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*** (1.3549)	4.0273*** (0.4636)	5.3629*** (0.6357)
β_1	Preharvest labour	Personhours	0.1487^{ns} (0.2134)	0.2859*** (0.0760)	0.1718* (0.1089)
β_2	Fertiliser cost	₱	0.1635^{ns} (0.1677)	0.3803*** (0.0575)	0.2708*** (0.0770)
β_3	Field area	ha	0.7185*** (0.2234)	0.4034*** (0.0776)	0.5913*** (0.0878)
β_4	Soil fertility	Dummy	0.7331** (0.3198)	—	0.1253** (0.0650)
β_5	Barangay	Dummy	—	-0.2977*** (0.0964)	-0.1782*** (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*** (0.7994)	5.4469*** (0.6355)	4.4663*** (0.6530)
β_1	Preharvest labour	Personhours	0.1326^{ns} (0.1101)	—	0.3608*** (0.1269)
β_2	Fertiliser cost	₱	0.4444*** (0.1168)	0.3491*** (0.1019)	0.3107*** (0.0738)
β_3	Field area	ha	0.5058*** (0.1334)	0.4668*** (0.1519)	0.4728*** (0.1116)
β_4	Soil fertility	Dummy	0.2536^{ns} (0.1895)	—	0.2221* (0.1177)
β_5	Barangay	Dummy	—	0.2407* (0.1316)	-0.1252^{ns} (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
$\bar{R}^2 = 0.32$		Farm size	–	1
		Rate of interest	–	1
		Full-time farming of household head	–	5
Second	1984–85	Technical efficiency	+	1
		(Technical efficiency)^2	–	1
$\bar{R}^2 = 0.30$		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
$\bar{R}^2 = 0.21$		Total income from last season	+	5
First	1986–87	Technical efficiency	–	1
		(Technical efficiency)^2	+	1
$\bar{R}^2 = 0.87$		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.

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CHAPTER FIVE

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

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* 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.

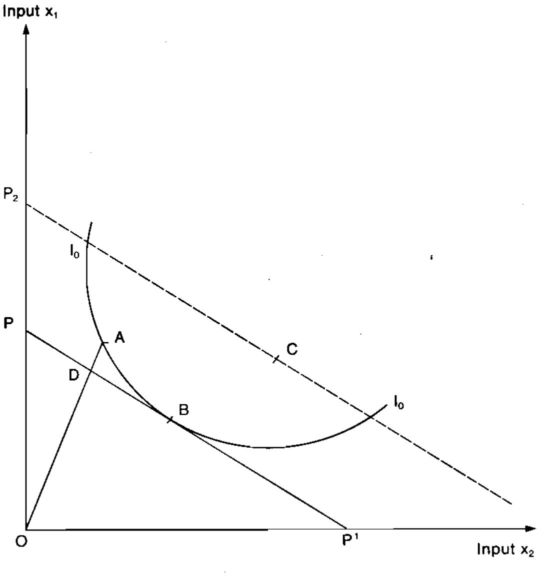

Fig. 1. Farrell's concepts of technical and allocative efficiencies.

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

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* 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.

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:†

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

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

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

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.

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

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

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:

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

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) $\gamma = \dfrac{\sigma_u^2}{\sigma_u^2 + \sigma_v^2}$ 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 extreme situations, input costs may exceed output value and negative profits result. Hence allocative efficiency can vary between a negative real number and 100%.

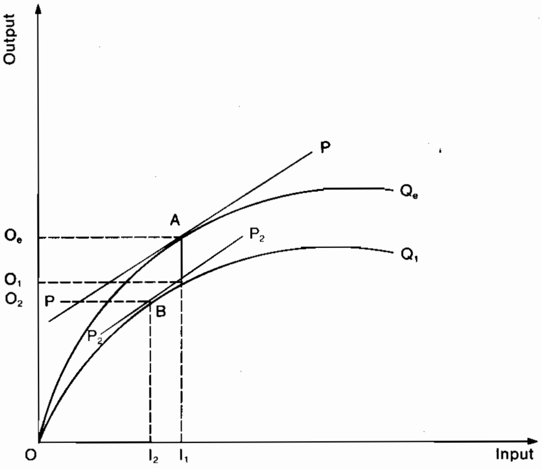

Fig. 2. Field-specific technical, allocative and economic efficiencies.

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.

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CHAPTER SIX

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

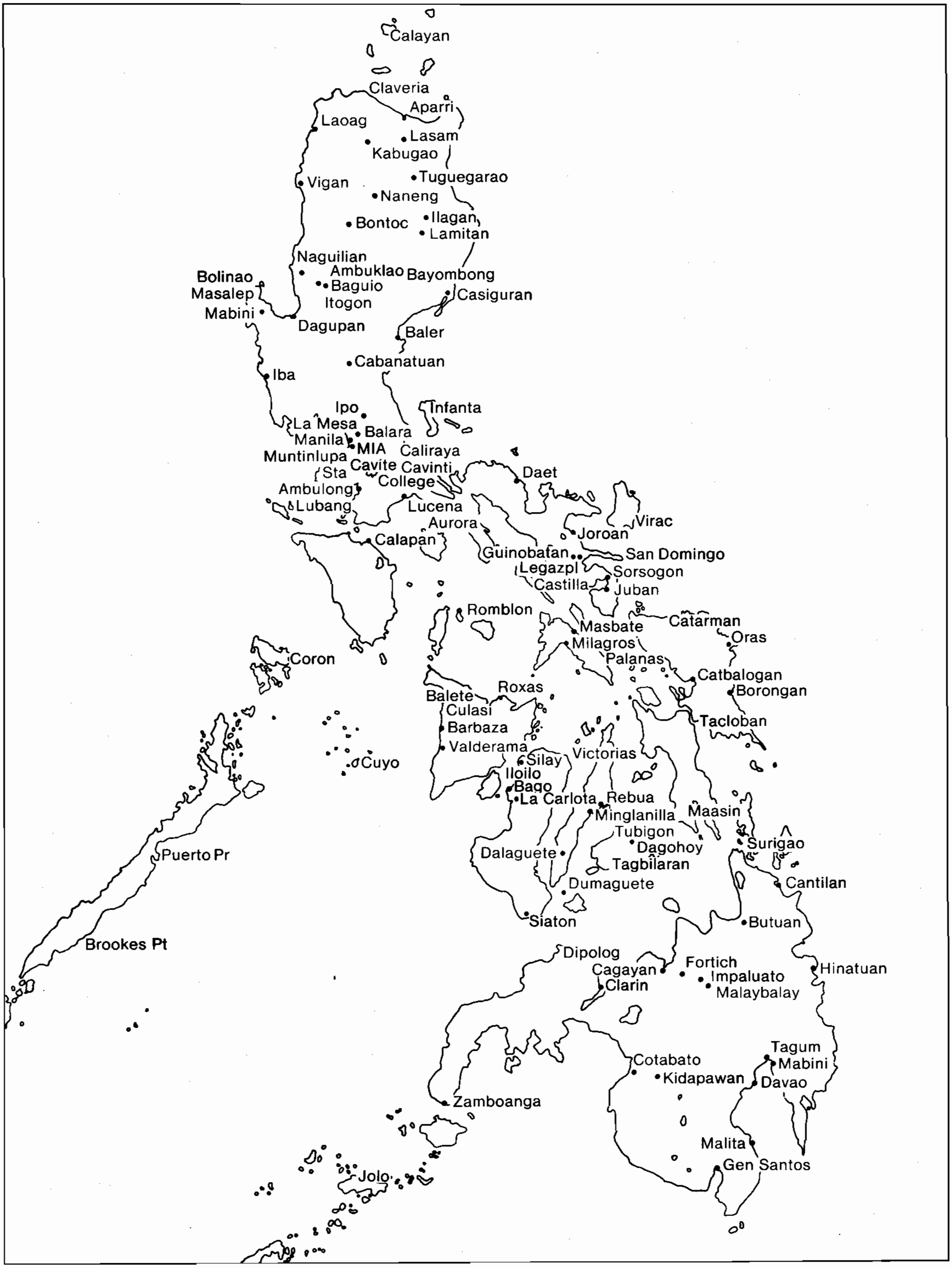

Fig. 1. Locations of the rainfall stations in the Philippines used in the simulation studies.

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.

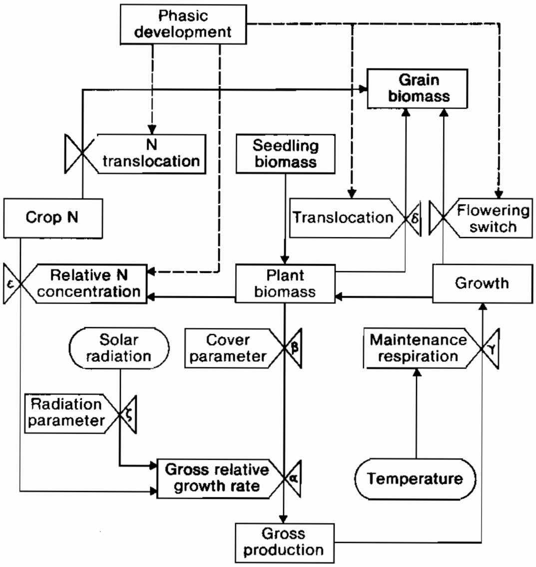

Fig. 2. Flow chart of the simulation model of rice growth and development. Solid lines depict flows of mass and dotted lines flows of information. The Greek letters refer to parameters discussed in the text.

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:

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

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:

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

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:

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

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:

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

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:

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

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:

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

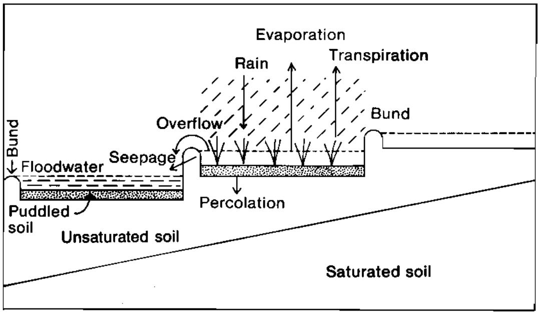

Fig. 3. Cross-section of a toposequence of bunded fields, showing components of the water balance.

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

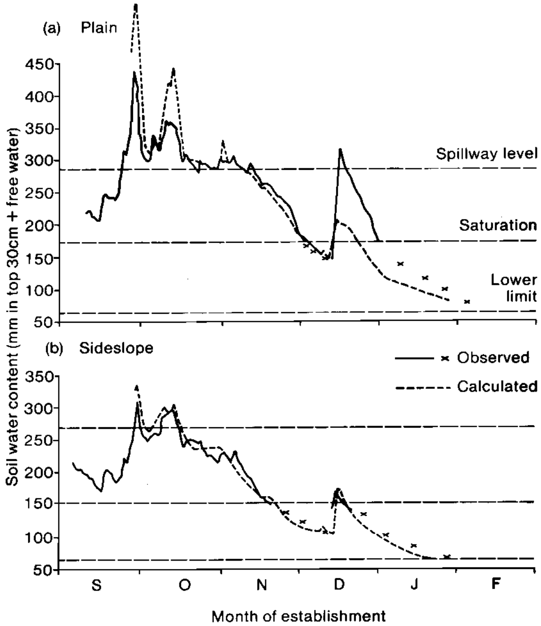

Fig. 4. Fit of the water balance model (dashed lines) to observations of soil water and standing water (solid lines and crosses) for two rainfed rice fields in Tigbauan, Iloilo. (a) plain position, (b) sideslope position. Observations are those of Bolton (1980).

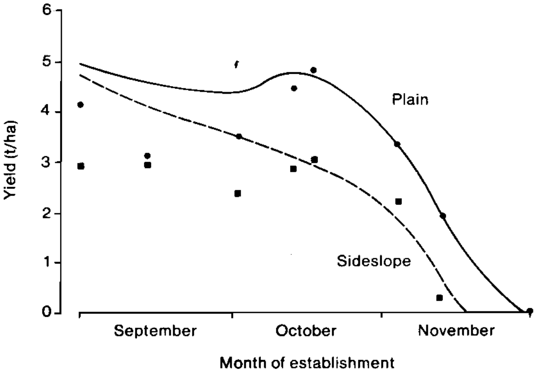

Fig. 5. Fit of the simulated yields to observations for the time-of-establishment experiment of Bolton (1980). The points represent measurements and the lines simulated yields.

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.

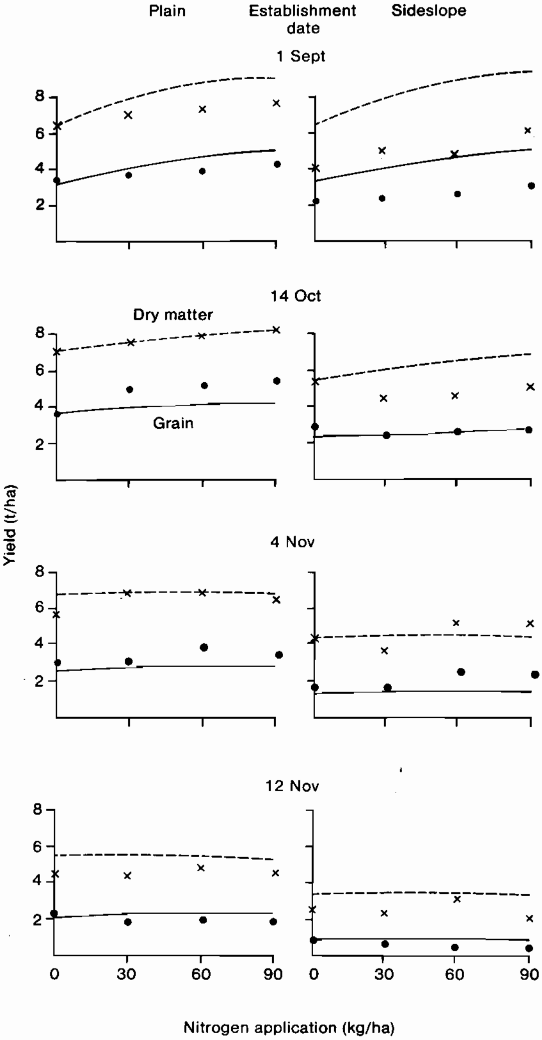

Fig. 6. Fit of simulated yields to observations of yield responses to applied nitrogen at four times of crop establishment.

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

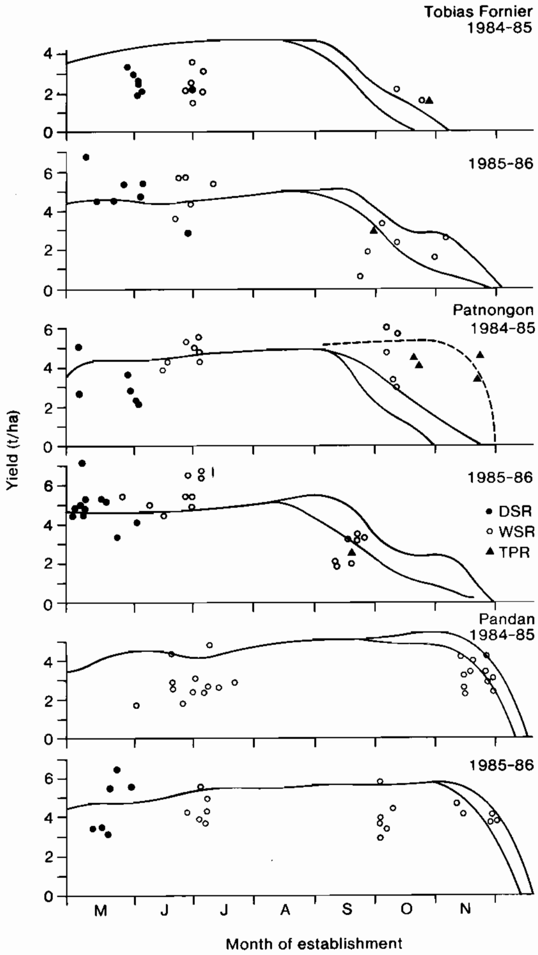

Fig. 7. Tests of the simulation model against researcher-managed yields in three locations in Antique over two years. The points refer to measured yields of crops established at different times and by different methods and the lines refer to simulated yields for plain (upper line), plateau (lower line)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

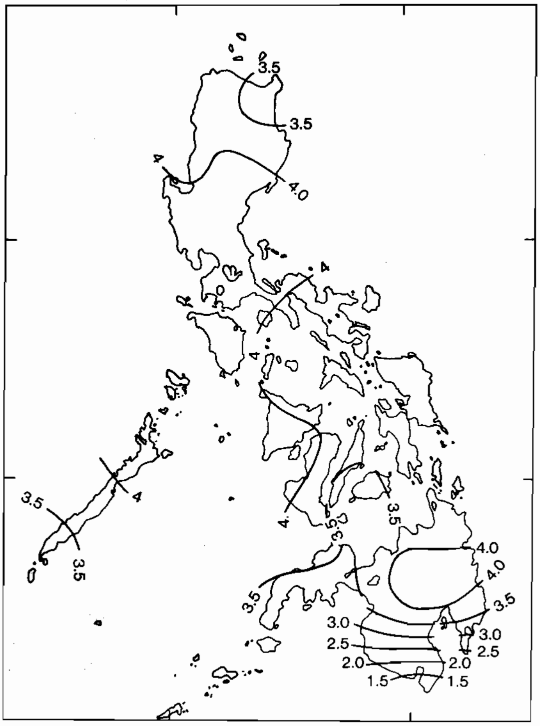

Fig. 8. Simulated yields (t/ha) of a single wet-seeded rice crop growing on a rainfed plain, based on simulations using weather data for 103 locations.

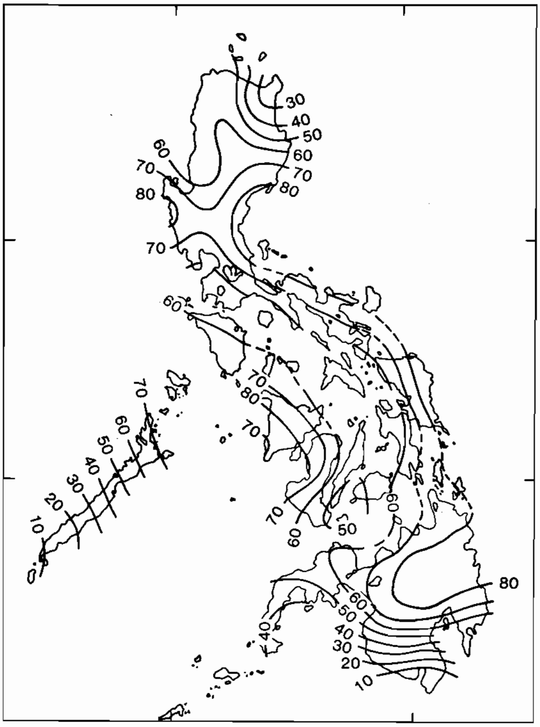

Fig. 9. Percentage of years when the model simulated two wet-seeded rice crops growing on a rainfed plain with a turnaround period of 30 days, based on simulations using weather data for 103 locations.

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
          -----------------------------------------------------
```

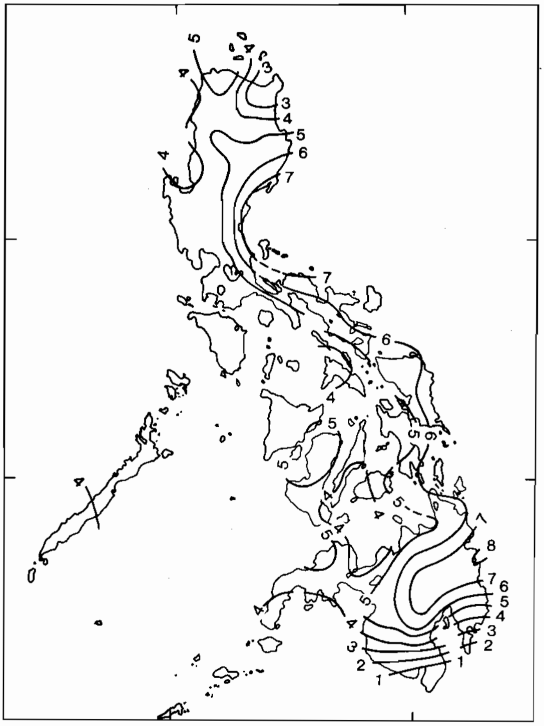

Fig. 10. Simulated yields (t/ha) of two wet-seeded rice crops growing in sequence on a rainfed plain with a turnaround period of 30 days, based on simulations using weather data for 103 locations.

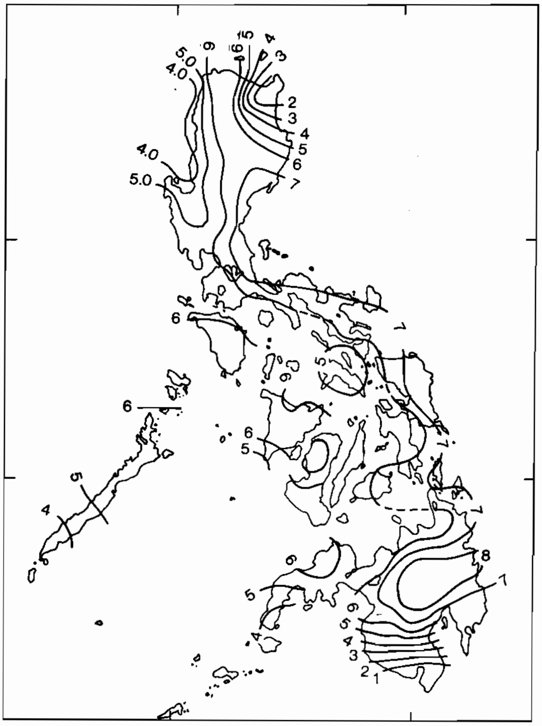

Fig. 11. Simulated yields (t/ha) of two wet-seeded rice crops growing in sequence on a rainfed plain with a turnaround period of 10 days, based on simulations using weather data for 103 locations.

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

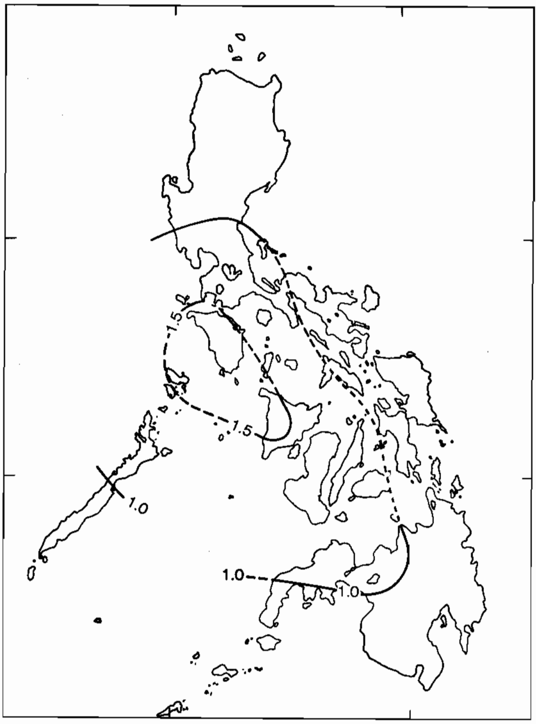

Fig. 12. The yield advantage (t/ha) of rapid turnaround (10 days versus 30 days) for a double wet-seeded cropping pattern.

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.

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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

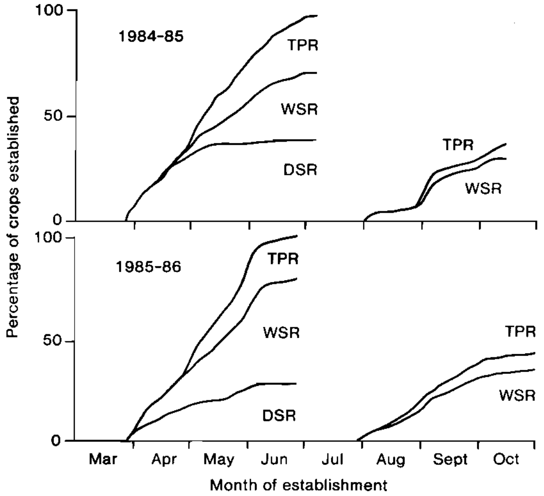

Fig. 1. Cumulative percentage of rice crops established in Patnongon during two growing seasons, as determined from the farm surveys.

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.

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* 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).

	Tobias Fornier			Patnongon			Pandan		
	Number of carabaos per farm								
Barangay location	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.

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

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:

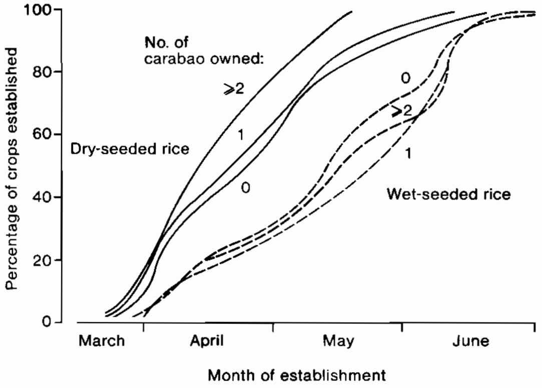

Fig. 2. Cumulative percentage of first crops established in relation to number of carabaos owned by farmers.

	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

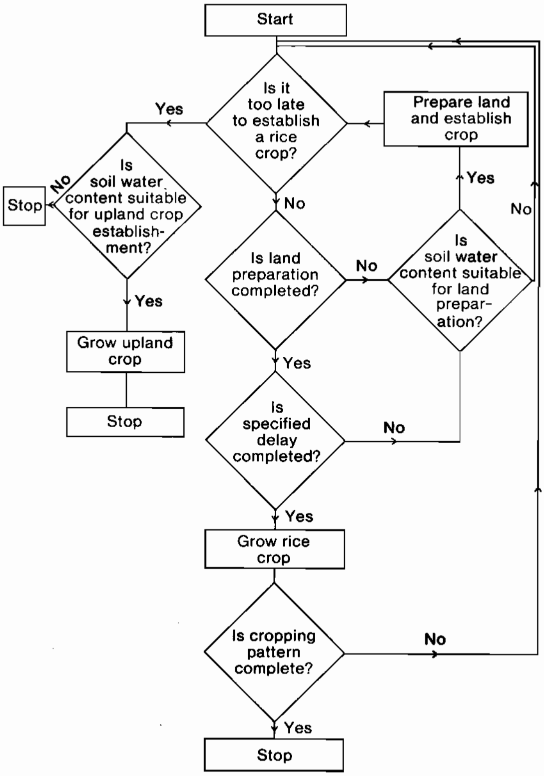

Fig. 3. Decision rules used in simulating land preparation and crop establishment in a multiple cropping system.

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.

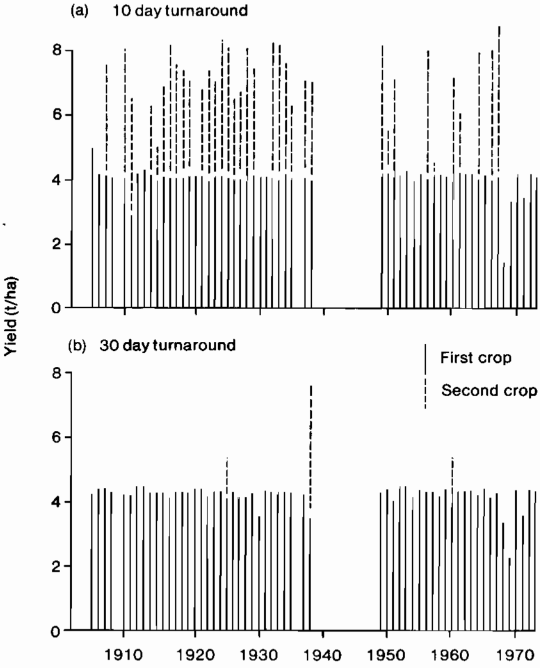

Fig. 4 Simulated yields over 58 years of weather data for Iloilo City for WSR grown when possible as two crops in sequence on a sideslope position, for turnaround periods of (a) 10 days (b) 30 days.

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,

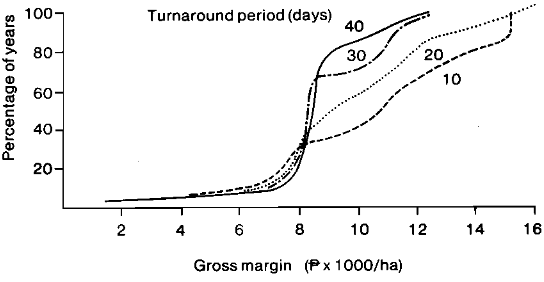

Fig. 5 Cumulative distribution of gross margins for two simulated WSR crops grown in sequence for four different turnaround periods.

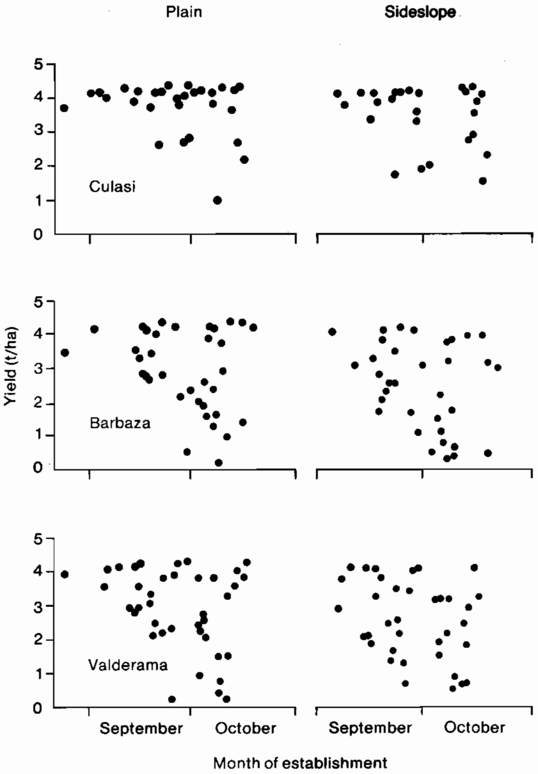

Fig. 6 Simulated yields of second WSR crops for three Antique locations in relation to the date of establishment for landscape positions of plain and sideslope.

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.

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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

CHAPTER EIGHT

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-

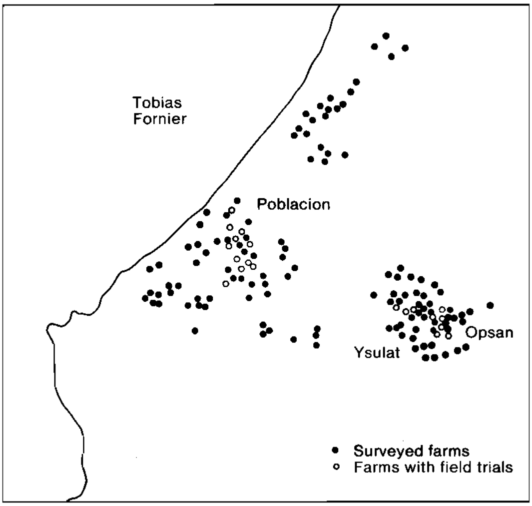
sized fields, in order to avoid inflated yields which may result from excessive attention from agronomists (Davidson 1962). Those trial yields measured on plots (see Chapter 3 for details of the component-technology trials) were corrected for the 'small plot' effect using a factor calculated as the ratio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

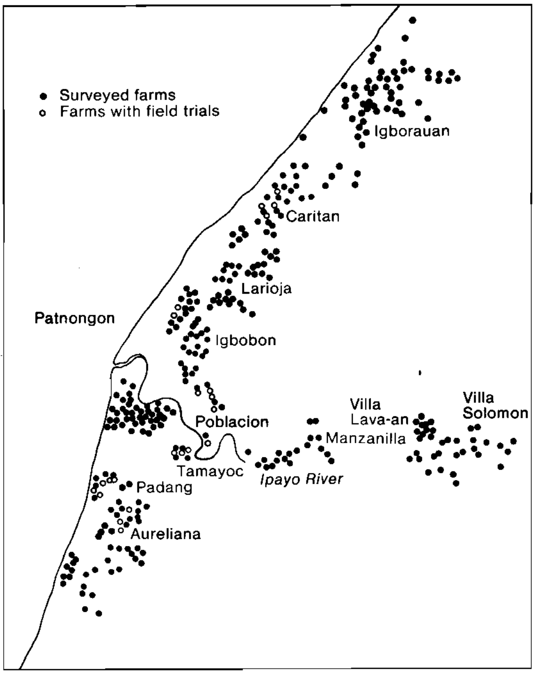
(2) Trials may be placed in unrepresentative environments because, in general, cooperative farmers and physically accessible fields are selected for field trials. Symptoms of this problem can be identified by comparing mean yields from the surveys with those from the crop-cuts made on farmers' fields 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,





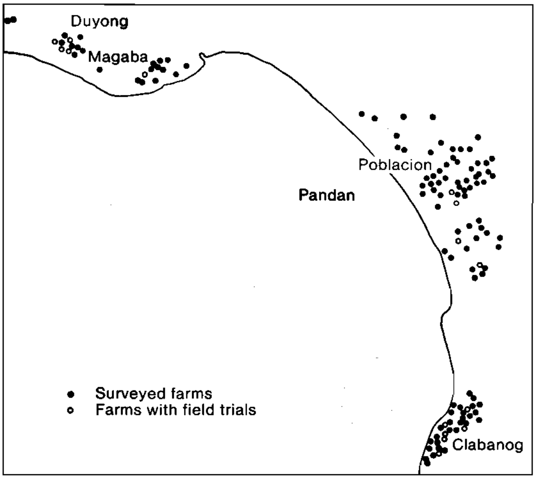


Fig. 1. Locations of surveyed farms and farms with field trials for the three municipalities: Tobias Fornier, Patnongon and Pandan.

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.

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.

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.

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.

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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.

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