, tenurial status was the most consistently significant variable. In Patnongon it showed negative significance, associating land ownership with lower technical efficiency in four of the five seasons analysed. This result is unexpected although its temporal instability makes any firm conclusion impossible. It appears that most tenant-farmers in Patnongon were found in favourable landscape positions while owner-farmers tended to be located in relatively remote villages where soil fertility was a problem, where farms were smaller and often produced only for home consumption, and where access to credit was more difficult. This heterogeneity in the physical aspects of the survey farms in Patnongon is likely to have had a direct bearing on technical efficiency, particularly for owner-farmers.

The level of nonfarm income had a significant positive influence on technical efficiency in three of four seasons analysed in Pandan, as did availability of credit and use of borrowed cash, each in one season. This suggests, particularly in a region where double cropping is widespread, that readily available cash from any source enabled greater timeliness in operations and hence higher technical efficiency. In contrast, nonfarm income was positively significant in only one season in Patnongon and not at all significant in Tobias Fornier, reflecting the lower cropping intensities in the latter location which reduce the need for supplementary finance.

Other variables, such as number of buffaloes

Table 8. Significant variables in OLS regressions on technical efficiency in Patnongon by crop season and year, 1984–85 to 1986–87.

Crop season	Year	Variables	Sign	Significance level (%)
First	1984–85	Use of pesticides	+	5
		Timing of crop establishment	+	5
		Establishment method	+	5
$\bar{R}^2$ = 0.46		Age of household head	+	5
		Tenurial status	–	5
		Motivation in farming	+	5
Second	1984–85	Date of harvesting	+	5
		Timing of crop establishment	–	5
		Age of household head	+	5
$\bar{R}^2$ = 0.45		Tenurial status	–	5
		Motivation in farming	+	5
		Use of pesticides	+	5
First	1985–86	Use of pesticides	+	1
		Seed quantity	+	1
		No. of buffaloes	+	1
$\bar{R}^2$ = 0.45		No. of family members on farm	+	1
		Early crop establishment	+	5
		Remote barangays	–	5
		Total farm size	–	5
Second	1985–86	Nonrice income	+	10
		Tenurial status	–	10
		No. of pairs of buffaloes	+	1
$\bar{R}^2$ = 0.16		Date of harvesting	+	1
		Early crop establishment	+	5
		Total rainfed farm size	–	5
First	1986–87	Use of herbicides	+	1
		Use of K fertiliser	–	1
		Timing of crop establishment	+	5
$\bar{R}^2$ = 0.18		Seed quantity	+	5
		Transplanted crop	+	1
		Tenurial status	–	10

(carabaos), numbers of family members on the farm, remoteness of location, farm size and conflict in family labour allocation between rice and other activities (all negatively related) and full-time farming (positively related) were only very occasionally significant.

Allocative Efficiency

As explained in Chapter 5, the second component of economic efficiency is allocative efficiency which was also measured using the methodology described in Chapter 5. Allocative efficiency is 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 location and season using OLS regression (Tables 10–12) showed the dominance of technical efficiency as an explanatory variable. Another variable of importance was farm size which was negatively and significantly related in most seasons, showing that allocative efficiency falls as farm size increases. Higher rates of interest were generally negatively significant. High interest rates deter farmers from using appropriate input levels. Full-time participation in farming, was, with one exception, positively related to allocative efficiency. Additional years of farming allow a better knowledge of the technical relationships associated with the farm.

Table 9. Significant variables in OLS regressions on technical efficiency in Pandan by crop season and year, 1984–85 to 1986–87.

Crop season	Year	Variables	Sign	Significance level (%)
First	1984–85	Use of pesticides	+	5
		Use of herbicides	+	5
		Age of household head	+	5
$\bar{R}^2 = 0.50$		Tenurial status	–	5
		Nonfarm income	+	5
		Motivation in farming	+	5
Second	1984–85	Date of harvesting	+	5
		Timing of crop establishment	–	5
		Use of herbicides	+	5
		Age of household head	+	5
$\bar{R}^2 = 0.49$		Tenurial status	+	5
		Nonfarm income	+	5
		Motivation in farming	+	5
		Use of pesticides	+	5
First	1985–86	Not available		
Second	1985–86	Use of P fertiliser	–	1
		Tenurial status	–	1
		Use of herbicides	+	1
$\bar{R}^2 = 0.13$		No. of buffaloes	–	1
		Use of K fertiliser	+	5
		Full-time farming	+	5
		Use of borrowed cash	+	10
First	1986–87	Use of pesticides	+	5
		Use of herbicides	–	5
		Availability of credit	+	5
$\bar{R}^2 = 0.34$		No. of buffaloes	–	1
		Conflict in family labour allocation	–	5
		Use of IR50 and subsequent releases	+	10
		Nonfarm income	+	5

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 coefficients are known, either because of extension advice and/or experience, allocative efficiency will usually be positively related. In this case, overall economic efficiency, since it consists of technical and allocative efficiency, will be high (for an explanation of economic efficiency, see Chapter 5).

Conclusions

Overall, the results from the frontier analysis reinforce the thrust of the agronomic research (Chapter 3). Large field-to-field variability, as reflected in yields, is the dominant feature of the area, particularly in Tobias Fornier and Patnongon. Responses of yields to inputs highlighted the location- and season-specific nature of the best management practices, given the extreme heterogeneity of the natural environment across fields.

Analysis of the determinants of technical efficiency revealed the consistent importance of the timeliness factor across seasons and locations. However, although the regressions were all statistically significant, the explanatory power ($\bar{R}^2$) of the determinants was never above 50% and often substantially below. Thus, most of the field-to-field variation in technical efficiency remained unexplained in terms of management-related variables and was most likely due to field-specific biophysical factors. Even the agronomic field trials, conducted under uniform researcher management, were unable to explain the large field-to-field variability in terms of

Table 10. Significant variables in OLS regressions on allocative efficiency by crop season and year in Tobias Fornier, 1984–85 to 1986–87.

Crop season	Year	Variables	Sign	Significance level (%)
First	1984–85	Technical efficiency	+	5
		(Technical efficiency)^2	–	1
$\bar{R}^2 = 0.27$		Farm size	–	1
		Rate of interest	–	1
Second	1984–85	Technical efficiency	+	1
		(Technical efficiency)^2	–	1
$\bar{R}^2 = 0.29$		Farm size	–	1
		Rate of interest	–	1
		Full-time farming by household head	+	5
First	1985–86	Technical efficiency	–	5
		(Technical efficiency)^2	–	1
$\bar{R}^2 = 0.64$		Area of rainfed lowland	–	1
Second	1985–86	Technical efficiency	+	1
		Farm size	+	1
$\bar{R}^2 = 0.58$		Years of formal schooling	–	5
First	1986–87	Technical efficiency	+	10
		(Technical efficiency)^2	–	5
$\bar{R}^2 = 0.17$		Farm size	–	1
		Total farm income in season	+	5
		Nonfarm income in season	+	10

Table 11. Significant variables in OLS regressions on allocative efficiency by crop season and year in Patnongon, 1984–85 to 1986–87.

Crop season	Year	Variables	Sign	Significance level (%)
First	1984–85	Technical efficiency	+	1
		(Technical efficiency)^2	–	1
$\bar{R}^2 = 0.33$		Farm size	–	1
		Rate of interest	–	5
Second	1984–85	Technical efficiency	+	1
		(Technical efficiency)^2	–	1
$\bar{R}^2 = 0.33$		Rate of interest	–	1
		Full-time farming by household head	+	5
First	1985–86	Technical efficiency	+	1
		(Technical efficiency)^2	–	1
$\bar{R}^2 = 0.02$		No. of family members on farm	–	5
		Area of rainfed lowland	+	1
Second	1985–86	Technical efficiency	+	1
		(Technical efficiency)^2	–	1
		Years of formal schooling	–	1
$\bar{R}^2 = 0.27$		Full-time farming by household head	+	5
		Use of borrowed cash	+	10
		Household head younger than 45 years	+	10
First	1986–87	Technical efficiency	+	n.s.
$\bar{R}^2 = 0.21$		(Technical efficiency)^2	–	10

Table 12. Significant variables in OLS regressions on allocative efficiency by crop season and year in Pandan, 1984–85 to 1986–87.

Crop season	Year	Variables	Sign	Significance level (%)
First	1984–85	Technical efficiency	+	1
		(Technical efficiency)^2	–	1
$\overline{R}^2 = 0.32$		Farm size	–	1
		Rate of interest	–	1
		Full-time farming of household head	–	5
Second	1984–85	Technical efficiency	+	1
		(Technical efficiency)^2	–	1
$\overline{R}^2 = 0.30$		Rate of interest	–	1
		Farm size	–	1
		Full-time farming by household head	+	1
First	1985–86	Not available		
Second	1985–86	Technical efficiency	+	1
$\overline{R}^2 = 0.21$		Total income from last season	+	5
First	1986–87	Technical efficiency	–	1
		(Technical efficiency)^2	+	1
$\overline{R}^2 = 0.87$		Farm size	–	1
		Availability of cash	+	10

any of the biophysical variables measured during the trials (Chapter 3).

From the analysis of the determinants of allocative efficiency, it is clear that knowledge of technical input-output parameters is a key element of overall economic efficiency. Farmers are not always aware of these input-output responses for a number of reasons, but if the relevant knowledge can be obtained by farmers for their specific conditions (either by extension and/or experimentation) there will be a double benefit in terms of economic efficiency, through both the technical and allocative components.

To exploit the full cropping potential of the region, a more refined extension program is required. This should provide farmers with the resources and basic skills to fine-tune the broad technology package for their own farm conditions, by means of a suitable program which makes it feasible to carry out simple, onfarm experiments. If this can be achieved, then many of the currently underutilised human capital endowments of both farmers and extension workers are likely to permit increases in efficiency and considerable productivity gains in Antique Province.

References

Herdt, R.W., and Mandac, A.M. 1981. Modern Technology and Economic Efficiency of Philippine Rice Farmers. Economic Development and Cultural Change, 29, 375–399.

Mangabat, Minda, Jayasuriya, Sisira, Law, Toni, and Shand, R.T. 1988. Technology, Farm Specific Technical and Allocative Efficiencies in Rainfed Lowlands of Antique Province, Philippines, First Crop Season 1986/87, Project Working Papers, PHARLAP P/5, Canberra, National Centre for Development Studies, Australian National University.

Mangabat, Minda, Kalirajan, K.P., and Shand, R.T. 1987a. Technology, Farm Specific Technical and Allocative Efficiencies in Rainfed Lowlands of Antique Province, Philippines, First Crop Season 1984/85, Project Working Papers, PHARLAP P/1, Canberra, National Centre for Development Studies, Australian National University.

1987b. Farm Specific and Location Specific Performance of Farmers in Rainfed Lowlands of Antique Province, Philippines, Second Crop Season of 1984/85, Project Working Papers, PHARLAP P/2, Canberra, National Centre for Development Studies, Australian National University.

Mangabat, Minda, and Shand, R.T. 1987. Location and Farm Specific Performance of Survey Farmers in Antique Province, First Crop Season 1985/86, Project Working

Papers, PHARLAP P/3, Canberra, National Centre for Development Studies, Australian National University.
Mangabat, Minda, Shand, R.T., and Law, Toni. 1987c. Location and Farm Specific Performance of Survey Farmers in Antique Province, Second Crop Season 1985/86, Project Working Papers, PHARLAP P/4, Canberra, National Centre for Development Studies, Australian National University.
Shand R.T., Mangabat, Minda, and Jayasuriya, Sisira. 1988. Farm and Farmer Attributes and Technical Practices by Location and Season of Survey Farmers in Antique Province, Philippines, Project Working Papers, PHARLAP P/6, Canberra, National Centre for Development Studies, Australian National University.

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, fertiliser 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 constraints 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 productivities 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

* 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.

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.

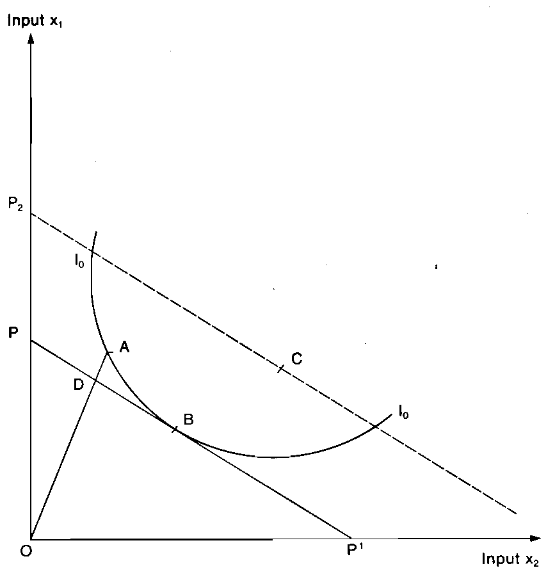


Fig. 1. Farrell's concepts of technical and allocative efficiencies.

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.

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 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

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

output with multiple inputs from a single period cross-section. These individual technical efficiency measures are more useful for policymakers 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 output 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) and Kalirajan and Shand (1985, 1986a–e).

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.

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

As is clear from the analysis presented in Chapter 4, only one of the models could be applied to the survey data, and this was the single period cross-sectional analysis of randomly selected fields by location and season over several years. In all, there were five seasons over 3 years and for each season there were three locations.

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:†

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

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 4 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:

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

In the above model (2), if the j^{th} field realises its technical efficiency fully, then U_j takes the value zero and if not, U_j takes a value less than zero, depending on the extent of its technical inefficiency.

† 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.

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:

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

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

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

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 that 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):

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

Introducing the following notation,

(i) $\Phi(\cdot)$ 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:

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

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

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

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 simultaneously 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 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 output levels possible at any input levels, e.g. O_e at I_1 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 4.

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 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

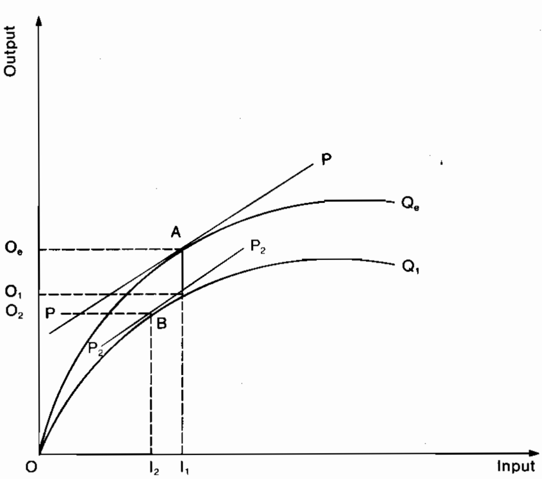


Fig. 2. Field-specific technical, allocative and economic efficiencies.

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 multiple 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 $A = ln\left(\frac{1}{1\text{-}AE}\right)$. (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.

1986a. A measurement of farm-specific absolute technical efficiency for multiple-output farms. Project Working Papers Methodology Series, M/2, Canberra, National Centre for Development Studies. Australian National University.

1986b. Simultaneous estimation of farm-specific technical and allocative efficiencies. Project Working Papers, Methodology Series, M/3, Canberra, National Centre for Development Studies. Australian National University.

1986c. Estimating location-specific and farm-specific technical efficiency. Project Working Papers, Methodology Series, M/4, Canberra, National Centre for Development Studies. Australian National University.

1986d. Multi-output profit functions and factor demand functions. Project Working Paper Series, M/5, Canberra, National Centre for Development Studies. Australian National University.

1986e. A generalized measure of technical efficiency. Project Working Paper Series, M/6, Canberra, National Centre for Development Studies. Australian National University.

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.

Simulation Models of Water Balance and the Growth of Rainfed Rice Crops Growing in Sequence

J.F. Angus and A.G. Garcia

The promise of crop simulation models is that they can be used to solve problems for which conventional field experimentation is unsuitable, costly or very slow. One such problem is to determine the mean yield and yield variability of crops in relation to defined management practices over long periods of time. In many agricultural systems, yields may vary so much from year to year that specification of appropriate management practices is difficult or impossible on the basis of a few years of experimentation.

The intensification of rainfed cropping systems from one to two crops in a year depends on the annual pattern of weather (Zandstra 1982). The problem of specifying the optimal cropping pattern for a particular landscape position in a region is one for which simulation methods are appropriate. Simulation of a multiple cropping system requires models of water balance, crop growth and the timing of biological processes and management practices in a cropping pattern. Suitable weather data are also needed. These components of the analysis are available from a variety of sources and have been brought together in the work reported here.

The essence of crop growth simulation is a representation, as equations, of the processes which determine the yield of a crop in relation to the factors limiting production. In the models presented here, water supply is simulated in the greatest detail. Associated with water is an accurate accounting of timing, so as to simulate the developmental stage of a crop when stress is incurred. Nitrogen status is also simulated because of the importance of nitrogen supply to the yield of rainfed rice.

Major emphasis is given to the balance of components within the models so that there is not undue focus on processes which are well understood in favour of those which are important but not well understood.

Weather Data

The minimum input data set necessary for simulating the water balance and growth of rainfed crops includes values of daily precipitation and evaporation. Precipitation is routinely recorded at many locations in the Philippines, and for some of these locations the data are available on computers. Students at the University of the Philippines at Los Baños have studied the sequences of wet and dry days for 103 locations, and in so doing have produced clean files of weather data for periods averaging 35 years (Serquina 1977; Cabezon 1978; Tirol-Labios 1979). Locations of the 103 rainfall stations are shown in Fig. 1.

Evaporation data are available for neither the number of locations, nor for the length of record that is available for precipitation. In order to calculate the daily water balance, it is necessary to make estimates of evaporation from the available data. A three-stage estimation procedure was used to convert the available data for monthly mean potential evapotranspiration (PET), to estimates of daily PET:

- Estimates of monthly mean PET for 36 selected locations were obtained from Tamisin (1977);
- Estimates of monthly mean PET for 103 rainfall stations were made by interpolation from the 36 selected stations, using the method of cubic splines and cross validation (Hutchinson et al. 1984);
- Weekly mean PET for each rainfall station was estimated by temporal interpolation by

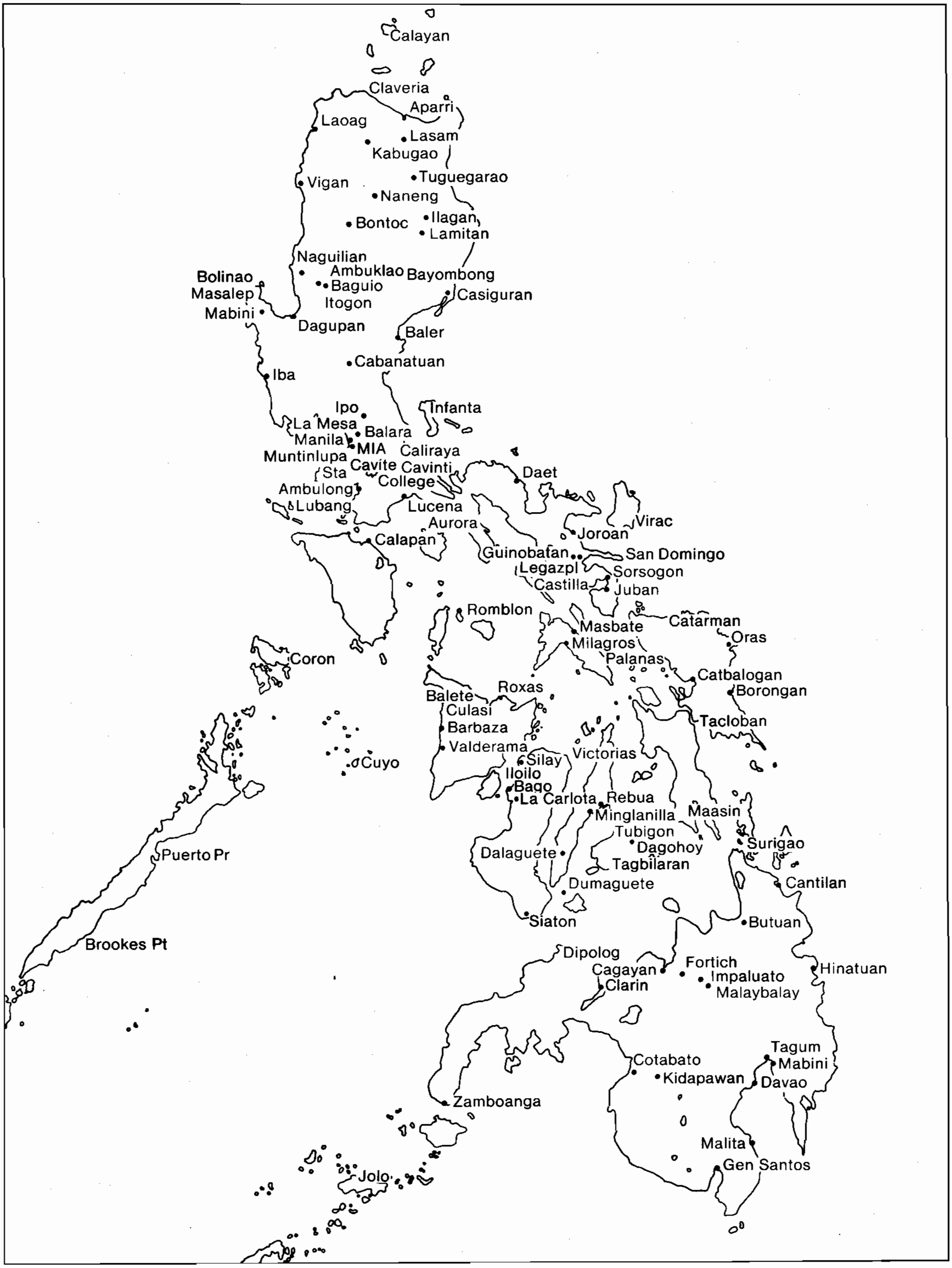


Fig. 1. Locations of the rainfall stations in the Philippines used in the simulation studies.

Bessel functions using a computer program of M.F. Hutchinson (pers. comm.);

- Daily PET for each rainfall station was estimated from the weekly mean data using the method of Reddy (1979), which is based on the principle that the evaporation rate is below average (for the time of year) on a rainy day and above average on a dry day.

In addition to the estimates of PET, estimates have also been made for the 103 Philippine rainfall stations for:

- Weekly mean solar radiation based on Tamisin's (1977) estimates;
- Weekly mean maximum and minimum temperatures based on PAGASA data processed by Angus and Manalo (1979).

The above estimates were made using the sequence of calculations used for evaporation. These data are publicly available for both mainframe and microcomputer use.

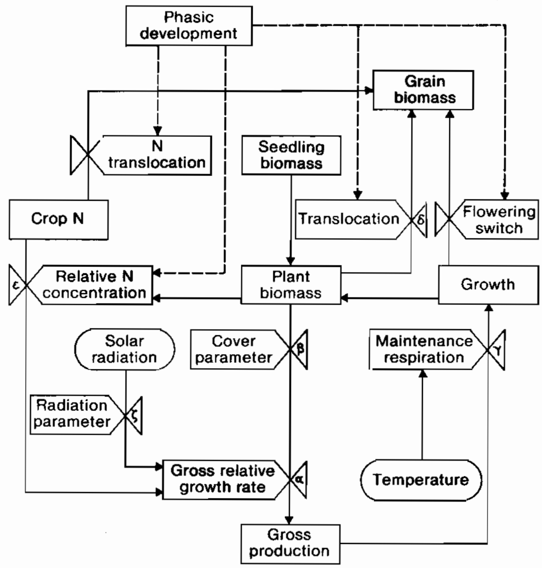


Fig. 2. Flow chart of the simulation model of rice growth and development. Solid lines depict flows of mass and dotted lines flows of information. The Greek letters refer to parameters discussed in the text.

A Crop Growth Model

The core of the model is a simple simulation model of the growth of irrigated rice in relation to radiation, temperature and nitrogen status. This model was devised and fitted to growth data for IR36 rice collected by Mr R. Wetselaar and colleagues from field experiments carried out in West Java, Indonesia. The model itself has been described by Angus et al. (1987). A flow chart is presented in Fig. 2 showing the relationships between the components.

Growth

The central part of the model consists of two difference equations describing daily growth and daily grain growth. Equation (1) is a photosynthesis-respiration model of Byrne (1973) which is simplified to express daily biomass growth, ΔW, in terms of the parameter α, which resembles the gross relative growth rate, the parameter β, representing the canopy cover, such that the maximum growth rate is equal to α/β, the parameter γ, the respiration rate, and the total crop biomass, W:

$$\Delta W = \frac{\alpha \, \mathrm{RI} \, \mathrm{NI} \, W}{1 + \beta W} - \gamma Q_{10} \, W \qquad (1)$$

The influence of radiation on relative growth rate is simulated by means of the radiation index of Fitzpatrick and Nix (1970), RI, which is a nonlinear function of daily radiation, RAD, with a curvature controlled by the parameter ζ:

$$\mathrm{RI} = [1 - e^{-\zeta \mathrm{RAD}}] \, / \, [1 - e^{-\zeta}] \qquad (2)$$

Temperature affects respiration by the Q_{10}, in which maintenance respiration doubles for a 10 C° increase in temperature. The nitrogen index, NI, is discussed in a later section.

After anthesis, daily grain growth, ΔG, is simulated as comprising all daily biomass growth, ΔW, plus a contribution from the material stored in the crop at the time of anthesis, W_{anth}, expressed as a proportion, δ, and scaled by the daily rate of phasic development, r_g, described below:

$$\Delta G = \Delta W + \delta \, r_g \, W_{anth} \qquad (3)$$

Phasic Development

The progression through the vegetative and grain-filling phases is simulated in relation to mean daily temperature, t, and for the vegetative phase (from emergence or transplanting to anthesis), also in relation to photoperiod, p. For both phases, development is simulated as a daily rate, that is, the proportion of the development completed each day; the units are 1/day. For the vegetative period, the rate of development, r_v is calculated by:

$$r_v = k_1[1 - e^{-k_2 (t-t_b)}] [1 - e^{-k_3 (p_c-p)}] \quad (4)$$

The form of the equation, proposed by Angus et al. (1983a) for short-day plants, is based on a nonlinear response of development to both temperature and photoperiod, a base temperature, t_b, for development and a critical photoperiod, p_c, above which development does not proceed. The constants, k_1–k_3 are fitted, the value of k_1 representing the fastest obtainable rate of development.

For the grain-filling phase, the rate of development, r_g is simulated by an equation similar to (4) but with no response to photoperiod:

$$r_g = k_4 [1 - e^{-k_5 (t-t_b)}] \quad (5)$$

Nitrogen

The N supply is one of the major factors affecting rice yield, and N fertiliser is a major way in which farmers can influence yield. The simulation of the effect of N on production is by means of a nitrogen index, NI, proposed by Angus and Moncur (1985) and analogous to other indices of Fitzpatrick and Nix (1970). Using this approach, the nitrogen status of the above-ground biomass is expressed as the Relative Nitrogen Concentration, RNC, which is dependent on the stage of development:

$$RNC = [\frac{N - N_g}{W - G} - N_{min}] / [N_{max} - N_{min}] \quad (6)$$

In this equation, the nitrogen in the above-ground biomass which is not in the grain is calculated as $N - N_g$, and expressed as a proportion of the nongrain biomass, W - G, in relation to the upper and lower nitrogen concentrations, N_{max} and N_{min} respectively, for the stage of development. The reason for excluding the grain in this part of the calculation is that the N in the grain contributes nothing to growth. NI is calculated as a nonlinear function of RNC, with the curvature of the response governed by the parameter ϵ:

$$NI = [1 - e^{-\epsilon RNC}] / [1 - e^{-\epsilon}] \quad (7)$$

Model Fitting

This model was fitted to growth and yield data for crops of irrigated IR36, differing in nitrogen status, from two experiments in West Java. In the process of fitting the crop growth model to these data, every second experimental treatment was excluded from fitting and used only for testing the fit of this model. The procedure for model fitting was to code the model as a subroutine of a nonlinear least-squares fitting program, and so objectively estimate the parameters and test the estimates for statistical significance and intercorrelation as well as for biologically reasonable values. Details of the estimates are presented by Angus et al. (1987).

Water Balance

The model presented so far was modified to simulate the growth of rainfed rice by including a water balance component. In its simplest form, the water balance is a running budget of the soil water content on day i, SW_i, in relation to SW_{i-1} on the previous day, and daily values of rainfall, R_i, soil evaporation, ES_i, transpiration, T_i, infiltration, I_i and runoff, O_i:

$$SW_i = SW_{i-1} + R_i - ES_i - T_i - I_i - O_i \quad (8)$$

In simulating the water balance of flooded fields, it is necessary to account for the lateral flow of water which may comprise a large part of the water supply of fields on a plain (Angus and Zandstra 1980).

The nature of the flooded water balance includes the usual components of rainfall, soil evaporation and transpiration. In addition, it includes flow over the spillway of the bunds, seepage through bunds and percolation into the soil (Wickham and Singh 1978). For irrigated fields, Walker and Rushton (1984) have identified a component of lateral percolation, due to infiltration through the unpuddled soil beneath the bunds. In this model, lateral percolation is included with seepage because, on the sloping landscapes of rainfed areas, it is likely to flow into a neighbouring field rather than enter the groundwater.

Figure 3 shows the components of the flooded water balance model. There are several distinctive features of the flooded water balance. One is that the water content of two layers of soil is simulated, the top layer of 30 cm depth approximating the root zone of rice. The losses of seepage and overflow from one field become an input to the next field downhill. The loss of percolation from one field is added to the groundwater, which moves downhill at a rate determined by the slope of piezometric head, the cross-sectional flow and the hydraulic conductivity of the soil. This groundwater is available for crops growing on downhill fields if its level rises to within the range of capillary rise.

The effect of water status on growth is simulated by a two-stage procedure that first involves the calculation of the Relative Water Content, Θ:

$$\Theta = \frac{SW_i - LL}{DUL - LL} \qquad 0 \leq \Theta \leq 1 \qquad (9)$$

where LL is the lower limit of crop extractable soil water and DUL is the drained upper limit of soil water. WI is then calculated by means of a nonlinear function of Θ:

$$WI = [1 - e^{-\eta\Theta}] \,/\, [1 - e^{-\eta}] \qquad (10)$$

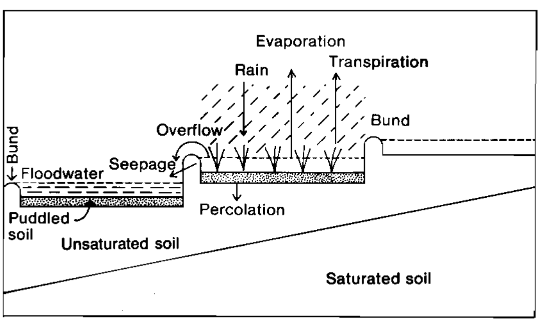


Fig. 3. Cross-section of a toposequence of bunded fields, showing components of the water balance.

Model Calibration

The parameters of the water balance model were calibrated on the soil water data of Bolton (1980) for rainfed rice fields in Tigbauan, Iloilo. The procedure for calibration involved setting the rates of seepage and percolation to measured rates and then adjusting a parameter regulating the rate of flow of the groundwater so that the soil water in fields in the upper and lower positions of the toposequence fitted the observations. Figure 4 shows the closeness of fit of the model to these data. During the period of these soil water measurements, rice crops were wet-seeded in a series of experiments in which the levels of nitrogen fertiliser were also varied. Yields for the treatment with the highest level of applied nitrogen (90 kg N/ha) were compared with yields simulated by the crop growth model with parameters set at the values used for the simulations described above; Fig. 5 shows the fit. It is clear that yields were

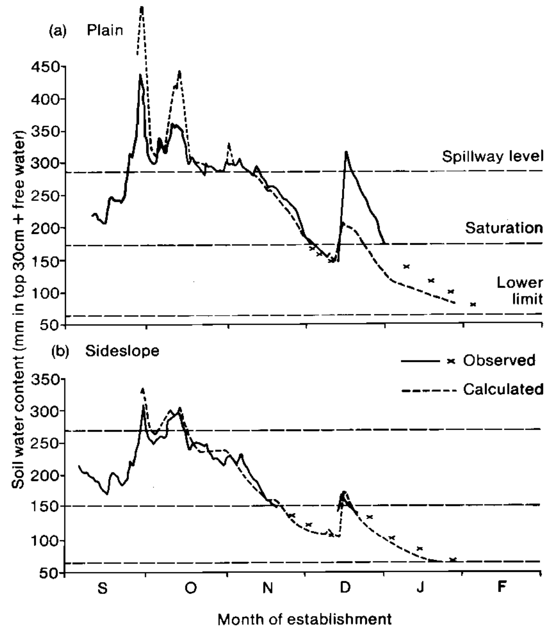


Fig. 4. Fit of the water balance model (dashed lines) to observations of soil water and standing water (solid lines and crosses) for two rainfed rice fields in Tigbauan, Iloilo. (a) plain position, (b) sideslope position. Observations are those of Bolton (1980).

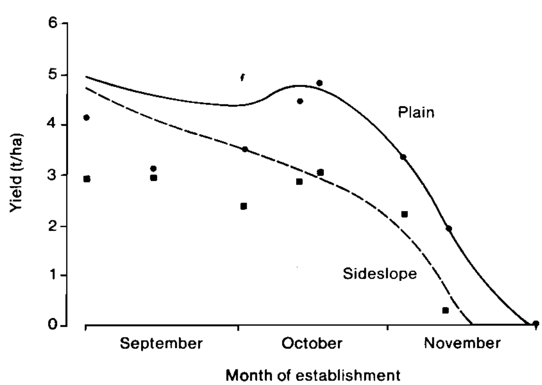


Fig. 5. Fit of the simulated yields to observations for the time-of-establishment experiment of Bolton (1980). The points represent measurements and the lines simulated yields.

seriously overestimated for the earlier crops, but well estimated for later crops. The reason for the earlier overestimation was a typhoon in November which damaged flowering crops but not vegetative crops.

The model was also tested against data from the lower nitrogen levels of this experiment (Fig. 6). The model accurately simulated the generally large nitrogen responses for establishment dates when soil water was favourable, and also simulated the zero nitrogen response for crops established late in the season and subject to water deficit.

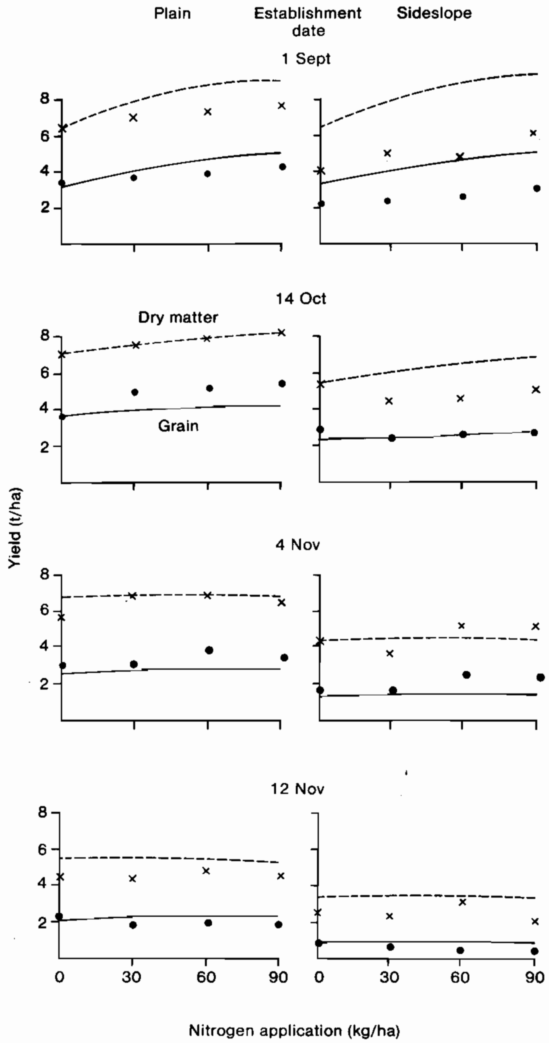


Fig. 6. Fit of simulated yields to observations of yield responses to applied nitrogen at four times of crop establishment.

Model Validation

The model was validated against independent yield data obtained from experimental crops grown with researchers' management in the PHARLAP field experiments. The procedure for field validation was to run the model with the same parameter values as those used for the calibrations on the Tigbauan data of Bolton (1980), but with the N fertiliser supply set at 70 kg N/ha, the amount applied to the treatments from the PHARLAP experiments used for model testing. The toposequence profile used for the calibration was also retained, although it was recognised that a different landscape profile applied to every field. The toposequence used in the Tigbauan simulations effectively becomes the standard toposequence used in the remainder of the model simulations presented here.

Yields simulated for the major landscape positions, plain and plateau, are presented as an envelope within which yields from most parts of the landscape were expected to fall. Figure 7 shows the simulated yields graphed against establishment date for the two major landscape positions.

The agreement of the model with the data was less satisfactory than for the previous calibrations and tests. In particular, the model overestimated yields for most first crops in the three locations. However, it was generally more accurate in calculating yields of second crops, except for the 1984–85 season in Patnongon. The simulated yields of fields on the plateau and plain were similar for first crops but diverged for second crops, because of the poorer water supply on the plateau fields.

The most likely reason for the overestimation of first crop yields is that the PHARLAP crops were deficient in mineral nutrients other than N, even though the data used for testing came from treatments which had received recommended applications of P and K. The PHARLAP component-technology trials showed large nutrient responses to P, K, S and Zn in many fields, and it is possible that other deficiencies remain undetected. It is also not certain whether the known deficiencies were fully corrected by the amounts of fertiliser supplied. This result shows a limitation of crop growth models in which N is the only nutrient included.

The simulations of first crop yields generally form an envelope over the experimental yields. The model should therefore be considered as representing a yield potential which may be attainable if the nutrient deficiencies are corrected.

The other situation in which the model fitted

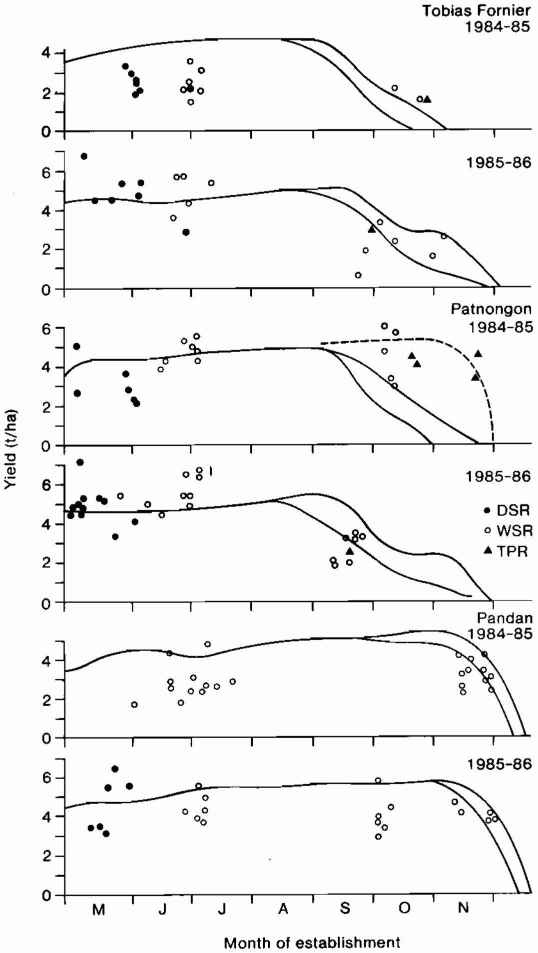


Fig. 7. Tests of the simulation model against researcher-managed yields in three locations in Antique over two years. The points refer to measured yields of crops established at different times and by different methods and the lines refer to simulated yields for plain (upper line), plateau (lower line) and waterway (dashed line) for a standard toposequence.

poorly was for the second crops in Patnongon during 1984-85. In fact, most of these observed yields did not come from regular PHARLAP cooperators' fields where few second crops were grown, but from a restricted group of fields located on a creek bank where there was an unusually large supply of soil water (Tasic et al. 1987). This situation was simulated well by the waterway landscape position representing only 1% of the landscape (Fig. 7).

The yields which were most accurately simulated were for second crops, other than those in Patnongon in 1984-85. These were crops for which the main limiting factor was water supply rather than nutrient deficiency.

The model can be considered as simulating the yield of first crops in the absence of nutrient deficiencies other than N, while simulating second crop yields with reasonable accuracy. Since the variability of second crop yields is the key to understanding the risks of double cropping, it is considered that the model is useful for simulating cropping patterns of two rice crops, and extrapolating such patterns in time and space.

Multilocation Cropping Pattern Simulations

Having calibrated the simulation model to growth data in Iloilo, and validated it against the yields measured in the PHARLAP experiments, the model was run on long-term weather data for 103 locations. The simulations were all based on the hydrology of a plain and a rice variety with the developmental pattern and yield potential of IR36, and supplied with 40 kg N/ha, the mean amount applied to rice in the Philippines.

Single WSR

The simulated yields were remarkably constant over much of the Philippines (Fig. 8), reflecting the fact that water supply is usually not limiting during the middle of the rainy season. The exceptions were lower yields in the far south of Mindanao where short growing seasons limited yields in many years.

Double WSR

Simulations of crops growing in sequence were run by looping the crop growth part of the model, so that the growth of one crop was simulated after another. The assumptions tested were different turnaround periods, that is, the time between harvest of one crop and establishment of a second on the same field. These delays which are simulated before crop establishment apply to both first and second crops. A rule within the model is that crop establishment is simulated only if soil water conditions are satisfactory which, in the case of wet-seeded rice, means saturation.

(i) Turnaround Period: 30 Days

Figure 9 shows the percentage of years in which the establishment of a second crop was simulated. This map shows a complex pattern with a high frequency of double crops in the eastern Philippines,

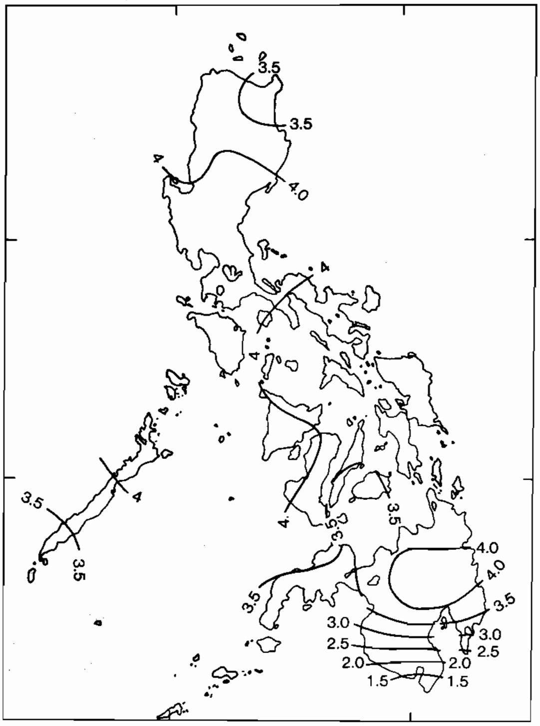


Fig. 8. Simulated yields (t/ha) of a single wet-seeded rice crop growing on a rainfed plain, based on simulations using weather data for 103 locations.

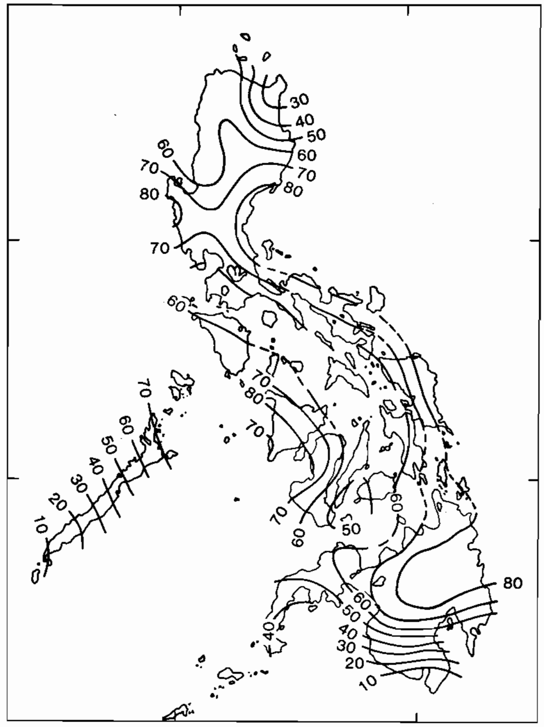


Fig. 9. Percentage of years when the model simulated two wet-seeded rice crops growing on a rainfed plain with a turnaround period of 30 days, based on simulations using weather data for 103 locations.

with the exception of northeastern Luzon. There were lower frequencies simulated for southern Mindanao. The simulated mean yields (Fig. 10) for this cropping pattern reflect the frequency with which second crops were simulated, with highest yields in eastern areas.

(ii) Turnaround Period: 10 Days

With faster simulated crop establishment, the simulated yields rose in most parts of the Philippines (Fig. 11), both because of a higher frequency of years in which second crops were established and because of higher second crop yields. The exceptions were in the dry locations in northern Luzon and southern Mindanao where there were so few second crops simulated that the productivity of the cropping pattern was the same as that of a single crop.

(iii) Benefit of Faster Turnaround

The yield difference of cropping patterns with 10- and 30-day turnarounds is shown in Fig. 12. The largest gains to rapid turnaround are likely in the western Visayas. The apparent reason is that there is little advantage to rapid turnaround in dry environments because there is little chance of double cropping. Equally, there is little advantage in environments with a long growing season where delayed establishment confers little yield penalty.

An Interactive Water Balance for Annual Rainfed Cropping Patterns

The simulation model presented in the previous section has the disadvantage that it is programmed for a mainframe computer and requires considerable programming experience to operate and modify. To make the simulations more accessible, a simplified, interactive version was prepared. The features and operations of this program, called POLYCROP, are presented here.

The POLYCROP system is based on an interactive microcomputer program which estimates productivity, in relation to water use, of annual rainfed crops growing in sequence. The system uses the minimum acceptable set of weather, soil and crop

Table 1. Overview of options in the POLYCROP program.

1 Before entering program

1.1 Obtain header file

1.2 Obtain weather data

- 1.2.1 Load weather data provided for 103 stations
- 1.2.2 Supply other weather data

2 After entering program

2.1 Select weather data

- 2.1.1 Rainfall station
- 2.1.2 Evaporation station
- 2.1.3 Specify tolerable number of days of missing data

2.2 Select land class:

- 2.2.1 UPLAND
- 2.2.2 LOWLAND

2.3 Select soil texture from menu:

- 2.3.1 HEAVY texture
- 2.3.2 MEDIUM texture
- 2.3.3 LIGHT texture
- 2.3.4 Specify soil parameters following prompts:
  - 2.3.4.1 Soil water lower limit
  - 2.3.4.2 Soil water drained upper limit
  - 2.3.4.3 Soil water saturation
  - 2.3.4.4 Rate of bund seepage (for LOWLAND)
  - 2.3.4.5 Rate of percolation

2.4 Select TACTICAL or STRATEGIC crop selection (TACTICAL here means a separate crop selection each year, STRATEGIC means a specified cropping pattern to be attempted each year)

- 2.4.1 If STRATEGIC, specify:
  - 2.4.1.1 Number of crops per year (≤ 3)
  - 2.4.1.2 Turnaround period between crops

2.5 Select crop

- 2.5.1 If UPLAND, select from menu:
  - 2.5.1.1 Upland rice
  - 2.5.1.2 Corn
  - 2.5.1.3 Peanut
  - 2.5.1.4 Mungbean
  - 2.5.1.5 Soybean
- 2.5.2 If LOWLAND, select from menu:
  - 2.5.2.1 TPR
  - 2.5.2.2 WSR
  - 2.5.2.3 DSR
  - 2.5.2.4 Mungbean
  - 2.5.2.5 Green corn
- 2.5.3 Specify crop attributes:
  - 2.5.3.1 Days to flowering
  - 2.5.3.2 Days to maturity
  - 2.5.3.3 Maximum root depth
  - 2.5.3.4 Maximum percentage foliage cover
  - 2.5.3.5 Water-use efficiency

Table 2. Sample screen outputs of the POLYCROP program for weather data at Dumaguete (labelled DUMGTE) (a) Output for crop year 1964–65 (b) Output summary for a series of 14 years.

(a)

```
CROP YEAR 1964/1965 IS ACCEPTABLE WITH LESS THAN  20. DAYS OF MISSING DATA

CROP 1  MUNGBEAN
ESTABLISHMENT DATE:  MAY 19
      HARVEST DATE:  JUL 15
ESTIMATED TOTAL CROP TRANSPIRATION:   158. mm
MAXIMUM POTENTIAL YIELD (LIMITED BY TRANSPIRATION ONLY):   1.3 t/ha dry mat
ESTIMATED EXCESS WATER FROM RUN-OFF AND PERCOLATION:  221. mm

CROP 2  UPLAND RICE

CROP 2  UPLAND RICE
ESTABLISHMENT DATE:  SEP 19
      HARVEST DATE:  JAN  6
ESTIMATED TOTAL CROP TRANSPIRATION:   270. mm
MAXIMUM POTENTIAL YIELD (LIMITED BY TRANSPIRATION ONLY):   3.5 t/ha dry mat
ESTIMATED EXCESS WATER FROM RUN-OFF AND PERCOLATION:  740. mm
```

(b)

```
                    O U T P U T   S U M M A R Y

                              DUMGTE

CROP 1 - MUNGBEAN

                  MIN    1 QUART   MED    3 QUART  MAX      MEAN

ESTABLISHMENT   MAY 13   MAY 21   JUN 16   JUN 26  AUG 17   JUN 18
HARVEST         JUL  9   JUL 17   AUG 12   AUG 22  OCT 13   AUG 14

                          YIELD CLASSES (t/ha)

      -----------------------------------------------------------
      | TOT |  -  |  0  | 0-1 | 1-2 | 2-3 | 3-4 | 4-5 | 5-6 |     m   sd
      -----------------------------------------------------------
 yrs  | 14  |  0  |  0  |  1  | 13  |  0  |  0  |  0  |  0  |    1.3  .1
      -----------------------------------------------------------
CROP 2 - UPLAND RICE

                  MIN    1 QUART   MED    3 QUART  MAX      MEAN

ESTABLISHMENT   AUG  6   AUG 17   SEP 13   SEP 30  NOV  2   SEP 15
HARVEST         NOV 23   DEC  4   DEC 31   JAN 17  FEB 19   JAN  2

                          YIELD CLASSES (t/ha)

      -----------------------------------------------------------
      | TOT |  -  |  0  | 0-1 | 1-2 | 2-3 | 3-4 | 4-5 | 5-6 |     m   sd
      -----------------------------------------------------------
 yrs  | 14  |  0  |  0  |  0  |  0  |  2  | 12  |  0  |  0  |    3.2  .3
      -----------------------------------------------------------
```

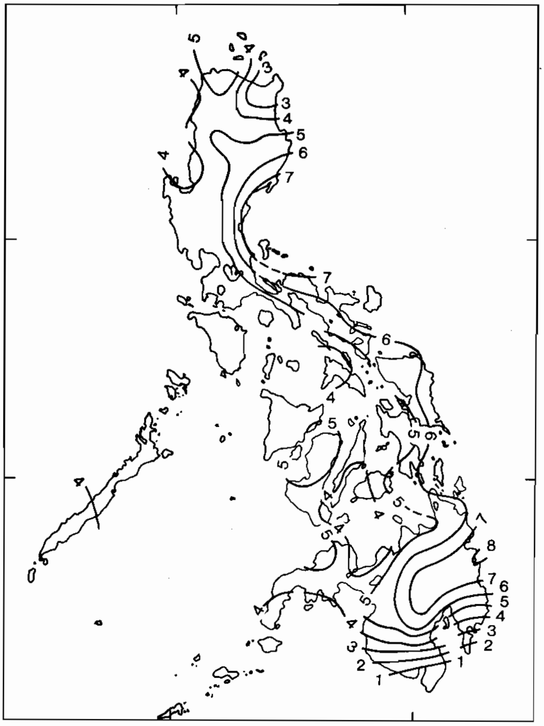


Fig. 10. Simulated yields (t/ha) of two wet-seeded rice crops growing in sequence on a rainfed plain with a turnaround period of 30 days, based on simulations using weather data for 103 locations.

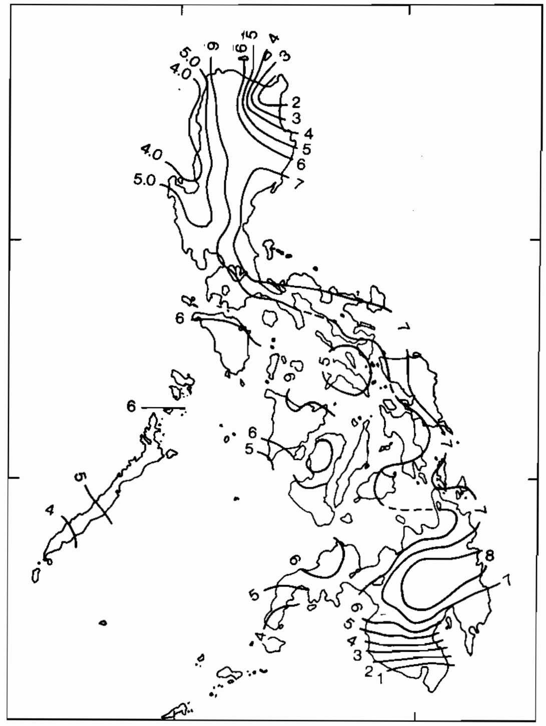


Fig. 11. Simulated yields (t/ha) of two wet-seeded rice crops growing in sequence on a rainfed plain with a turnaround period of 10 days, based on simulations using weather data for 103 locations.

data. It links the weather data with parameters describing aspects of soil hydrology, crop biology and crop management. Parameters describing soil hydrology and the biology of selected crops are contained within the computer program, but options exist for the user to specify other parameters for the standard crops, or to define the attributes of other crops. Management aspects related to cropping sequence selection and turnaround period must be specified by the user. An overview of the options available in the system is shown in Table 1. The system is self-contained and can be operated by users with a working knowledge of agronomy and soil science.

The water balance model contained in POLYCROP is equation (8). Productivity is estimated as a function of transpiration, using estimates of water-use efficiency such as those given by Angus et al. (1983b). The allocation of evapotranspiration is simulated by assuming a linear increase in the percentage of foliage cover from the date of establishment until 80% of the specified time to anthesis, after which it remains at the user-specified maximum cover until 50% of the grain-filling time has elapsed, after which it declines linearly to zero cover.

The limitations of the model are that it simulates neither intercrops nor crops which grow for more than a year.

The weather data required are historical daily rainfall and estimated weekly mean potential evapotranspiration (PET). A set of such data for the 103 locations shown in Fig. 1 is available, but for other locations users may provide their own data. The program thus does not prevent data from different locations being linked, so that rainfall data from an obscure location may be used with evaporation data from a nearby major centre.

Users may supply weather for other locations based on data formats identical to those in the existing files, or they may modify the FORTRAN code to accept weather data in other formats.

The program is written in FORTRAN 77 and is available from the authors on IBM/PC-compatible 5-1/4″ diskettes, at densities of 360 Kbytes or 1.2 Mbytes. The 1.2 Mbyte-diskettes can be supplied

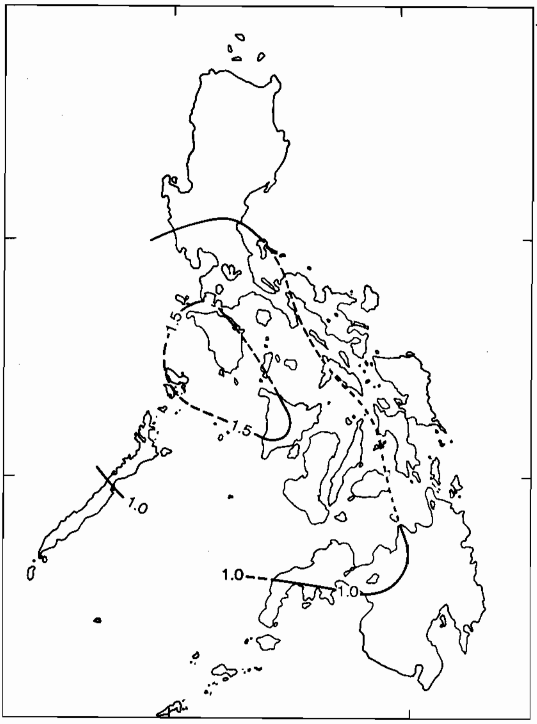


Fig. 12. The yield advantage (t/ha) of rapid turnaround (10 days versus 30 days) for a double wet-seeded cropping pattern.

containing the FORTRAN source code, an executable code for a standard PC, or for a PC with an 8087 co-processor, as well as example sets of weather data. The smaller-capacity diskettes cannot contain both source and executable codes.

An example of the output is presented in Table 2. It shows the form of output for individual years and for all years of record for a location. The objective of the program is to provide users with the facility to make calculations, based on their own assumptions about the productivity and stability of proposed rainfed cropping systems in relation to water regime and crop timing.

Uses for the program are in education, in comparing experimental crops and simulated crops with the same soil hydrology, crop attributes and management, and in exploring the likely long-term adaptation of possible cropping patterns to environments for which weather data are available. In providing a facility for studying these aspects, it is hoped that interested scientists will be able to test and refine agroclimatic studies relevant to their areas of interest.

References

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

Angus, J.F., Mackenzie, D.H., Myers, R.J.K., and Foale, M.A. 1983a. Phasic development in field crops III. The pseudocereals, buckwheat and grain amaranth. Field Crops Research, 5, 305–318.

Angus, J.F., and Manalo, E.B. 1979. Weather and climate data for Philippine rice research. IRRI Research Paper Series No. 41.

Angus, J.F., and Moncur, M.W. 1985. Models of growth and development of wheat in relation to plant nitrogen. Australian Journal of Agricultural Research, 36, 537–544.

Angus, J.F., Sudjadi, M., Fazekas de St.Groth, C., Hadiwahyono, Sri Mulyani, N., Damdam, A.M., and Wetselaar, R. 1987. A simulation model of nitrogen response of irrigated rice. In Efficiency of Nitrogen Fertilizers for Rice. Los Baños, IRRI. 135–140.

Angus, J.F., and Zandstra, H.G. 1980. Climatic factors and the modeling of rice growth and yield. In Agrometeorology of the Rice Crop. Los Baños, IRRI. 189–199.

Bolton, F.R. 1980. Double-cropping rainfed rice in Iloilo Province, Central Philippines. Ph.D. thesis, University of Reading.

Byrne, G.F. 1973. An approach to growth curve analysis. Agric. Meteorol., 11, 161–168.

Cabezon, W.E. 1978. A Markov chain model for Philippine rainfall data. MS thesis. Department of Statistics, University of the Philippines at Los Baños.

Fitzpatrick, E.A., and Nix, H.A. 1970. The climatic factor in Australian grassland ecology. In Moore, R.M. (ed.) Australian Grasslands. Canberra, ANU Press, 3–26.

Hutchinson, M.F., Booth, T.H., McMahon, J.P., and Nix, H.A. 1984. Estimating monthly mean values of daily total solar radiation in Australia. Solar Energy, 32, 277–290.

Reddy, S.J. 1979. User's manual for the water balance models. Patancheru, India, ICRISAT.

Serquina, C.M. 1977. Statistical analysis of Philippine rainfall data. MS thesis. Department of Statistics, University of the Philippines at Los Baños.

Tamisin, M.M. 1977. Numerical modelling of potential evapotranspiration in different regions of the Philippines. MS thesis, Department of Agricultural Engineering, University of the Philippines at Los Baños.

Tirol-Labios, Lutgarda C. 1979. Rainfall probabilities of some selected gaging stations in the Philippines. MS thesis, Department of Statistics, University of the Philippines at Los Baños.

Tasic, R.C., Fazekas de St.Groth, C., and Angus, J.F. 1987. PHARLAP: A Cropping Systems Study on Rainfed Rice Farms in Antique Province, Philippines. Natural Resources Series No 7. Canberra. CSIRO Division of Water and Land Resources.

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

Wickham, T.H., and Singh, V.P. 1978. Water movement through wet soils. In Soils and Rice, Los Baños, IRRI. 337–358.

Zandstra, H.G. 1982. Effect of soil moisture and texture on the growth of upland crops after wetland rice. In Cropping systems research in Asia. Los Baños, IRRI. 43–54.

CHAPTER SEVEN

Environmental and Management Factors Affecting Cropping Intensity

J.F. Angus and S.K. Jayasuriya

For farmers in rainfed areas to increase the number of rice crops grown each year from one to two, they must establish the first crop earlier than is normal for a single crop, and harvest the second crop later than normal for a single crop. Where the growing season is reliably longer than the duration of two rice crops (plus a reasonable time for crop establishment), the productivity benefits are likely to outweigh the costs. However, where the growing season is of marginal or variable duration, crops may suffer greater risk of drought at the start or finish of the growing season than is experienced by a single crop growing in the middle and most reliable part of the season.

In this chapter the extent of double cropping in the study areas is reported along with factors affecting the proportion of land which was double cropped. The effect of available tillage power and the environmental constraint of water supply on double cropping are discussed in relation to the potential extent of double cropping, as determined by a simulation model. These simulations provide an opportunity to evaluate the benefits, costs and risks of multiple cropping, with a view to specifying the cropping systems which are stable and profitable in relation to long-term weather patterns.

Extent of Double Cropping

As part of the socioeconomic farm surveys reported in Chapter 2, rice farmers in the three study areas of Antique Province were surveyed over 2 years (1984–85 and 1985–86) and were asked, among other questions, about the time of establishment of the first rice crop, and if applicable, the second rice crop, on each of their lowland fields.

Figure 1 shows an example of the timing of the double rice cropping pattern for the Patnongon study area over 2 years. It can be seen that, in both years, first rice crops were grown on all fields included in the surveys, but only about 40% of the fields supported a second rice crop. The period during which first crops were established lasted about 90 days while second crops were established over about 80 days. The method of crop establishment varied with the time of establishment and with the position of the crop in the cropping pattern. First crops established early in the rainy season were dry-seeded (DSR), while crops established later tended to be wet-seeded (WSR) or transplanted (TPR). The second crops were mostly wet-seeded, with a small proportion transplanted. The restricted extent of transplanting among both first and second crops was due to a limited supply of rice seedlings in rainfed areas (Tasic et al. 1987).

A summary of the data on the time of crop establishment for the three study areas is presented in Table 1. Here, the number of days of staggered establishment refers to the period over which 80% of the district's crops were established. The earliest 10% and latest 10% of crops are not considered so that aberrant or unrepresentative data are excluded.

Table 1 shows that the smallest proportion of land growing a second crop was in Tobias Fornier where the mean growing season duration is about 5 months. In Patnongon, where the duration is about 7 months, more of the fields were double cropped, while in Pandan, where the duration is about 9 months, virtually all fields were double cropped. The mean turnaround period, that is, the mean number of days between harvest of the first crops and establishment of the second crops, was longest in Pandan and shortest in Tobias Fornier. However, this ranking of the study areas reflects the fact that most fields were double cropped in Pandan and fewest were double

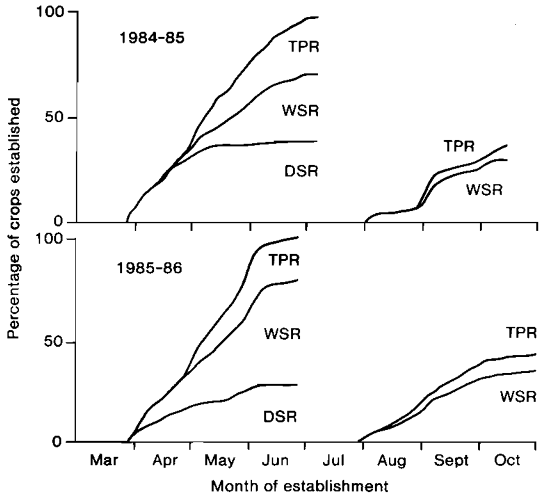


Fig. 1. Cumulative percentage of rice crops established in Patnongon during two growing seasons, as determined from the farm surveys.

cropped in Tobias Fornier. When allowance was made for the different proportions of land on which two crops were grown, the rankings of the turnaround period were reversed, with the shortest area-corrected mean turnaround in Pandan and the longest in Tobias Fornier.

Factors Affecting the Practice of Double Rice Cropping

In this part of the study, data from the socioeconomic surveys were analysed statistically so as to identify attributes of individual fields, and of the farmers who cultivated them, that distinguished those fields on which two rice crops were grown in a year. Data from Pandan were excluded from this analysis because two rice crops were grown over the complete area of farmland. For the two other areas where a second crop was grown on relatively few fields, the hypothesis tested was that the practice of double rice cropping of a particular field was related to the date and method of first crop establishment, the soil and landscape position of the field and whether the farmer owned two or more carabaos.

For each crop year, the farmers' fields in these study areas were classified into two groups according to whether or not they were double cropped. The variables 'explaining' group membership were explored by canonical discriminant function analysis (Bennett and Bowers 1978), using the SPSSX computer package (1983).

In preliminary analyses not reported here, it was observed that the relationship between the date and method of establishing the first rice crop was such that the probability of double cropping increased when, at any given date, the crop was transplanted. The shorter field duration of the transplanted crop naturally facilitated earlier establishment of the second crop. However, in practice, farmers cannot simultaneously choose between the three methods of establishment and the date of establishment. The pattern of rainfall and water accumulation in rice fields, as well as the availability of seedlings, determines the feasible establishment method at a given time. As observed in the surveys, earliest crop establishment is by DSR followed by WSR and TPR. Therefore, in subsequent analyses, the date of crop establishment was retained while the method of establishment was excluded. The soil and landscape variables were found not to have much explanatory power, perhaps partly due to measurement problems (soil was described by a three-level factor representing light, medium and heavy textures; landscape was described by a three-level factor representing high, medium and low landscape positions). This left only two variables, the date of establishment of the first crop and the ownership of carabaos, in the final discriminant functions.

Although the percentage of cases correctly classified by the discriminant functions was only about 60%, the results support the hypothesis that establishment date was important in both locations and that the ownership of carabaos was important in Tobias Fornier. Delayed first crop establishment decreased the probability of double cropping in each location. Carabao ownership increased this probability in Tobias Fornier but had no significant effect in Patnongon. Both first crop establishment date and carabao ownership point to the importance of draught power in facilitating double cropping.

The apparent lack of relationship between double cropping and soil or landscape variables may have been because of offsetting factors. It was observed that DSR was commonly established early on friable soils on sideslopes, so favouring a second crop. On the other hand, the favourable water regime of heavy soils on plains also favoured second crop production, provided the first crop was not established very late.

Because of the importance of carabao ownership in the discriminant function analysis for Tobias Fornier, the survey data were more closely examined for patterns in the ownership of carabaos (Table 2).

Table 1. Percentages of fields cropped, the period of staggered crop establishment and the mean turnaround period in the three study areas for the crop years 1984–85 and 1985–86.

	Tobias Fornier		Patnongon		Pandan	
	First crop	Second crop	First crop	Second crop	First crop	Second crop
1984–85						
Fields cropped (%)	100	32	100	37	100	96
Days of staggered crop establishment*	53	71	68	58	38	40
Mean turnaround (days)**	23		24		33	
Area-corrected mean turnaround (days)***	72		65		34	
1985–86						
Fields cropped (%)	100	28	100	44	100	99
Days of staggered crop establishment*	70	59	72	63	43	37
Mean turnaround (days)**	22		28		33	
Area-corrected mean turnaround (days)***	79		64		33	

*The period of staggered crop establishment refers to the number of days over which surveyed crops (excluding the earliest and latest 10%) were established in a study area.

**Days between the harvest of the first crop and the establishment of a second crop on fields on which two crops were grown.

***Days between the harvest of the first crop and the establishment of a second crop, calculated on the basis of the whole farm area (i.e. Mean turnaround × 100/percentage of farm area growing a second crop).

Farmers in barangays located on the coastal plain were found to own fewer carabaos than those in barangays located in the foothills and inland valleys. The differences in carabao ownership between barangays were more pronounced in Tobias Fornier and Pandan than in Patnongon.

Carabao ownership was also found to affect the date and method of first crop establishment (Fig. 2). The graphs suggest that farmers owning two or more carabaos established DSR on their fields earlier than farmers owning fewer carabaos. However ownership of carabaos was not important for WSR.

The picture that emerges from Table 2 and Fig. 2 about draught power and tillage is that carabao ownership is concentrated at higher landscape positions, presumably near grazing land. At the commencement of the rainy season, carabao owners first use their animals to establish DSR on their own (generally) light textured fields. After these crops are established, the carabao owners assist with land preparation* for WSR and TPR for farmers in lower landscape positions.

Efficiency of Land Preparation

The results in the previous section support the conclusions of Bolton and Zandstra (1981) and Roxas (1981) that timeliness in crop establishment is important for double cropping. Since carabao provide the overwhelming source of power for land preparation in the study areas, the utilisation of this power was further investigated.

* Land preparation is the series of operations conducted on the land prior to crop establishment. It may include processes such as: ploughing, harrowing, bund-forming and herbicide application. The most time-consuming operations, normally ploughing and harrowing, use carabaos.

Table 2. Ownership of carabaos in relation to the locations of barangays (% farms in each class).

Barangay location	Tobias Fornier			Patnongon			Pandan		
	Number of carabaos per farm								
	0	1	≥ 2	0	1	≥ 2	0	1	≥ 2
Coastal plain	40	47	13	29	51	20	26	49	25
Foothills and inland valleys	27	38	34	26	49	25	17	40	43

Table 3. Reported estimates of the time required for land preparation for different forms of rice production on small farms.

Operations	Time required	Source
First crop DSR	163 carabao hours/ha	Roxas (1981)
First crop WSR	150 ,,	,,
First crop TPR	121 ,,	,,
Second crop TPR	187 ,,	,,
Unspecified	134 ,,	Freedman (1980)
Second crop WSR	28 hand tractor hours/ha	McMennamy and Zandstra (1978)

From information about the number of carabaos in each study area and the minimum duration of carabao work needed for preparing land prior to crop establishment, it is possible to calculate an efficiency index for the utilisation of carabaos for land preparation. This calculation is analogous to that used in estimating the time required for mechanised farm operations (Richey 1961). However, whereas the calculation used for mechanised operations is normally based on a single machine on a single farm, the calculation here (equation (1) below) is based on the aggregation of all carabaos in a study area. The justification for aggregating the data in this way is that much of the land preparation is done by various cooperative arrangements between farmers within a district.

$$\text{Days to prepare land to establish 1 ha of rice} = \frac{\text{Minimum number of carabao hours per hectare of land prepared}}{\text{Carabao Density} \times \text{Field Efficiency Index} \times \text{Carabao working time (hours per day)}} \qquad (1)$$

Equation (1) was used to calculate the Field Efficiency Index, defined as the actual pace of land preparation, expressed as a percentage of the potential.

The minimum work requirement for land preparation has been estimated in several studies (Table 3). These suggest that a farmer working with a single carabao requires between 121 and 187 hours/ha, depending on the method of crop establishment. For this calculation, a value of 150 (person + carabao) hours was taken as the time for WSR establishment. In the study areas of Antique, the density of carabao/hectare of rainfed lowland, as determined from the farm surveys, was:

	Carabao/ha
Tobias Fornier	0.69
Patnongon	0.45
Pandan	0.77

The remaining unknown term in equation (1) is the average working day of carabao operations. Roxas (1981) suggested 6 hours, made up of 3 hours in the early morning and 3 hours in the late afternoon. Longer working hours lead to stress on carabaos because, as wallowing animals, they are unadapted to working at midday temperatures.

Given equation (1), the recorded times for land preparation presented in Table 1 (days of staggered crop establishment), and the recorded densities of carabao, the field efficiency index for land preparation was calculated for each study area, as shown in Appendix 1. The estimates are as follows:

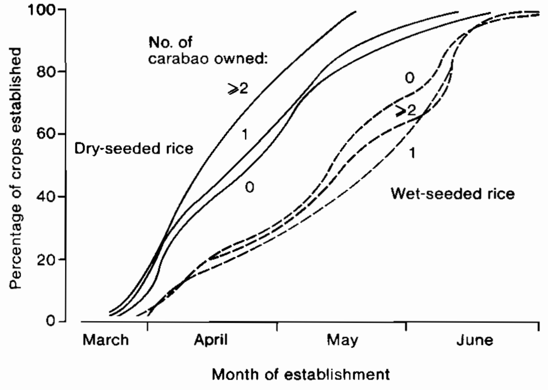


Fig. 2. Cumulative percentage of first crops established in relation to number of carabaos owned by farmers.

	Field Efficiency Index (%)
Tobias Fornier	19
Patnongon	35
Pandan	86

The value for Pandan is high in comparison with field efficiencies of 50–80% reported for mechanised operations by Richey (1961). There appear to be no reports of field efficiency for farm operations using animal power.

The field efficiencies in Tobias Fornier and Patnongon are low. There did not seem to be any substantial differences in soil, landscape or land tenure which would hinder cultivation in these municipalities. During the 2 years of the project, the soil water conditions during the turnaround period of September–October were favourable for land preparation. The most likely reason for the low field efficiencies in Tobias Fornier and Patnongon is that farmers in these areas were not confident that seasonal conditions would be suitable for growing two rice crops.

It is possible that the majority of farmers in Tobias Fornier and Patnongon who refrained from growing a second crop were justified because of the risks of drought. Although the second crop yields measured in the PHARLAP experiments were generally encouraging (Tasic et al. 1987), it is difficult to estimate the long-term potential for growing second crops from experiments conducted over 2 years because the seasons may have been unrepresentative. In rainfed environments, a series of years must be sampled for robust conclusions to be made.

Potential For Double Cropping

The simulation model described in Chapter 6, which simulates growth and development of rice crops growing in sequence, was used to estimate long-term productivity and stability of double cropping. The parameter values for the crop and the landscape components of the model were set to those used when the model was validated against the PHARLAP data. As explained in Chapter 6, the model was calibrated against a set of data for rainfed rice in Iloilo. The simulated yields represent those obtainable at a high level of management and unconstrained by the patchy deficiencies of P, K, Zn and S which were found in the study areas.

The timing of crop establishment was simulated using the decision rules shown in Fig. 3. In addition to a requirement that land preparation can proceed only when soil water conditions are suitable, these decision rules also provide for a specified minimum delay between the earliest planting rains and the simulated date of establishment. In the case of second crops, this delay is the turnaround period. In the case of first crops, the delay is analogous to the turnaround period, commencing when the first rains of the growing season first lead to soil water conditions which are suitable for land preparation.

Using these decision rules, the model was run to simulate a cropping pattern of two WSR crops for the locations in Antique for which several years of weather data were available (Tobias Fornier, Barbaza, Culasi and Valderama). It was also run for Iloilo City, the only location on Panay Island with a long sequence (58 years) of weather data. The growing season duration of Iloilo City appears to fall between those of Tobias Fornier and Patnongon. Insufficient weather data were obtainable for the study areas of Patnongon and Pandan for yields to be simulated at these locations.

The model was first run to estimate the productivity of a WSR-WSR cropping pattern with either the minimum feasible period of land preparation (turnaround), or the shortest observed period. The minimum period was taken to be 10 days, during which it was assumed that the process of straw decomposition proceeded sufficiently for unimpeded cultivation. The shortest existing period for land preparation was taken to be 30 days, a value based on the mean turnaround period in Pandan (Table 1).

Figure 4 shows the simulated yields of first and second rice crops growing on a sideslope at Iloilo City for the 58 years of weather record. This simulation

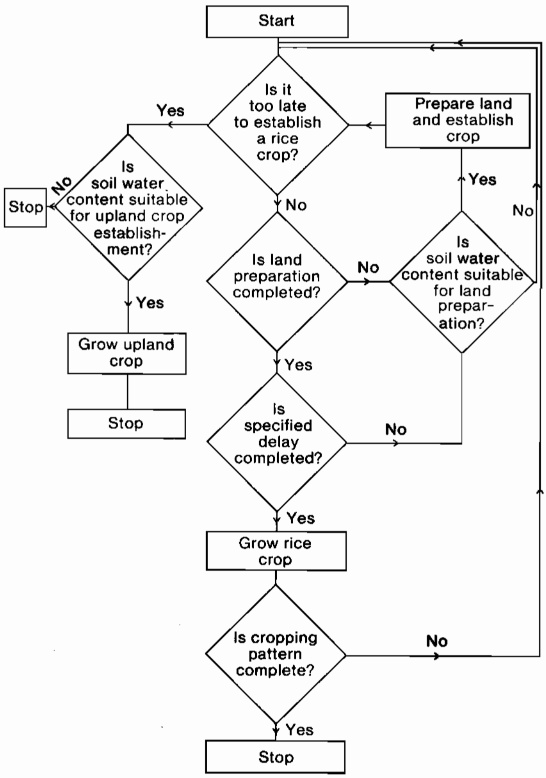


Fig. 3. Decision rules used in simulating land preparation and crop establishment in a multiple cropping system.

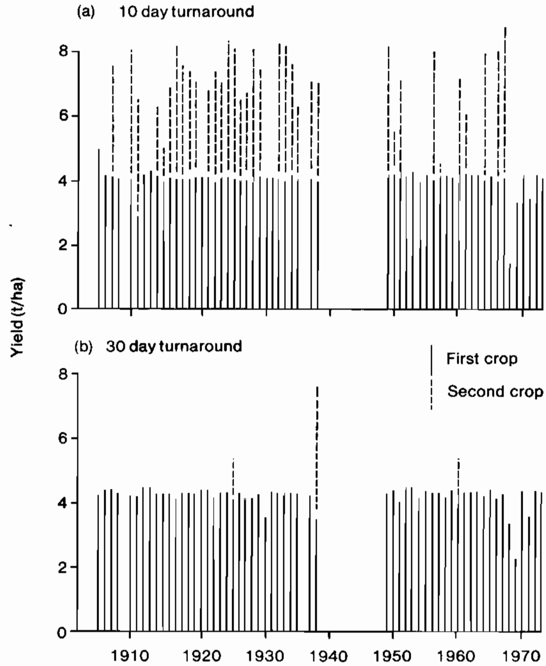


Fig. 4 Simulated yields over 58 years of weather data for Iloilo City for WSR grown when possible as two crops in sequence on a sideslope position, for turnaround periods of (a) 10 days (b) 30 days.

produced relatively constant yields of first crops, but an irregular pattern of seasons when conditions were suitable for establishing second crops, and variable yields of crops which were established. This simulation was repeated for the four locations in Antique. The estimated yields in relation to delay in establishment are shown in Table 4. Of the locations listed, Barbaza and Valderama have the environments which most closely resemble that of Patnongon, but both are wetter and have longer growing seasons. The environment of Culasi resembles that of Pandan but has a shorter growing season.

The simulations reported in Table 4 suggest that, by reducing delays, potential productivity can be increased substantially in all locations except Tobias Fornier. There, the percentage of years in which double cropping was possible was small when land preparation was slow, and second crop yields were low even when land preparation was rapid.

Risks of Double Cropping

An analysis of the profitability and risks of double cropping was attempted by first calculating the annual Gross Margin, equal to the revenue minus variable costs, for double rice cropping patterns with different turnaround periods. The assumptions involved in this calculation were based on prices, costs and recommended practices in 1985:

Rice price:	₱3/kg
Crop establishment costs:	₱1575/ha
Crop growing costs:	₱200/ha
Harvesting and threshing costs:	One-sixth of the harvest

The model was run for different turnaround periods for the 58 complete years of weather records for Iloilo City, and gross margins calculated. The results are presented in Fig. 5 in terms of the cumulative density functions of the gross margins for double cropping with four different simulated turnaround periods.

These functions, when examined in terms of the

Table 4. Simulated rice yields for locations in southern and western Panay in relation to delays in crop establishment.

		Rice yields (t/ha)					
		Existing delays (30 days)			Minimum delays (10 days)		
Location	Years of record	First crop	Second crop	Total	First crop	Second crop	Total
Iloilo City	58	4.2 (100)	3.4 (7)	4.4	4.0 (100)	3.5 (62)	6.2
Tobias Fornier	7	4.3 (100)	2.9 (14)	4.7	4.1 (100)	0.9 (86)	4.9
Barbaza	23	4.2 (100)	2.6 (17)	4.7	4.1 (100)	2.8 (91)	6.7
Culasi	22	3.9 (100)	3.8 (45)	5.6	4.1 (100)	3.7 (82)	7.1
Valderama	22	4.1 (100)	2.6 (18)	4.6	4.1 (100)	2.9 (100)	7.0

Numbers in parentheses refer to the percentage of years which were judged suitable for a crop to be established. The totals refer to the mean annual productivity over all years of record.

stochastic dominance of Anderson et al. (1977), indicate the relative profitability and risk of the different delays in establishment. Briefly, with the stochastic dominance approach, a line lying wholly to the right of another represents a more profitable and less risky policy. When two lines cross, the portion of a line lying to the left of another indicates the frequency of less profitable seasons with that policy.

The graphs in Fig. 5 suggest that shorter delays led to larger margins in about two-thirds of years. In the other one-third of years, shorter delays led to lower margins for the whole cropping pattern. Lower margins occur in seasons when revenue from the second crop does not exceed the costs of establishment and growth.

The ultimate decision for the farmer as to whether short delays (and hence more double cropping) are preferable depends on the individual's risk preference. In this case, the large expected benefits compared with the small expected losses suggest that only the most risk averse farmers should refrain from growing two crops in the specified environment of a plain at Iloilo City.

Cutoff Dates

Late establishment of the second rice crop normally leads to low yield because of its exposure to a long period of dry soil. Losses could be minimised if, as Bolton and Zandstra (1981) suggested, a cutoff date was specified after which second crops should not be established.

In order to estimate the cutoff dates for the three Antique locations with the longest sequences of weather data, the simulation model was set up to run on all years of weather data shown in Table 4, with a WSR-WSR sequence and various delays in crop establishment. These simulations generated a range of establishment dates and yields for the simulated second crops. Figure 6 shows the simulated yields in relation to the simulated date of establishment, with each point on the graphs representing the yield of a second WSR crop grown following a first WSR crop. The earliest establishment dates, in early September, were simulated for years in which the weather patterns enabled early establishment of the first crop and a short delay for second crop establishment. All second crops simulated with these early establishment dates gave yields close to 4 t/ha. For second crops simulated with later establishment dates, the yields were highly variable, reflecting the erratic rainfall in the later parts of the rainy season. From these results, it is possible to select cutoff dates which should lead to acceptable yields for the specified location. For example, a line drawn beneath all data points for Barbaza suggests that yields of 1 t/ha or less are obtained only from crops established after early October. Significantly, this is the latest time of year that surveyed farmers in Patnongon, the closest study area to Barbaza,

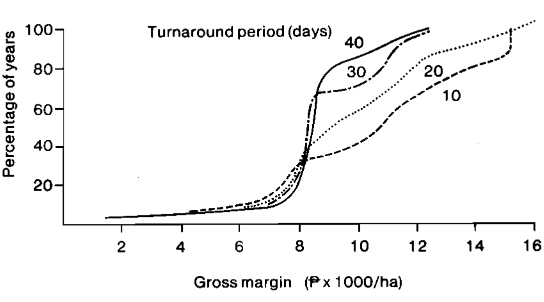


Fig. 5 Cumulative distribution of gross margins for two simulated WSR crops grown in sequence for four different turnaround periods.

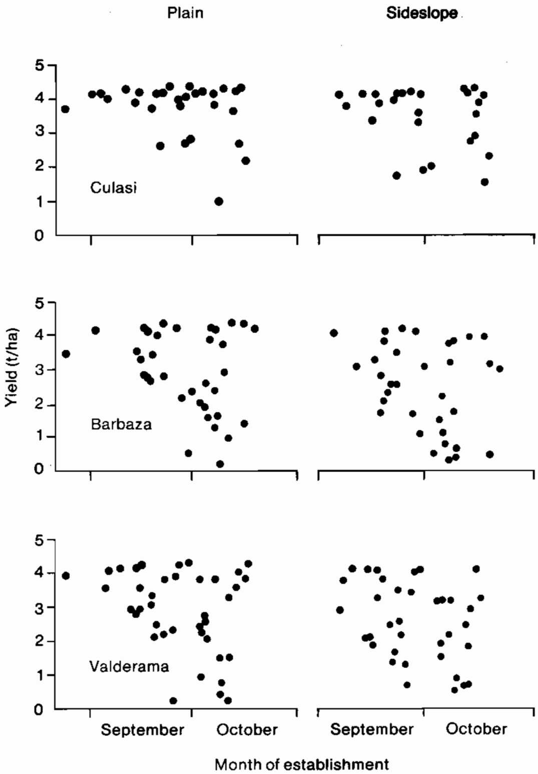


Fig. 6 Simulated yields of second WSR crops for three Antique locations in relation to the date of establishment for landscape positions of plain and sideslope.

established any rice crops (Fig. 1). It is likely that farmers are aware of the risk of attempted establishment after this time.

Discussion

The simulations suggest that output from some of the rainfed land of Antique could be increased if a greater proportion is used to grow two rice crops rather than one. At the current pace of crop establishment, however, extensive double cropping is stable and profitable only in Pandan. This is consistent with current practice. The relatively slow rate of establishment of first crops in Patnongon and Tobias Fornier effectively prevents establishment of a second crop on all fields.

The simulations suggest that if existing delays in crop establishment can be reduced from 30 days to 10 days (without a significant rise in the cost of land preparation), then double cropping could become an attractive proposition in the Patnongon area. It would also increase the profitability of this practice in Pandan. But even with such accelerated crop establishment, there appears to be no incentive for double rice cropping in Tobias Fornier.

Since carabao field efficiency in Pandan is already high, any acceleration in crop establishment would have to be achieved through mechanisation, which is likely to be uneconomic at current prices (Jayasuriya et al. 1986). More rapid crop establishment in the other areas, however, could be achieved if farmers utilised carabao at the level of field efficiency found in Pandan.

Why then do farmers in Antique not utilise more draught power to intensify crop production? Antique farmers are well aware that double cropping is feasible because, even in the dry environment of Tobias Fornier, about 30% grew a second rice crop. The analysis of draught power requirements suggests that it is not the availability of draught power that limits a greater proportion of double cropping, but the utilisation of that power.

It appears that the perceptions of most farmers in Tobias Fornier and Patnongon are that growing a second rice crop is too risky. In contrast, farmers in Pandan are confident of growing two crops and so are prepared to utilise their resources for rapid crop establishment.

The simulations support the conservative approach of farmers in Tobias Fornier and the optimism of farmers in Pandan. However, for central Antique locations like Patnongon, the simulations diverge from current practice by suggesting that double cropping, although riskier than growing a single crop, is likely to be generally more profitable than farmers' current practices. The key is for farmers to establish a first rice crop on all their land as quickly as possible after the commencement of the rainy season, and to assess soil water conditions after its harvest. If the second crop can be established on lowland plains before mid October, the risks of crop failure are not great. On sideslopes, the cutoff date is one or two weeks earlier.

A possible reason for farmers' conservative attitudes to growing a second crop may be their own recollections of drought. The most recent drought affecting second crops was in 1982–83. The generally dry seasons in the late 1960s and early 1970s (Fig. 4), when short duration rice crops were first introduced, may also have disposed older farmers unfavourably to double cropping.

Another possible reason for fewer second rice crops being grown in Patnongon than expected from the simulations is that actual yields are lower than those simulated. As discussed in Chapters 3 and 6, this overestimation is likely to be due to the patchy nutrient deficiencies identified in the PHARLAP experiments and possibly to other unidentified nutrient deficiencies.

A precondition for more widespread adoption of double cropping may be for the profitability of rice growing in general to be improved. Specifically, if the nutrient deficiencies found in the PHARLAP experiments were corrected for first crops, the residual effects would increase second crop yields.

References

Anderson, J.R., Dillon, J.L., and Hardaker, J.B. 1977. Decision Analysis in Agriculture. Iowa. Iowa State University Press.

Bennett, Spencer, and Bowers, David. 1978. An Introduction to Multivariate Techniques for Social and Behavioural Sciences. London and Basingstoke. McMillan Press.

Bolton, F.R., and Zandstra, H.G. 1981. Evaluation of double-cropped rainfed wetland rice. IRRI Research Paper Series 63, Los Baños, IRRI. 11 p.

Freedman, S.M. 1980. Modification of traditional rice production practices in the developing world: an energy efficiency analysis. Agro-Ecosystems, 6, 129–146.

Jayasuriya, S.K., Te, Amanda, and Herdt, R.W. 1986. Mechanisation and cropping intensification: Economics of machinery use in low-wage economies. Journal of Development Studies, 22, 327–335.

McMennamy, J.A., and Zandstra, H.G. 1978. Farm machinery for improved rice-based cropping systems. Paper presented to the IXth International Congress of Agricultural Engineering, East Lansing, Michigan, USA.

Richey, C.B. 1961. Agricultural Engineers' Handbook. New York, McGraw Hill.

Roxas, N.M. 1981. The economics of timeliness in the crop intensification of rainfed farms in Iloilo, Central Philippines. M. Agr. Dev. Econ. thesis, Australian National University. 137 p.

SPSSX: Users Guide. 1983. McGraw Hill Book Co.

Tasic, R.C., Fazekas de St.Groth, C., and Angus, J.F. 1987. PHARLAP: A Cropping Systems Study on Rainfed Rice Farms in Antique Province, Philippines. Natural Resources Series No. 7. Canberra. CSIRO Division of Water and Land Resources.

Appendix 1.

Calculation of field efficiency index for land preparation for second crops.

	Tobias Fornier	Patnongon	Pandan
(A) Work requirement for land preparation (hours/ha)	150	150	150
(B) Second crop area (hours/ha)	0.3	0.4	1.0
(C) Person + carabao work required (hour) (A × B)	45	60	150
(D) Carabao density (animals/ha)	0.69	0.45	0.77
(E) Hours required for land preparation (C/D)	65	133	194
(F) Days required for land preparation (E/6 hours/day)	11	22	32
(G) Days actually spent in land preparation for second crops (from Table 1)	59	63	37
(H) Field efficiency index (%) (F/G) × 100	19	35	86

Linkage Between the Agronomic and Economic Projects

C. Fazekas de St.Groth

In this chapter on the linkage between the agronomic and economic research, the yields reported by farmers are compared with those measured in on-farm field trials conducted by researchers using the same inputs. There are two components of this comparison. One component is the difference between the researchers' yield and that of the most efficient farmer. The other component is the difference between the most efficient and the least efficient farmers. When the comparisons are made using the same inputs, yield differences reflect differences in technical efficiency. The technical efficiency of the best farmers is defined to be 100% while, in this context, the researchers' technical efficiency may be above 100%, although this could not be estimated in this project.

The reason for analysing the gap in this way, using two components, is that the most appropriate policies for improving yield will depend on where a major gap lies. If a major yield gap exists between the best farmer and the researcher working in the same environment, ways could be sought to bring the most efficient farmer's practice closer to researchers' management. Where there is a negligible gap, between the best farmers and researchers, yield improvement for the most efficient farmers may be achieved by application of new inputs, or other products of research such as new technology. If, however, a major gap exists between the most and least efficient farmers, then the solution may lie in improving extension services to the less efficient farmers. It is also possible that the spread in efficiency levels is due to a heterogeneous landscape, which manifests itself in apparent variations in technical efficiency. In this case, extension advice based on blanket recommendations is unlikely to be effective, and new approaches to technology development and transfer to farmers which recognise the field-scale variability of input responses are needed.

Data

Yield data were obtained from three different sources, viz. the economic farm surveys, the researchers' field trials on farms, and the crop-cuts taken on a farmer-managed field adjacent to each researcher-managed trial. The crop-cuts were used to assess the degree of bias in the choice of farms on which field trials took place and were also used in the agronomic analysis (Chapter 3). Since a large number of farmers could be interviewed in the economic surveys, but only a limited number of field trials could be conducted by the researchers, the number of yield estimates from the surveys was very much greater than from the trials and the accompanying crop-cuts (Table 1).

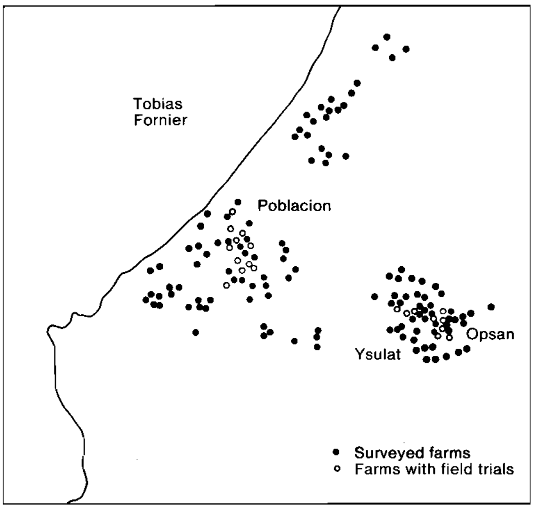
The different methods of data collection have strengths and weaknesses. The economic surveys, being random samples of all rainfed rice farmers from each municipality, have the advantage of a wide coverage of environmental as well as social conditions, but suffer from the possible weaknesses of inaccuracy and subjectivity in the form of reporting errors. The field trials and crop-cuts in farmers' fields have the advantage of accurately measuring yield but the disadvantage of a relatively poor environmental coverage and a small number of observations (trials).

Field Trials and Crop-Cuts

In making comparisons between farmers' yields and those of researchers, there are some general problems of method and measurement:

(1) Trial yields were normally assessed on farm-

sized fields, in order to avoid inflated yields which may result from excessive attention from agronomists (Davidson 1962). Those trial yields measured on plots (see Chapter 3 for details of the component-technology trials) were corrected for the 'small plot' effect using a factor calculated as the ratio of plot yield to field yield for the same inputs.



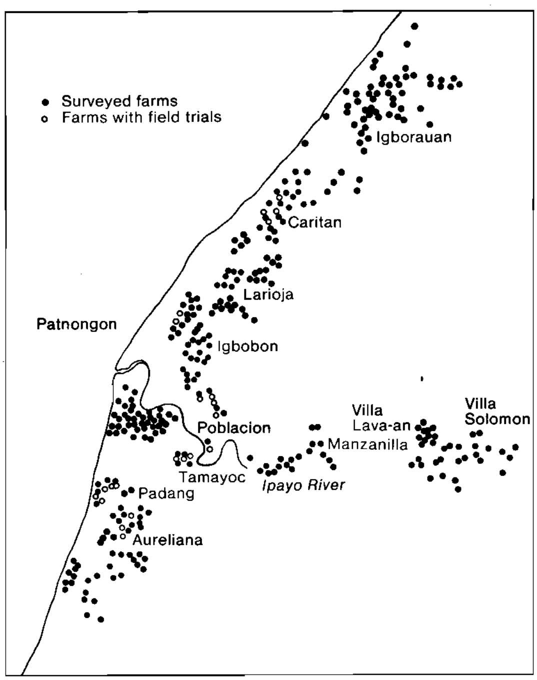


Fig. 1. Locations of surveyed farms and farms with field trials for the three municipalities: Tobias Fornier, Patnongon and Pandan.

(2) Trials may be placed in unrepresentative environments because, in general, cooperative farmers and physically accessible fields are selected for field trials. Symptoms of this problem can be identified by comparing mean yields from the surveys with those from the crop-cuts made on farmers' fields adjacent to the trials. There was a problem of this sort in Patnongon, where the surveys included a considerable number of farmers from 'remote' barangays/villages; there was also a lesser problem in Pandan (Table 2). Figure 1 shows the geographical spread of the surveyed farms and those farms on which field trials were conducted. For both Tobias Fornier and Pandan, the distributions were reasonably similar, but for Patnongon there is obvious bias in the location of trials, favouring the more accessible areas. It is likely that the yield differences between the economic surveys and the crop-cuts reflect this distribution of the agronomic field trials in Patnongon.

(3) Farmers with fields adjacent to trials may adopt practices from researchers during a project and/or compete for high yields with researchers, thus potentially biasing the comparison. It is impossible to prevent this, but researchers were asked to avoid giving advice to cooperating farmers about fields other than those on which researcher-managed trials were located. However, it was not possible to avoid the 'demonstration effect' completely.

Frontiers

Yields for the best farmers were estimated using the frontier production functions (tables 1–4,

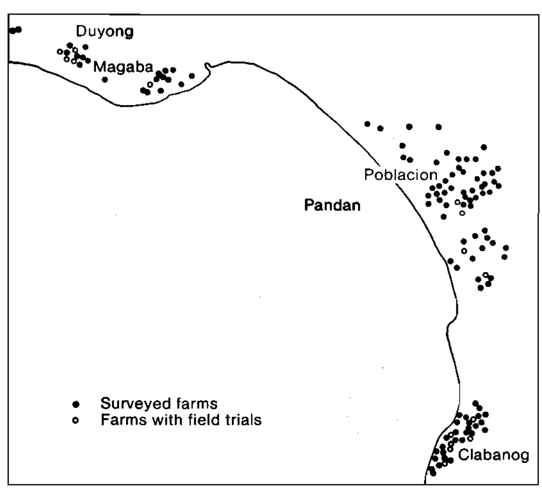


Table 1. Numbers of yield estimates.

	Tobias Fornier	Patnongon	Pandan
1984–85 First Crop			
Economic survey	125	475	135
Field trials and farm crop-cuts	14	12	10
1984–85 Second Crop			
Economic survey	54	196	152
Field trials and farm crop-cuts	4	6	11
1985–86 First Crop			
Economic survey	221	541	166
Field trials and farm crop-cuts	13	21	12
1985–86 Second Crop			
Economic survey	59	228	162
Field trials and farm crop-cuts	6	9	12

Table 2. Mean yields, in t/ha, for rice crops in three municipalities over four cropping seasons. Standard deviations are in parentheses.

	Tobias Fornier	Patnongon	Pandan
1984–85 First Crop			
Economic survey	2.4 (1.3)	1.8 (1.1)	2.2 (0.9)
Farm crop-cuts	2.6 (0.6)	3.2 (1.0)	2.8 (1.0)
1984–85 Second Crop			
Economic survey	2.1 (1.0)	1.6 (1.0)	2.1 (1.0)
Farm crop-cuts	0.6 (0.3)	1.5 (0.8)	3.1 (0.7)
1985–86 First Crop			
Economic survey	2.8 (1.2)	2.4 (0.9)	2.4 (1.3)
Farm crop-cuts	4.0 (0.9)	4.8 (1.1)	3.3 (0.7)
1985–86 Second Crop			
Economic survey	2.2 (1.2)	2.1 (1.0)	2.4 (0.9)
Farm crop-cuts	1.9 (1.1)	2.5 (1.0)	3.0 (0.7)

Chapter 4). There were 12 frontiers (three locations by two seasons by 2 years). No frontiers were used in these comparisons for the first crop of 1986 (table 5, Chapter 4) since there were no agronomic trials in this season. Values for each variable listed in tables 1–4, Chapter 4, were substituted in the frontier equations. The frontier yield estimate for the best farmer in a particular municipality and season is given by:

$$\exp\left(\alpha + \sum_{i=1}^{4} \beta_i \ln x_i + \beta_5 x_5 + \beta_6 x_6\right)$$

where α and $\beta_1 \ldots \beta_6$ are the parameter estimates given in tables 1–4, Chapter 4, and $x_1, \ldots x_6$ are the values of the variables and the dummy variables, as below. These values were chosen to be the same as those used in the agronomic trials.

Variable		Values used for frontier estimates
x_1 Field area	:	1 ha
x_2 Preharvest labour	:	250 personhours
x_3 Fertiliser cost	:	₱770, the cost of 70 kg N
x_4 Other expenses	:	₱1000, (₱600 for seed, ₱200 for herbicide, ₱200 for insecticide)
x_5 Barangay (location) x_6 Soil Fertility	:	these are dummy variables taking the values 0 or 1 for each surveyed field

The yield comparisons were made by season and municipality. For the agronomic trials, a mean yield was calculated for each season and municipality, using all researcher-managed trials where 70 kg N/ha was applied. For each frontier, the estimate of the best farmer's yield was calculated using the variables field area, preharvest labour, fertiliser cost and other expenses at the values shown above. The calculation of a single frontier estimate for each municipality and season was less straightforward because of the dummy variables. Four combinations of the dummy variables are possible, thus leading to four frontier yield estimates for each season and municipality. Rather than taking a simple mean, a weighted mean was calculated using the distributions of the dummy variables for each season and municipality. This gives a more realistic estimate for comparison with the agronomic trial means. The labour variable was not actually measured in the agronomic trials, so a 'reasonable' value, above the survey means and consistent with values in the literature, was used.

Results and Discussions

Yield estimates for the best farmers were evaluated for the frontier production functions at the 70 kg/ha level of N application but without P or K fertiliser (Table 3). The reason for excluding P and K from consideration at this stage was that both nutrients were generally unavailable to farmers. In addition, the fertiliser cost variable in the frontiers was based mainly on N and did not distinguish between nitrogen and other fertilisers. No substantial differences were found between yield means for the researcher-managed trials and those of the best farmers at the N70 level for Tobias Fornier or Pandan (Table 3). Patnongon was not included in the comparisons because of the incompatibility in site location between the agronomic field trials and the economic surveys. Since farmers' and researchers' yields at the N70 level were similar, there is nothing to be gained by attempting to bring farmer practices closer to those of researchers. The option remains for farmers to add new inputs. Table 3 also shows the field trial yield levels obtained by adding 30 kg P/ha and 30 kg K/ha, that is, the full recommendation used by the researchers. It was only in Pandan, the wettest municipality with almost 100% of farmers practicing double-cropping, that substantial gains were obtained by adding these fertilisers.

Although the best farmers' and researchers' yields at the N70 level of inputs were not substantially different, it was shown in Chapter 4 that the variability in farm yields for given inputs (i.e. technical efficiency) was considerable. Therefore, the possibility exists to bring less efficient farmers up to the yield levels of the best farmers and researchers. Factors which could raise technical efficiency were discussed in Chapter 4.

For the wetter environments such as Pandan, farmers at all levels of efficiency can increase their yields by adding P and K. In Tobias Fornier, additional inputs of P and K were not justified. Thus, for the best farmers in this municipality, there is only one yield-increasing option which is to add new inputs. Two other additional inputs, Zn and S, were shown to be effective in some areas throughout each of the three municipalities (Chapter 3). For the less efficient farmers two options exist. They can add P and K (for the wetter environments) or Zn or S, or they can improve their technical efficiency at their existing level of inputs. Combinations of these two strategies are clearly also possible.

Table 3. Frontier estimates and researchers' mean yields, in t/ha, for rice crops in two municipalities over four cropping seasons. Standard deviations are in parentheses.

	Tobias Fornier	Pandan
1984–85 First Crop		
Researcher (N70)	2.4 (0.6)	2.6 (1.0)
Researcher (70/30/30)	2.4 (0.6)	2.8 (0.8)
Frontier (N70)	2.5	2.5
1984–85 Second Crop		
Researcher (N70)	1.6 (0.7)	3.0 (0.8)
Researcher (70/30/30)	1.7 (0.6)	3.2 (0.7)
Frontier (N70)	2.9	2.7
1985–86 First Crop		
Researcher (N70)	4.4 (0.8)	3.3 (1.1)
Researcher (70/30/30)	4.8 (1.0)	4.4 (1.1)
Frontier (N70)	4.6	2.6
1985–86 Second Crop		
Researcher (N70)	1.7 (1.0)	3.2 (0.5)
Researcher (70/30/30)	2.0 (1.1)	3.9 (0.8)
Frontier (N70)	2.7	3.3

Note: In Tobias Fornier, for both second crops, the researchers' yields were lower than the estimates of best farmers' yields because a greater proportion of the farmers included in the agronomic field trials grew a second crop than is usual in Tobias Fornier and some of these farmers established their crops late. In the economic surveys, only those farmers who found it profitable to double crop were included in the frontier estimates.
No standard errors are available for the frontiers.

Conclusions

Within the scope of the fertiliser inputs included in the economic survey data, farmers at all levels of efficiency in the wetter environments can substantially improve yields by adding P and K. Imparting this information through extension activity and otherwise assisting in making these inputs available from commercial suppliers would seem to be a priority.

In the absence of P and K, the best farmers are obtaining yields equivalent to those obtained by researchers. Therefore, extension advice should aim to bring the yields of the less efficient farmers closer to those of the most efficient farmers for given input levels.

References

Davidson, Bruce. 1962. Crop yields in experiments and on farms. Nature, 194, 458–459.

Tasic, R.C., Fazekas de St.Groth, C., and Angus, J.F. 1987. PHARLAP: A Cropping Systems Study on Rainfed Rice Farms in Antique Province, Philippines. Natural Resources Series No. 7. Canberra. CSIRO Division of Water and Land Resources.

CHAPTER NINE

Conclusions

At the time these projects were conceived, field research on rice in the Philippines had been mostly conducted on well irrigated lands, and the limited research on rainfed land had been concentrated at the fringes of irrigation areas. This was not surprising since modern technology for rice production was developed under the controlled conditions of experiment stations. The Department of Agriculture in the Philippines recognised that many farmers did not enjoy the benefits of assured irrigation and produced under relatively unfavourable conditions of partial irrigation, or more typically under rainfed conditions. At that time, therefore, there was a paucity of information on the performance of modern rice technology under less favourable conditions, i.e. on how modern technology performed and to what extent farmers benefited economically from its use.

A prime objective of the projects was to study complex farming systems located in less favourable production environments. The chosen sites for the study in Antique Province fulfilled the environmental requirements as they largely comprised rainfed lowlands and some uplands, with varying agroclimatic characteristics. The second characteristic, complex farming systems, was not met. Within the cropping component, rice was not only dominant, but often the only crop of any significance. For the typical farm, the rice cultivation activity was the main means of securing subsistence rice requirements, while noncrop and nonfarm sources provided the bulk of cash incomes. Agronomic research (Chapter 3) indicated little potential for growing more upland crops because of soil constraints, so it is unlikely that a major boost to farm incomes will come in the forseeable future from extensive cultivation of upland crops in a rice-based cropping pattern. Most lowland landowners and tenants farm no upland crops so the potential for upland crop cultivation is confined to subsidiary crops before or after rice. The main conclusions are addressed to rice production.

In order to analyse performance within individual crop seasons, a stochastic frontier production function 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 five seasons surveyed, and in all locations.

A number of variables which were important determinants of technical efficiency were identified. Many have not been detected previously, although their influence had long been suspected. Most important of these was a range of variables which can be collectively described as crop management practice or management decision variables. Amongst these, timeliness of operations stood out as being critical to best practice, or frontier performance, within a crop season. 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 all three locations, but particularly in Tobias Fornier and Patnongon where growing-season durations are shorter. It was also shown that allocative efficiencies (the second component of overall economic performance) were dependent upon technical efficiencies. Therefore, raising technical efficiency has both a direct and indirect positive influence on economic performance.

The simulation study confirmed the importance of timeliness for growing two rice crops in much of Antique. The simulation study was extended by testing a double rice cropping system with long-term weather data from throughout the Philippines. It showed that the importance of timeliness extended to much of the area of the central Philippines where Antique is located. However, for the northern Philippines, the simulations did not indicate that more timely farm operations would normally lead to a successful extension of double cropping. It appeared that the potential saving of time would not usually compensate for the constraint of the brief growing season. However, for the generally longer growing seasons in the southern Philippines, the simulations suggested that double cropping was normally safe and that timely farm operations were not so critical.

The agronomic field trials showed the importance of fertiliser in terms of yield potential. Raising technical efficiency requires a better definition and knowledge of best practice technology. The agronomic analyses provided insights into the profitability of broad recommendations for the province, of components of these recommendations and of previously unrecognised, location-specific nutrient requirements. For the first season crop, it was found that the full recommendation (herbicide plus N, P and K fertiliser), was consistently profitable on 75% of farms.

The farm surveys indicated widespread adoption of herbicide and N, but that few farmers used P or K, and then at low rates. When the components of the recommendation were examined singly, it was found that 35 kg of N fertiliser per hectare was the most reliably profitable component of the recommendation. Economic returns to P fertiliser application were relatively unreliable in all areas. The profitability of K fertiliser was relatively reliable in Tobias Fornier and Pandan but unreliable in Patnongon. Use of zinc was generally reliable in both seasons in the three study areas. The economic returns to fertiliser inputs for the second crop were less reliable than for the first crop owing to water stress.

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. At comparable input levels, yield estimates were obtained from both the frontiers and field trials. These estimates indicated that farmers at the frontier were obtaining yields close to those of researchers. In some locations, the field trials indicated that additional inputs could raise farmers' yields.

The conclusions arising from the agronomic and economic analyses of the field trials fell into: (i) a set of conventional recommendations for practices which had not been adopted at the time of the study; (ii) the need for vigilance with nutrient deficiencies in other areas; and (iii) a more general conclusion on a research and extension strategy for variable responses.

Conventional recommendations

1. Apply potassium to both rice crops in northern Antique.
2. Apply zinc to first rice crops throughout Antique.
3. Apply sulfur to first rice crops growing on red soils.
4. Do not apply nitrogen to second rice crops in central and southern Antique.

All of these represent departures from existing practices and blanket recommendations for Antique Province. They represent fine tuning of the technology for local conditions which has been lacking in the past.

Vigilance with Nutrient Deficiencies

It is possible that the nutrient deficiencies found in Antique are unique to soils derived from the ultrabasic rocks in the area, or it may be that other areas with high rainfall and coarse-textured and readily leachable soils may be subject to similar deficiencies. The increased production associated with both relatively high inputs of nitrogen fertiliser and increased intensification of cropping may be placing demands on the supply of nutrients from the soil which cannot be sustained. The deficiencies found in the Antique soils may be a warning of deficiencies which may arise in other areas which currently appear fertile.

The national significance of the deficiencies of P, K, Zn and S in Antique is that it raises the question as to whether there are other areas with undiagnosed deficiencies of the nutrients studied here and possibly of other nutrients. The significance of the patchy deficiencies is that it may not be possible to identify such deficiencies from a small number of field experiments.

Strategies for Correcting Variable Deficiencies

A fruitful line of future investigation would be to search for other areas with similar patterns of nutrient deficiencies. Possible candidates are areas with intensive cropping practices, locations remote from sources of fertiliser, and those with coarse-textured or heavily leached soils.

The patchiness of the deficiencies also deserves further research. There appears to be little published data on the magnitude of between-field variability in responses to nutrients, and there is no convincing explanation for the variability. One theory is that much of the land has marginal levels of available nutrients, and variability has been exaggerated by withdrawals of nutrients by different cropping intensities and application of different amounts of nitrogen fertiliser. Another speculation on the reasons for the variability is a transfer of nutrients from field to field by the day-night system of animal tethering.

The system of supplying blanket extension advice is called into question by the patchy responses. Although the nitrogen responses were reliable and the blanket recommendation for nitrogen fertiliser is justified, the responses to the other nutrients were probably not sufficiently reliable to justify blanket recommendations. It is not known what level of reliability is needed for a blanket recommendation to be generally accepted by farmers.

Strategic research aimed at understanding the patchy nutritional status of these soils may eventually lead to methods of predicting which fields will be most deficient. Meanwhile, it is suggested that extension workers cooperate with farmers to establish systems of strip trials, that is, small portions of many farm fields on which suspected deficiencies are tested, so that farmers can see for themselves whether a particular treatment is justified.

The change in extension methods implied by this suggestion will require that farmers develop greater understanding of the factors affecting production on their own land and in their immediate district. It has been suggested that such changes are needed generally in post-Green Revolution agriculture, since the gains in production from blanket recommendations, at least for rice in Asia, may be diminishing.

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, Phillipines, 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.