PN-AAC-450
ISN 61209

IRRI RESEARCH PAPER SERIES
Number 28 May 1979

Agency for International Development
Library
Room 106 SA-18
Washington, D.C. 20523
FEB 24 1982

MEASURING THE ECONOMIC BENEFITS OF NEW TECHNOLOGIES TO SMALL RICE FARMERS

C. BARLOW, S. JAYASURIA, V. CORDOVA, N. ROXAS, L. YAMBAO, C. BANTILAN, and C. MARANAN

The International Rice Research Institute
P.O. Box 933, Manila, Philippines

PN-AAC-650

MEASURING THE ECONOMIC BENEFITS OF NEW TECHNOLOGIES TO SMALL RICE FARMERS[1/]

ABSTRACT

Costs and returns analysis is a good method for comparison of the economic impact of new cropping technologies at the field level. It suffers from several disadvantages, however, the most notable being that the major resources of land, labor, and capital are valued without reference to the actual supply-demand position within the farm. This error may lead to seriously distorted comparisons being made between different technologies.

In this report *whole-farm analysis* is presented as a system of *ex ante* assessment which can usefully qualify the results of costs and returns analysis. Such analysis measures the economic benefits of both new and historical cropping technologies in the context of *all* the farmers' economic activities, including his other agricultural enterprises and his household and off-farm operations. The major resources of land, labor, and capital are all valued with due regard to their actual availability, and to the demand which exists for them at a particular time. Linear programming, a widely used form of mathematical modeling, can be used as a technique for whole-farm analysis. The modeling procedure chooses a selection of technologies, which maximizes the overall money surplus over cash costs for each situation treated, subject to the major constraints of land, labor, and capital. This selection of technologies is known as an *optimal solution*. By assessing each technology according to its effect on the overall cash surplus, the modeling procedure simulates the decision-making process of the farmer and looks at the economic impact on the whole farm of any new technologies that he might wish to adopt.

Linear programming is applied to the cases of two selected farmers, one *quite poor* and the other *quite rich*, in the barrio of Lamot, west of Iloilo. The basic linear programming model used in the study is presented and the information needed to build the model for each of the case study farmers is detailed. The basic structure is considered useful for modeling small rice farms in many countries of the region.

The economic impacts on the farmer of dry-seeded, wet-seeded, and transplanted IR36 as a first crop are examined in some detail, and the assessment of the cultivation technologies by the model is compared with that by cost and returns analysis. It is concluded that the model gives better assessments in a given farm situation, and that it highlights complementarities between the different technologies where the technologies use labor at different times.

The application of whole-farm analysis to a range of resource situations pertinent to wide geographical areas is discussed, and some useful modifications of procedures used in the present study are suggested. Whole-farm analysis is a methodology that can help research workers at central research institutes in identifying technologies likely to be most valuable, and in tailoring these technologies to farmers' practical situations. Whole-farm analysis is judged to be complementary to simpler methods of economic assessment, notably costs and returns analysis.

[1/] By Colin Barlow, visiting agricultural economist, Sisira Jayasuriya, postdoctoral fellow, Violeta Cordova, senior research assistant, Nicanor Roxas, research assistant, Leonida Yambao, Cresencia Bantilan, and Constancia Maranan, research aides, The International Rice Research Institute, Los Baños, Laguna, Philippines.
Submitted to the IRRI Research Paper Series Committee March 1979.

MEASURING THE ECONOMIC BENEFITS OF NEW TECHNOLOGIES TO SMALL RICE FARMERS

A prime concern of agricultural research in South and Southeast Asia is the development of useful technology for small rice farmers -- better varieties of rice and associated crops, better livestock, better cropping patterns, and improved methods of crop and livestock husbandry. Essential to technology development is measurement of its economic benefits to farmers. Such measurement identifies technologies that should be promoted by extension workers, or guides research workers toward better tailoring of new technologies to practical farm circumstances and applications. Measurement of economic benefits can also identify areas where more new technologies are economically significant.

COSTS AND RETURNS ANALYSIS

The most common method of determining the economic impact of a new technology is costs and returns analysis. In its traditional form, which is used by the International Rice Research Institute (IRRI), the method measures the benefit of a technology as a net return (outlined in Table 1). The gross returns and total variable costs are usually determined for each hectare and with average market prices. Overhead inputs, such as land and capital, are ignored in the calculation. The physical outputs and inputs are typically averages, derived from field experiments or recorded farm performances in a range of situations.

A concrete example of traditional costs and returns analysis is given in Table 2. The net returns from the first and second rice crops in Iloilo province are compared, using the alternatives of wet seeding or transplanting. The figures are averages from many farm plots. The major inputs of land, cash, and animal power are all omitted, with an implicit cost of zero. Net returns per hectare are calculated, and returns are also determined per hour of labor and per dollar (US$) of material costs. Other illustrations of costs and returns analysis are given in various specialist reports assessing the economic benefits from different crops on particular sites; for example, see Garrity (1976).

Essentially all costs and returns analysis of the kind described can be categorized as *partial analysis*. The farm is viewed as a superstructure of enterprises, resting on a *foundation* comprising basic resources of land, fixed capital, and entrepreneurship and, perhaps, even working capital (cash), family labor, and animal power. It is assumed that enterprises can be varied within broad limits without affecting the costs of basic resources, which can thus be omitted from the budgeting calculations. The partial analysis calculations attempt to measure the *extra* return and the *extra* (variable) costs incurred by enterprises using new technologies. The average costs and returns analysis ignores variability of outcomes; however, the technique can be modified to incorporate considerations of risk and uncertainty. Furthermore, the computation of returns to scarce resources and the use of judgmentally derived *shadow prices* for the basic resources can supplement the measurement of benefits from net returns. These various improvements to costs and returns analysis are more fully discussed by Anderson (1976) and by Perrin et al (1976).

Costs and returns analysis will continue to be the most widely used first approach in economic assessment of new technologies. It gives field workers a good initial guide to the benefits of the technologies, even without sophisticated computing facilities. It is particularly suitable when analyzing and comparing the relative benefits of directly substitutable component technologies -- different fertilizers, pesticides, seed varieties, etc -- when such substitutions involve only minor changes in resource use.

The limitations of costs and returns analysis can become important, however, when the technologies being considered involve major changes in resource use. For example, in the technologies of an early- and a late-maturing rice variety the late-maturing variety uses land for a greater period, and its peak labor requirements for harvesting and threshing are correspondingly delayed. When such technology is evaluated, the interactions between its activities and the farm household resource base need to be more explicitly considered. The relevant *price* or *cost* of the farmer's inputs and outputs will depend on their actual demand-supply position within the farm household. When the new technologies involve substantial changes in prices use of overall average (or zero) prices will lead to major inaccuracies.

Appendix A outlines the pricing of inputs and outputs in two situations. In one an active commercial market exists for inputs and outputs and current market prices can be applied. In the other situation, no active commercial market exists and the principle of *opportunity cost* must be employed. The market prices of some of the farmer's major resources usually do not reflect their real scarcity value to him. Thus, during the slack period family labor may be relatively abundant, but at peak periods it would be more scarce in terms of the demands for it. Similarly cash, family labor, animal time, and land will have different values at different times.

As mentioned earlier, average costs and returns analysis is sometimes refined by using judgmentally derived *shadow prices*. But when the number of farm activities and resources is large or the new technologies are likely to change the existing pattern of resource use, appropriate shadow pricing is difficult.

Costs and returns analysis does not provide an indication of how the farmer's resources should be allocated between different types of activities. These and other limitations of partial analysis become important when central research institutes attempt to assess the nature and possible impact of technologies that involve substantial changes in the existing farming systems.

We present a system of economic assessment that overcomes some of the limitations of costs and returns analysis and other forms of partial analysis. The system *whole-farm analysis* reviews the economic benefits of a new technology in the context of *all* the farmer's economic activities, including his other agricultural enterprises and his household and off-farm operations. Values are imputed to the major resources of land, labor, and capital available to the farmer, with due regard to the actual availability of such resources and to the demand which exists for them at a particular time.

We illustrate the whole-farm approach in measuring the economic benefits of various new cropping technologies developed for rice farmers. The technologies were developed by IRRI at an outreach site in Iloilo province, Philippines. We compare whole-farm analysis with costs and returns analysis, and give examples from the actual cases of two farmers, Mamerto Bañares and Julian Polido, in the barrio of Lamot.[2/] Each farmer represents one end of the range of resource endowments typical in the area. Bañares can be classified as *quite poor* and Polido as *quite rich*. The contrasting endowments have important effects on the choice of technology.

The need for better criteria to measure the benefits of new cropping patterns was stressed by Zandstra (1976), and the overall goals of economic analysis in relation to cropping systems were reviewed by Price (1976) and Vincent (1976). Banta (1976) discussed the basic data required to adequately describe given cropping systems, and thus to undertake a satisfactory economic analysis. Servano (1977) recounted in detail IRRI's collection at the Iloilo site of economic data on cropping systems. Norman and Palmer-Jones (1976) gave an excellent review of possible

[2/] The names of the two farmers and the village have been changed.

Table 1. An outline of costs and return analysis.

Average output x average price =	Gross return
Average labor input x average price = Labor cost	
Average animal input x average price = Animal cost	
Average seed input x average price = Seed cost	
Average fertilizer input x average price = Fertilizer cost	
Average pesticide input x average price = Pesticide cost	Total variable costs[a]
	Net return[b]

[a] Labor + animal + seed + fertilizer + pesticide costs. [b] Gross return *less* total variable costs. The costs of land and capital are ignored (see text), these inputs being effectively priced at zero.

Table 2. Costs and returns analysis of farmers' rice plots at the IRRI outreach site, Iloilo, Philippines, 1976-77

Crop, cropping pattern[a]	Plots reported (no.)	Yield (t/ha)	Costs (US$/ha)			Returns			
			Labor	Material	TVC[b]	Gross (US$/ha)	Net (US$/ha)	To labor[d] (US$/h)	To cash[e] (US$/US$)
First crop									
WSR	24	2.3	68	67	135	316	181	0.39	3.70
TPR	14	3.1	74	108	182	457	275	0.52	3.55
Second crop									
WSR	13	3.1	81	100	181	446	265	0.46	3.65
TPR	12	3.6	47	152	199	523	324	0.86	3.13

Source: International Rice Research Institute (1977).

[a] WSR = wet-seeded rice, TPR = transplanted rice. [b] Total variable costs (TVC) = labor cost + animal cost + material cost. [c] Net returns = gross return less TVC. [d] Returns to labor = $\frac{\text{Gross returns less material costs}}{\text{Labor (hours)}}$
[e] Returns to cash (spent on material inputs) = $\frac{\text{Gross returns less labor costs}}{\text{Material costs}}$

economic methodologies for assessing cropping systems, and of possible problems in collecting economic data from small farmers.

WHOLE-FARM ANALYSIS

In analyzing the impact of new technologies on the farm household, the whole-farm approach should consider the fact that the typical farmer operates with a set of resources -- land, family labor, capital -- that are limited, at least in the short run but whose levels may vary over the year. The farm may not be entirely cash oriented; it may, for example, be oriented toward meeting family food requirements. A number of sociocultural and institutional factors may impose constraints on what the farmer can do, and on what he would like to do.

Linear programming offers a technique for whole-farm analysis, which, despite certain limitations, is suitable for modeling and analyzing farms with varied characteristics. The method has been widely used in studying the optimal allocation of resources within a farm. Although its early applications focused mainly on large commercial farms in developed countries, it has increasingly been used to study semisubsistence and subsistence type farms in less-developed countries. Examples of its use in the latter context are in the works of Clayton (1975), Heyer (1972), Thodey and Repeepum Sektheera (1974), Hardaker (1975), Low (1975), Benito (1976), and Wardhani (1976). Many of these studies were hampered by the small model size dictated by the nature of the available data and available computer facilities. Adequate representation of the actual farm situation was difficult. In our study, the availability of appropriate data and access to adequate computer facilities helped overcome that limitation. A number of handy package programs are available for carrying out linear programming analysis. We used the IBM MPSX-370 program for most of the analysis. A simple but comprehensive explanation of the use of the linear programming technique in an agricultural setting is given by Heady and Candier (1958).

Essentially linear programming is a formal mathematical technique that selects the combination (and the levels) of activities from the set of all feasible activities so that a specified objective function, usually the cash surplus, is maximized without violating the resource and any other specified constraints. Formally, in matrix notation, the problem is usually presented as,

$$\text{Max } S = cx$$
$$\text{subject to } Px \leqslant S$$
$$\text{and } x \geqslant 0$$

where c is a row vector of surpluses from unit levels of the set of activities available to the farm (a surplus defined as a return over all cash costs), x is a column vector of the number of unit levels of the set of activities, P is a matrix of coefficients representing the amount of restricted resources (or inputs) used by the unit levels of the activities; and S is a column vector of the available amount of the restricted resources.

The problem is solved by an iterative procedure, which for all but very small matrices involves the use of a computer. A simple problem is illustrated in Appendix B, and the broad outline of the model we used is in Table 3.

Most activities in the model of Table 3 comprise the different technologies available to the farmer; they may be historical, in the sense that they have been used by the farmer in the past, or new, in the sense that they are not yet adopted. To be described in the model, each activity or technology must be specified in terms of the surplus c_k it is expected to give, and the requirements P_{mk} it has for all important farm resources a_m. Thus, the particular historical technology vector A, involving the production on 1 ha of rainfed land of a transplanted first crop of BE3 rice from weeks 20 to 50 on Bañares' farm, has certain requirements over time of labor, animal inputs, seed, and fertilizer (Table 4). The method of determining the expected surplus c_k is discussed next.

Apart from activities specifying historical and new technologies, others are included in the linear programming model to represent the various noncropping functions that may take place in a complete farm-household unit. Activity vectors may be included for livestock enterprises, daily household consumption, and off-farm employment. Details are given in the section *the linear programming model*.

With an adequate model, linear programming overcomes the problems of inappropriate pricing in costs and returns analysis. When it chooses the particular combination of technologies that gives maximum surplus, it imputes appropriate prices to all restricted resources. It also indicates the extra (marginal opportunity) cost to the farmer of deciding to include those technologies it has rejected as less profitable, and the shadow price of each resource (i.e., its unit worth) predictated for the maximum surplus situation. The whole process of optimum technology selection and measurement is

Table 3. Illustration of the matrix.

Surpluses per unit of activity, C	c_1	$c_2 \ldots c_k$	Activity levels
Restricted resourc availabilities, S	Input-output coefficients for each activity		X
	P_1	$P_2 \ldots P_k$	
s_1	P_{11}	$P_{12} \ldots P_{1k}$	x_1
s_2	P_{21}	$P_{22} \ldots P_{2K}$	x_2
.	.	. .	.
.	.	. .	.
.	.	. .	.
.	.	. .	.
s_m	P_{m1}	$P_m{}^2 \ldots P_{mk}$	x_k

Table 4. An activity analysis.

Farmer: Mamerto Bañares, No. 109 Crop : TPR, BE3, 1 crop Plot : 510 (rainfed)				Barrio: Lamot, Iloilo Year : 1975-76 Area : 0.254 ha		
Week no.[a]	Operation	Hours/ha		Kg/ha		
		Man	Animal	Seed	Fertilizer	Yield
19	Plowing seedbed	8	8	61		
20	Plowing seedbed	12	12			
20	Harrowing seedbed	24	24			
20	Sowing seedbed	12				
24	Weeding seedbed	12				
27	Fixing the bund	71				
27	Plowing	63	63			
28	Fixing the bund	32				
28	Harrowing	71	71			
28	Pulling and bundling	30				
28	Plowing	32	32			
28	Transplanting	350				
36	Replanting	8				
36	Weeding	28				
38	Weeding	118				
39	Weeding	63				
39	Fertilizing	8			180.2 (urea)	
50	Harvesting	79				1,680 (palay)
50	Piling	32				
51	Threshing	90				
51	Drying	12				
51	Winnowing	16				
51	Measuring	11				
51	Hauling	16	16			

[a]See code of cropping weeks in Appendix Table B.

performed within the framework of the defined farm-household model and takes into account interrelationships between all productive processes through their dependence on a common resource base.

Some of the limitations of the basic linear programming technique have been described, for example, by Anderson et al (1977). Some of the main drawbacks are that a) it ignores possible variability in the input-output coefficient and tenure, b) it assumes that all inputs are perfectly divisible, and c) it does not recognize the sequentially stochastic nature of real-life decision making. However, adjustments to the basic model can be made to overcome these drawbacks.

Activity analyses and historical technology vectors

Generally, both historical and new technologies must be considered in a realistic farm budgeting model. The historical technology vectors in this study are based on *activity analysis*. An activity analysis is a catalog, over time, of the recorded inputs and outputs pertaining to a given crop on a given plot in a given year.

An activity analysis is illustrated in Table 4 for transplanted BE3 as first crop on rainfed plot 510 of Bañares in 1975-76. These are the basic physical data needed to support both costs and returns analysis and whole-farm analysis.

There are two steps in determining historical technology vectors from activity analyses.

- The *first step* is to group all activity analyses that refer to a given technology. Thus, for the technology of transplanted BE3 as first crop on rainfed land (Table 4) the first step is to group all activity analyses for the technology as it was used in different plots in different years on the Bañares farm.

- The *second step* is to define, for each selected group of activity analyses, an appropriate set of vectors to cover the range of planting dates and performances represented. Thus, Table 5 shows the set of historical technologies defined to cover the range represented by the group of activity analyses for the technology transplanted BE3 as first crop on rainfed land. In vector A, the seedbed is plowed in week 20, and the crop harvested in week 49. In vector H, at the other end of the range, the seedbed is plowed in week 32, and harvest is in week 4. Six other vectors are defined between the extremes. Average labor inputs per hectare are shown for each operation. They are based on overall averages calculated from the relevant group of activity analyses, but some vary with changes in the estimated yield. In fact, the activity analyses on which the vectors of Table 4 are based showed a markedly lower yield from

Table 5. The set of historical technology vectors for transplanted BE3 as first crop on rainfed land, Bañares farm, Iloilo, Philippines.

Operations	Wk no.					Hours/ha	Wk no.			Hours/ha
Vector	A	B	C	D	E		F	G	H	
Fixing the bund	20	22	25	26	29	34	30	31	32	34
Plowing seedbed[a]	20	22	25	26	29	21	30	31	32	21
Harrowing seedbed[a]	21	24	26	27	30	15	31	32	33	15
Sowing seedbed	21	24	26	27	30	5	31	32	33	5
Plowing[a]	23	26	28	29	31	64	33	34	35	64
Plowing[a]	24	27	29	30	32	60	34	35	34	60
Harrowing[a]	25	28	30	32	34	79	35	36	37	79
Pulling and bundling	25	28	30	32	34	140	35	36	37	140
Transplanting	25	28	30	32	34	242	35	36	37	242
Weeding	33	36	38	49	42	60	43	44	45	60
Weeding	35	38	40	42	44	70	45	46	47	70
Weeding	36	39	41	43	45	70	46	47	48	70
Fertilizing	36	39	41	43	45	14	46	47	48	14
Harvesting	49	50	51	52	01	133	02	03	04	109
Piling	49	50	51	52	01	36	02	03	04	29
Threshing	50	51	52	01	02	137	03	04	05	112
Winnowing	50	51	52	01	02	27	03	04	05	22
Measuring	50	51	52	01	03	14	03	04	05	12
Hauling	50	51	52	01	03	22	03	04	05	18
Drying	50	51	52	01	02	22	03	04	05	18
		kg/ha		*₱/ha*			*kg/ha*		*₱/ha*	
Seed		58		62			58		62	
Fertilizer (urea)		197		335			197		335	
Yields or net returns[b]		1800		592			1470		242	

[a]Requirement of animal time also in these weeks. [b]Net returns as defined in Tables 1 and 2. Prices used are given in Appendix Table A.

later plantings because of drought. That lower yield is accordingly assumed for vectors F, G, and H, and the yield-dependent inputs of harvesting, threshing, winnowing, measuring, hauling, and drying are lower in these latter vectors (Table 5).

The set of vectors in Table 5 portrays in more orderly fashion the range of timings and performances represented by the relevant group of activity analyses. Each vector, which is based solidly on historical data, is defined in a manner that enables it to fit in a farm budgeting model of the nature described above. Because the budgeting process necessarily refers to the future, each vector represents the farmer's *most likely* expectation of the outcome, should the given inputs be committed in the year to which the budgeting exercise is applied. Although only single valued expectations are presented, measures of variability in both yield and input-output coefficients could also be calculated on the basis of data drawn from the individual activity analyses of the group. Net returns per hectare in Table 5 are estimated by traditional costs and returns analysis.

In constructing our linear programming model, historical technology vectors were determined for all important historical technologies on the two farms. In the case of Bañares, sets of such vectors were determined on the basis of recorded activity analyses for his farm in 1975-76 and 1976-77.

The case study farmers (Bañares and Polido) are among 45 economic cooperators at Iloilo. They are small rice farmers whose daily cropping and household activities were recorded by IRRI research staff for 3 years (1975-78). Their records served to monitor the systems of farming followed by ordinary farmers in the area. The economic cooperators contrasted with a further group of *agronomic cooperators* on whose farms the impact of new technologies was actively measured through IRRI trials and experiments.

New technology vectors

When new technology vectors are estimated for given farm situations, vectors must be constructed on the basis of informed estimates. In the cases of Bañares and Polido, the new technology vectors were estimated in close consultation with the farmers and agronomists and during visits to the farm parcels. The consultations noted the historical performance of various crops on the parcels, the performance of the proposed new technology in trials in the adjoining fields of agronomic cooperators, the estimated managerial ability of the farmer, and the farmer's and agronomists' expectations regarding the performance of the new technology.

Relative managerial ability is a major factor causing differences between farmers in the outcome of a given technology. Of our two subjects, Polido was a consistently better manager of crops and other activities. That was evident from the historical activity analyses for the same crop grown under similar conditions, and from observations of day-to-day behavior. The estimates of managerial ability formed in the course of the study are subjective, but are based on a careful assessment of personal characteristics and historical activity analyses, and on practical observations of farming performance.

The differing managerial ability of the two farmers is reflected in their estimated new technology vectors. Here we compare the same technology transplanted IR36 as first crop on rainfed land; its vectors were estimated in relation to similar rainfed parcels in the same general location (Table 6). The vectors for Polido indicate a superior situation, in that a considerably higher yield (2.9 t/ha compared with 2.4 t/ha on the Bañares parcels) is estimated as obtainable from somewhat higher inputs of urea, but lower inputs of labor and animal time.

The estimation of new technology vectors for given farm situations is a difficult task, especially in terms of eliciting the true expectations of the farmer concerned. In particular, the input levels that a farmer considers relevant to a given technology may differ substantially from the levels recommended by experimenters, partly because of resource constraints and farm peculiarities, and partly because of the personal preferences of the farmer. Expected yields will differ accordingly. The farmer's own assessment of the technology will also change as he becomes more familiar with it. As experience is gained in eliciting farmer's expectations, more accurate vectors can be estimated.

Net returns per hectare, and returns per labor-hour and per peso of material input costs, presented for the vectors of Table 6, were estimated using traditional costs and returns analysis.

THE LINEAR PROGRAMMING MODEL

A broad outline of the linear programming model used in this study is given in Table 7. The model expands on the matrix of Table 3, and tailors it to the reality of the farm situation. The model covers a year of operation for a farm household unit -- from the beginning of week 14 (2 April) to the end of week 13 (1 April) (Appendix Table B), the normal crop year in the area.

The various activities are shown across the top of Table 7. Crop production forms the first and major category, and in the models of most farm-household units it occupies about one-half of the total matrix area. The units of crop production activity have differing requirements of the various restricted resources; these resources, detailed on the left side of Table 7, include land, labor, animal (carabao) time, and cash supply. Each is defined on a weekly basis.

The requirement of each restricted resource by a unit of a given activity is expressed by a coefficient, r_{mk}, following the notation of Table 3, in the relevant row vector. This particular r_{mk} has a positive (+) sign in Table 7, denoting that resources are *used up* by the relevant activity. Each unit of crop production activity also contributes yield to a *crop balance* row. This is the yield *net* of landlord's and harvesters' shares, as explained in the discussion of Table 8. The r_{mk} for this yield contribution has a negative (-) sign in Table 7, because yield is *contributed to* the row. This nomenclature of positive and negative signs for the r_{mk} is followed for all activities in the matrix. The surplus, c_k, per unit of crop production activity, is zero (Table 7); this is because the yield from which any surplus can be generated is passed into the crop balance row.

The second category of activities is those for crop consumption, one such vector being defined for each crop consumed in the farmer's home. These vectors take quantities of crop out of the relevant crop balance row, and add them to the relevant consumption minimum row; each minimum is set at a level to satisfy the minimum consumption requirements of the particular farm household. These items are necessary because all small rice farmers generally use a large portion of the farm produce for feeding family members and animals.

The third category of activities is those for crop sales, whose vectors also take crop out of the balance rows and add the value to the relevant cash supply row. The surplus per unit of crop sales activity is again zero.

The remaining categories of activities cover the range of functions normal to a farm household unit. Thus, another earnings vector adds cash to the cash rows in those weeks where such earnings are expected. A household expenditure vector takes from the weekly cash rows the total amount of cash expenditure expected in each week. Loan vectors serve to add cash in earlier weeks of the crop year, but take away cash (or crop balance) at a later stage of the year when repayments of principal and interest are due. Family labor transfer vectors are explained below.

Sets of weekly labor hiring and carabao and labor hiring vectors allow, respectively, for hiring units of labor on their own, or in conjunction with a work animal. These vectors add to labor and animal time in particular weeks, but also take away from the cash row (because payments for these resources are needed) in the same week. Finally cash-saving vectors perform the function of transferring extra cash from week to succeeding week during the year, and cash surplus vectors allow cash not needed in the profit-maximizing combinations of activities to be set aside as a surplus. Each cash surplus vector, which is defined in one peso (₱) units,[3/] has a

[3/] The exchange rate is ₱7.35 to US$1.

surplus, e_k, of ₱1.00 per unit of cash surplus activity. The total of the individual surpluses generated by all the units of cash surplus vectors specified in the final solution is the total surplus, ex, which is maximized in the linear programming process. It is what the farmer earns *after* buying all his purchased inputs, including labor and animal time, during the crop year covered by the model. As such, the total surplus is a return to management, land, family labor, and working capital tied up in the farm-household enterprise.

This discussion indicates how the farm model allows for the interrelationships between the various activities of the farmer, and for the dependence of these activities on the basic farm resources of land, labor, animal time, and cash. The selection process of linear programming chooses the economic optimum combination of activities in the light of farm resource prices determined in the framework of the model.

Table 8 illustrates in more detail how the model accommodates the new technology vector, *transplanted IR36 as first crop on shared-tenanted, rainfed land, harvested by family labor (planting week 27)*, on the farm of Bañares.

Table 8 shows how the 1-ha unit of this vector links with the relevant resources. The vector uses 1 ha of share-tenanted rainfed land from week 25 through 40; each of these requirements appears as a coefficient, or P_{mk} of +1.0 in the budgeting matrix. The

Table 6. The new technology vectors for dry seeded (DSR), wet seeded (WSR), or transplanted (TPR) IR36 on rainfed land. Bañares and Polido's farms, Iloilo, Philippines.

Operations	Bañares			Polido		
	DSR	WSR	TPR	DSR	WSR	TPR
Operations (hours/ha)						
Fixing the bund	34	34	34	30	30	30
Plowing seedbed			10			16
Harrowing seedbed			5			9
Sowing seedbed			1			2
Plowing	60	90	120	86	86	110
Harrowing	25	48	70	76	76	80
Furadan application		10	10		5	5
Seeding	18	6		18	18	
Fertilizer application 1	5	5	5	9	9	16
Pulling and bundling			140			60
Transplanting			242			133
Hand weeding 1	50	45	45	65	65	20
Fertilizer application 2	5	5	5	9	9	16
Hand weeding 2	40	40		60	60	
Harvesting	147	162	178	163	176	189
Piling	40	44	47	72	77	83
Threshing	152	166	182	163	176	189
Winnowing	29	32	36	41	44	47
Measuring	15	17	19	26	28	30
Hauling	24	27	29	41	44	47
Drying	24	27	29	41	44	47
Total	668	758	1,207	900	947	1,129
Range of weeks[b]						
1st plowing, seedbed			21-26			23-27
1st plowing, main area	17-20	19-23	22-27	19-23	20-24	24-28
Broadcasting	19-22	21-25		19-23	22-26	
Transplanting			24-29			23-29
Harvesting	33-36	35-39	36-41	33-37	36-40	39-43
Material inputs (kg/ha)						
Seed	76	76	60	82	82	70
Urea	88	122	122	156	156	156
0-20-2	125	100	100	125	100	100
Furadan		17	17	17	17	17
Yields (kg/ha)	2,000	2,200	2,400	2,500	2,700	2,900
Net returns[c] per ha	1,311	1,309	1,220	1,437	1,648	1,728
Returns to labor[c] per h	2.58	2.48	1.50	2.35	2.43	2.12
Returns to cash[c] per ₱	4.93	3.82	4.45	3.63	4.23	4.75

[a]Requirement of animal time also for the operations. [b]Only first and last weeks are given for each set of vectors. [c]As defined in Tables 1 and 2. Returns "per ₱" are per *peso* of cash spent on material inputs.

vector also uses labor in week 23 through 40, and the appropriate (positive) labor coefficients for each week are given. Further detail of how labor is used by this vector for individual farm operations appears in Table 6. The vector also requires carabao time (for plowing and harrowing) in weeks 24, 25, and 26, and in weeks 27 and 32. Finally it *adds* the farmer's share of the crop harvested in week 39 to the relevant rice balance row. This farmer's share is two-thirds of the expected yield from the 1 ha of share-tenanted land, *plus* that part of the remaining one-third that is owed to the farmer and his family for their part in harvesting the crop. It is entered in the matrix as -1.733 t. The balance in excess of the farmer's share goes to the landlord.

Although the new technology vector of Table 8 is specified as using family labor for harvesting, a realistic model of most farmers' situations in the Philippines, including that of Bañares, must also allow for the possible use of outside labor for harvesting. In this latter situation a share of the crop goes to such labor as a payment for work in harvesting, threshing, and associated activities.

Consequently, a separate column vector is incorporated in the Bañares farm model for the new technology. This vector, unlike that of Table 8, has no physical requirements of family labor for harvesting and associated activities because all this work is done by share labor and paid in kind. To account for such payment in the model the yield entered in the vector against the rice crop balance row is reduced accordingly.

Table 7. Outline of the whole-farm model.

ACTIVITIES, RESOURCES	Crop production (ha) /35/[b]	Crop consumption (t) /4/	Crop sale (₱) /7/	Other earnings (₱) /1/	Household expenditure (₱) /1/	Loans (₱) /13/	Family labor transfer (h/wk) /52/	Labor hiring (h/wk) /52/	Carabao/ labor hire (h/wk) /52/	Cash saving (₱/wk) /52/	Cash surplus (₱/wk) /52/
Land (diff. types) wkly (ha) /156/[b]	$+p_{mk}$[c]	0[d]	0	0	0	0	0	0	0	0	0
Labor (diff. types) wkly (h) /104/	$+p_{mk}$	0	0	0	0	0	$+p_{mk}$[e] $-p_{mk}$	$-p_{mk}$	$-p_{mk}$[e]	0	0
Carabao time, wkly (h) /52/	$+p_{mk}$	0	0	0	0	0	0	0	0	0	0
Cash supply, wkly (₱) /52/	$+p_{mk}$	$+p_{mk}$	$-p_{mk}$	$-p_{mk}$	$+p_{mk}$	$+p_{mk}$ $-p_{mk}$	0	$+p_{mk}$	$+p_{mk}$	$+p_{mk}$ $-p_{mk}$	$+p_{mk}$
Credit maxima (₱) /2/	0	0	0	0	0	$+p_{mk}$	0	0	0	0	0
Household expenditure min (₱) /1/	0	0	0	0	$+p_{mk}$	0	0	0	0	0	0
Other earnings, maxima (₱) /1/	0	0	0	$+p_{mk}$	0	0	0	0	0	0	0
Crop balances (t) /7/	$-p_{mk}$	$+p_{mk}$	$+p_{mk}$	0	0	0	0	0	0	0	0
Consumption minima (t) /2/	0	$+p_{mk}$	0	0	0	0	0	0	0	0	0
Carabao availability (h) /1/	0	0	0	0	0	0	0	0	$+p_{mk}$	0	0
Surplus per unit of activity	0	0	0	0	0	0	0	0	0	0	$+c_k$

[a]These crop production vectors occupy about half of the matrix area and account for most of its density. [b]Figures in round brackets ( ) are units in which the relevant vector is measured. [c]Figures in square brackets / / are numbers of vectors in each category in the Bañares model, including both historical and new technology vectors. $+p_{mk}$ ($-p_{mk}$) indicates that the input-output coefficients p_{mk} (Table 3) in this particular submatrix are positive (negative), or zero. [d]0 indicates that all p_{mk} are zero. [e]$+p_{mk}$, $-p_{mk}$ indicate that the p_{mk} are positive, negative.

Table 8. Resource and constraint linkages of the new technology vector transplanted IR36 as first crop on share-tenanted rainfed[a] land harvested by family labor (planting week 27). Bañares farm, Iloilo, Philippines.

Resources	Weeks	Resource linkage per ha of technology
Share-tenanted rainfed land (ha)	25-40	+1 ha
Family (or hired) labor (h)	23	+34 h
	24	+16
	25	+120
	26	+80
	27	+387
	30	+45
	32	+5
	39	+225
	40	+295
Carabao time (h)	24	+15 h
	25	+120
	26	+70
Cash supply (₱)	26	+₱94
	27	+₱237
	32	+₱75
Palay first crop balance (t)	39	-1.733 t[b]

[a]On share-tenanted land one-third of the crop goes to the landlord, *after* harvesters' share of one-sixth has been deducted. [b]Farmers' share (harvesting by family labor) on share-tenanted land = 2/3 (Total yield-harvesters' share of 1/6 of total yield) + harvesters' share = 2/3 (2400 - 1/6 x 2400) + 1/6 x 2400 = 1.733 t.

By defining separate vectors the budgeting model allows the use of either family or share labor, or combinations of both. Vectors are defined for both historical and new crop production technology. The possible use of hired or wage labor within each technology is also provided for, and explains the presence of *family labor transfer* column vectors (Table 7). The linear programming process thus selects those proportions of hired, family, and share labor that are economically optimum according to the conditions of the model.

The case study farmers

The basic situations of the two case study farmers are summarized in Tables 9 and 10. The details explain how the level of constraints is set in the model for each farm household.

In the case of Bañares, 3 distinct tenure categories are specified for land in the budgeting model; these are partly owned upland (1.026 ha), share-tenanted rainfed land (0.338 ha), and fully owned rainfed land (0.225 ha). These are also the weekly land constraints limiting the areas of crops that can be grown (Table 7). In this instance landscape differences within each category are considered insufficient to justify any further breakdown, although such may be necessary in other circumstances.

For the Bañares farm family, the labor hours specified for each working member are the maxima that they each feel they can contribute each week, both generally and during school vacations. The persons concerned do not necessarily work all these hours, but can work if required. The relevant numbers of hours are entered in the matrix as weekly maxima, and represent the family labor constraint. The animal hours are specified similarly.

The liquid cash of ₱600 attributed to Bañares in week 14 is the estimated amount of cash available for various purposes in the farm household at the beginning of the cropping season. It is treated as the initial cash supply at the beginning of the budgeting year.

Bañares' cash supply can be augmented by loans, but the increase is limited by his personal decision not to borrow more than ₱800 from the two forms of credit available (Table 9).

The household expenditure and other earnings in Bañares' and Polido's case are taken to occur evenly throughout the weeks of the year, but that may not be so in all farm situations.

The model also incorporates items of essential home consumption, which in Bañares' situation are estimated as 1.14 t of rough rice and 0.24 t of shelled corn.

The figures for Polido's budgeting model were extracted from the details of Table 10. The details emphasize his superior asset position in comparison with Bañares' -- a much larger land area, some of which is irrigated and much of which is fully owned. Other earnings, also far greater, are contributed by the members of the family working away from the farm household. The superior asset position of Polido accounts for his higher limit on loans and for the lower rate of interest charged.

Particulars of all crop production vectors included in the farm model for Mamerto Bañares are given in Appendix Table A. A similarly wide range of vectors was considered for Polido's.

Optimal solutions from the model

Some solutions from the linear programming model of Bañares' farm household are given in Table 11. The optimal solutions cover three separate situations: first, where only historical technology vectors are included in the model; second, where both historical and relevant new technology vectors are included; and third, where historical and new technology vectors are included, but *other earnings* are raised from the basic assured level of ₱628 (Table 9) to ₱2,000. The second and third solutions are described as having *limited cash* and *more cash*. The historical and new technology vectors considered for the whole-farm models of Bañares are detailed in Appendix Table C.

Table 9. Basic farm-household situations. Bañares farm. Iloilo, Philippines.

	Parcel 1	Parcel 3	Parcel 5	Parcel 6	Parcel 7
Land					
Class[a]	U	R	R	R	U
Landscape[b]	UP	P	PS	F	UP
Texture[c]	Sa.L	Si.L	Si.L	Si.L	Si.L
Tenure[d]	P O	S T	F O	S T	P O
Historical crops[e]	C-C/YB	R-M R-R	R-R	R-T	C-C/YB
Area (ha)	0.804	0.225	0.225	0.113	0.222
Total area (ha)		1.589			

Farm family	*Name*	Max hours available/week *Generally*	*Vacations*
	Mamerto	53	53
	Encarnacion	6	6
	Domingo	8	48
	Aquilis	16	48
	Terry	18	18
	Total	101	173

Carabao	No.	Max hours available/week
	1	48

Liquid cash, week 14 (estimated)	₱ 600
Maximum credit availability	300 from carabao loan (1%/month) 500 from loan shark (50%/year, repayable in kind)
Household expenditure (1976-77)	2409
Other earnings (1976-77)	688
Home consumption	*Tons*
(estimated annual)	
Rough rice (for family)	1.14
Shelled corn (for animals)	0.24

[a]U = upland, R = rainfed, I = irrigated. [b]UP = unbunded plain, P = plain, S = side slope, F = foot slope, Pl = plateau, B = bottomland. [c]Sa.L = Sandy Loam, Si.L = silty loam, C = clay, Si.C = silty clay. [d]PO = partly owned, St = share-tenanted, FO = fully owned. [e]C = corn, YB = yam bean, R = rice, T = tobacco, M = mung bean.

The model solution for Bañares' first situation of only historical technology vectors is similar to the actual plan Bañares followed in 1977-78. That indicates that the simulated decision-making process of the specified model closely follows that of the farmer. More confidence can thus be placed in the indications of the farm model where new technology vectors are also included. In this first situation the model selects a combination of family labor and share labor for harvesting the second crop of corn and yam bean. The combination depends on the relative shadow prices of the two classes of labor at the particular times labor is required. The solution indicates a staggered planting of most specified crops, again according to the relative prices and availabilities of the basic resources needed. Thus, Singapore corn as first crop is specified as using the partly owned upland of parcels 1 and 7, both in weeks 14-31 (0.555 ha) and in weeks 16-33 (0.471 ha). The further splitting of the corn crop into areas grown with and without fertilizer is also indicated, but this detail is not included in Table 11. The total annual surplus earned in the first situation is ₱1,656.

The optimal solution for the second situation (historical and new technology vectors, limited cash) denotes that new technologies are specified for parts

Table 10. Basic farm-household situation. Polido farm, Iloilo, Philippines.

	Parcel 1	Parcel 2	Parcel 3	Parcel 4	Parcel 5	Parcel 6
Land						
Class[a]	U	I	I	I	I	I
Landscape[b]	UP	F	P1, F	P	F, B	P1
Texture[c]	Si.L	Sa.L	C	C	Si.C	Si.C
Tenure[d]	F O	S T	F O	F O	F O	F O
Historical crops[e]	C-C/YB	R-R/M	R-R/M	R-R/M	R-M	R-M
Area (ha)	1.847	0.520	0.131	0.144	0.713	0.306
Total area (ha)			3.661			

Farm family

Name	Max labor-hours available/week: *Generally*	*Vacations*
Julian	49	49
Gloria	7	7
Henry	8	49
Total	101	173

Carabao

No.	Max hours available/week
1	48

Liquid cash, week 14 (estimated)	₱1060
Maximum credit availability	1500 (from Rural Bank, 1%/mo)
Household expenditure (1976-77)	4240
Other earnings (1976-77)	2400
Home consumption	*Tons*
(estimated annual)	
Rough rice (for family)	1.804
Shelled corn (for animals)	0.378

[a]U = upland, R = rainfed, I = irrigated. [b]UP = unbunded plain, P = plain, S = side slope, F = foot slope, P1 = plateau, B = bottomland. [c]Sa.L = sandy loam, Si.L = silty loam, C = clay, Si.C = silty clay. [d]PO = partly owned, ST = share tenanted, FO = fully owned. [e]C = corn, YB = yam bean, R = rice, T = tobacco, M = mung bean.

of all parcels. Some DMR 2 corn is indicated for the upland parcels 1 and 7, and some IR36 and improved minimum cultivation mung bean are indicated for the rainfed parcels 3, 5, and 6. All these new technologies are expected to give higher yields than their historical counterparts; IR36 has other superior characteristics such as good drought resistance, excellent insect and disease resistance, and good eating quality. It is noteworthy that considerable areas of historical technologies, expecially Singapore corn, IR5, and Kapopoy, are still specified in the second solution (Table 11). With incorporation of the new technologies, the total surplus in the second situation rises to ₱3,343.

Further examination of the second solution indicates that the partial adoption of new technologies directly reflects the absence of sufficient cash. Thus, no first crop of IR36 is grown in parcels 3 and 6 because of the technology's relatively high requirement of cash to purchase fertilizer and pesticide (Table 6). Scrutiny of the detailed figures in the linear programming results (Table 12) shows that the shadow price of the cash resource is very high indeed in the first part of the crop year, when the tight cash supply (Table 9) is set against a high demand from all the possible cropping activities. In these circumstances the extensive cultivation of IR36 as a first crop would reduce the overall surplus generated by the farm-household business. The historically adopted technologies of transplanted IR5 and Kapopoy are more economically optimal because their cash

Table 11. Optimal solutions from linear programming, Bañares farm, Iloilo, Philippines.

	HT[a] vectors only (limited cash[b])	HT and NT vectors[a] (limited cash)	HT and NT vectors (more cash[b])
Parcels 1 and 7 Upland and partly owned (1.026 ha)	Singapore corn, 1st crop FL[c] (14-31 to 16-33)[d]:1.026 ha S. corn/yam bean, 2d crop FL (40-06 to 42-08):0.400 ha SL (40-06 to 42-08):0.626 ha	DMR2 corn, 1st crop FL (22-38 to 26-42):0.850 ha Singapore corn, 1st crop FL (14-31):0.176 ha DMR2 corn/yam bean, 2d crop FL (41-07 to 44-10):0.556 ha SL (42-08 to 44-10):0.322 ha S. corn/yam bean, 2d crop FL (40-06 to 41-07):0.148 ha	DMR2 corn, 1st crop FL (22-38 to 26-42):1.026 DMR2 corn/yam bean, 2d crop FL (41-07 to 44-10):0.567 SL (41-07 to 44-10):0.334 S. corn/yam bean, 2d crop FL (40-06 to 41-07):0.135
Parcels 3 and 6 Rainfed and share-tenanted (0.338 ha)	Kapopoy, TPR 1st crop FL (21-36 to 22-37):0.318 ha Kapopoy, WSR, 1st crop FL (17-34):0.020 ha BE3, TPR, 2d crop FL (36-52 to 40-03):0.225 ha Mung, 3d crop FL (02-10 to 041-12):0.225 ha	IR5, TPR, 1st crop FL (23-40):0.207 ha Kapopoy, TPR, 1st crop FL (21-36 to 23-39):0.131 ha IR36, TPR, 2d crop FL (40-03):0.018 ha Mung min. cult., 2d crop FL (41-04):0.207 ha Mung, 3d crop FL (02-10 to 06-14):0.225 ha	IR36, TPR, 1st crop FL (22-37):0.050 ha IR36, WSR, 1st crop FL (19-36):0.071 ha IR36, DSR, 1st crop FL (17-34):0.168 ha Kapopoy, TPR, 1st crop FL (21-36):0.049 ha IR36, TPR, 2d crop FL (36-51 to 40-03):0.225 Mung, 3d crop FL (04-12):0.225 ha
Parcel 5 Rainfed and fully owned (0.225 ha)	Kapopoy, TPR, 1st crop FL (22-37 to 24-39):0.225 ha BE3, TPR, 2d crop FL (29-02 to 40-03):0.225 ha	IR36, DSR, 1st crop FL (17-34):0.102 ha Kapopoy, TPR, 1st crop FL (21-36):0.123 ha IR36, TPR, 2d crop FL (36-51 to 38-01):0.225 ha	IR36, TPR, 1st crop FL (22-37):0:117 ha IR36, WSR, 1st crop FL (19-36):0.108 ha IR36, TPR, 2d crop FL (37-52 to 40-03):0.225 h
Total surplus	₱1,656	₱3,343	₱4,273

[a]HT = historical technology, NT = new technology. [b]Limited cash = *other earnings* of ₱1,238, more cash = *other earnings* of P2,000. [c]FL = family labor for harvesting, SL = share labor for harvesting. [d]Figures in parentheses are ranges of weeks over which the crop uses the ground. In this particular case, only two lots of Singapore corn, 1st crop, are specified by the program, viz., 0.555 ha from weeks 14-31 and 0.471 from weeks 16-33. The first week given is the week of first plowing, and the last week is the week directly after the weel of harvesting. [e]Surplus = gross return *less* cost of all purchased inputs (material, labor, and animals).

Table 12. Shadow prices of major resources in selected weeks (limited cash situation). Bañares farm, Iloilo, Philippines.[a]

Shadow prices		
Share-tenanted rainfed land[b] (₱/ha)	Family labor (₱/ha)	Cash (₱/₱)
0 (25)	0 (23)	5.2 (14)
15 (26)	0.86 (24)	5.2 (31)
65 (28)	0.98 (25)	1.0 (32)
481 (40)	0.38 (42)	1.0 (13)
665 (50)	0 (46)	
171 (8)	1.04 (7)	
65 (12)	0.72 (10)	
0 (13)	0 (11)	

[a]Figures in parentheses are week numbers of stated prices. [b]Parcels 3 and 6.

requirements are much less. It is probable that similar conditions are widespread among small farmers with low asset levels, and are one important reason for nonadoption or only partial adoption of, new technologies.

The third optimal solution tests the reaction of Bañares to a situation in which other earnings are raised to ₱2,000 during the 12 months of the assessment. As can be seen in Table 11, this solution greatly changes the selection of crops in all rainfed parcels, and except for a small area of Kapopoy in parcels 3 and 6, IR36 is selected whenever rice cultivation is possible. In parcels 3 and 6, substantial dry seeding is stipulated for the first crop, with cultivation beginning in week 17; the balance of the area is wet seeded and transplanted, with cultivation beginning in weeks 19 and 22. For the second crop, only transplanting is stipulated, but this is staggered over 5 weeks. In parcel 5 some wet seeding (with cultivation from week 19) and some transplanting (with cultivation from week

22) are prescribed. A transplanted and staggered second crop is again denoted.

The surplus in the third situation rises to ₱4,273, which is ₱930 more than in the second situation. It should be recalled, however, that the other earnings available to supplement the annual cash flow were raised by ₱712 (₱2,000 less ₱1,288) between the second and third situations, so that the *net increase* in surplus resulting from a considerably greater usage of cash is only ₱218. This is a 23% return on extra working capital, and should be set against an interest rate of at least 50% on loans in the barrio setting. This rate is a fair estimate of the opportunity cost for cash.

An optimal solution for Polido's farm-household situation, in which both historical and relevant new technology sectors are considered, is presented in Table 13. As in Bañares' case, the optimal solution where only historical technology vectors are considered is similar to Polido's actual choice of cropping patterns in 1976-77. The solution in Table 13 denotes acceptance of new technologies for most of the farm area, notwithstanding the fact that only the actual current cash flow (Table 10) is taken. There is no difficulty in sustaining the more intensive required use of cash in this case, because Polido has a far higher cash flow and asset level. The estimated total surplus in this solution is ₱8,727.

COSTS OF ADOPTING SUBOPTIMAL TECHNOLOGIES

The extra or marginal opportunity costs of including suboptimal technologies are among the information given by the linear program in presenting optimal solutions. The marginal opportunity cost of the various first crop technologies specified in both the limited-cash and more-cash solutions for rainfed parcels 3 and 6 of Bañares (Table 11) are presented in Table 14. The marginal opportunity costs of some other technologies are also detailed.

For those technologies specified as optimal in the limited-cash situation transplanted IR5 (weeks 23-40) and transplanted Kapopoy (weeks 21-30 and 23-39), the marginal opportunity costs are zero. There is no extra cost in introducing these vectors, because they are already in the optimal solution. The marginal opportunity costs under limited cash of transplanted IR36 (weeks 22-37) and wet-seeded IR36 (weeks 19-36), both of which are optimal new technologies when more cash becomes available, are ₱919 and ₱536/ha, however. These substantial costs that spring from extra costs are only partly offset by higher yields. Because of the overall shortage of cash, inclusion of IR36 as a first crop in parcels 3 and 6 would also mean reducing the area of transplanted IR36 grown as a second crop in parcel 5 (Table 11). The much higher marginal opportunity costs of transplanted as opposed to wet-seeded IR36 (Table 14) can be ascribed to the large requirement of the former for hired labor to pull, bundle, and transplant (Table 6).

On the other hand, the marginal opportunity cost of including dry-seeded IR36 (weeks 17-34) as a first crop of the new technology instead of IR5 or Kapopoy is *insignificant* (Table 14). Indeed, inclusion of this technology to partly replace IR5 and Kapopoy represents an alternative solution that would generate almost the same total surplus. Even though dry-seeded IR36 has slightly higher cash requirements than either transplanted IR5 or Kapopoy, as specified in the model, it produces a considerably greater yield. It also has some economic advantage in being harvested earlier, and in thus permitting more flexibility in turnaround time. The option of establishing a first crop of dry-seeded IR36 is actually chosen in the limited-cash solution for parcel 5 (Table 11), where the first crop is followed by a second crop of transplanted IR36. This option generates a much higher surplus per hectare than in parcels 3 and 6, where most of the second crop area is mung bean. The option is not feasible in the latter parcels, however, because of the cash limitation.

Table 13. An optimal solution from linear programming, Polido farm, Iloilo.[a]

	HT and NT vectors (normal cash - Table 10)
Parcel 1 Upland and fully owned (1.847 ha)	DMR2 corn, 1st crop SL (23-28 to 26-41):0.669 ha FL (23-28 to 26-41):1.178 ha DMR2 corn/yam bean, 2d crop SL (41-07 to 44-10):0.935 ha FL (41-07 to 44-10):0.912 ha
Parcel 2 Irrigated land and share-tenanted (0-520 ha)	IR36, WSR, 1st crop FL (20-35):0.520 ha IR36, WSR, 2d crop FL (28-02):0.050 ha FL (27-01):0.188 ha IR20, TPR, 2d crop SL (38-04):0.282 ha
Parcels 3 and 4 Irrigated land, fully owned (0.275 ha)	IR36, WSR, 1st crop SL (22-37):0.069 ha FL (22-37):0.206 ha IR20,TPR, 2d crop FL (39-06):0.275 ha
Parcels 5 and 6 Rainfed land, fully owned (1.029 ha)	IR28, WSR, 1st crop FL (24-39):0.520 ha IR36, WSR, 1st crop SL (21-36):0.509 ha IR36, TPR, 2d crop FL (38-52):0.164 ha IR36, WSR, 2d crop FL (40-04):0.382 ha SL (40-04):0.483 ha
Total surplus	₱8,727

[a]HT = historical technology, NT = new technology; SL and FL = share labor and family labor for harvesting. Figures in parentheses are ranges of weeks over which the crop uses the ground. WSR = wet-seeded rice, TPR = transplanted rice.

Table 14. Marginal opportunity costs of selected technologies. Bañares farm, Iloilo, Philippines.[a]

Technologies for parcels 3 and 6 (rainfed and share-tenanted, family labor for harvesting)	Optimal solutions for HT and NT vectors, more cash (₱/ha)	Optimal solutions for HT and NT vectors, more cash (₱/ha)
IR5, TPR, 1st crop		
Weeks 23-40 [b,c]	0	209
Kapopoy, TPR, 1st crop		
Weeks 21-36[b]	0	0
23-39[b]	0	170
IR36, TPR, 1st crop		
Weeks 22-37[b]	919	0
24-39	898	142
25-40	972	134
26-41	1380	146
27-42	1334	144
IR36, WSR, 1st crop		
Weeks 19-36[b]	536	0
20-37	575	53
21-38	826	210
22-39	994	316
23-40	1333	268
IR36, DSR, 1st crop		
Weeks 17-34[b]	Insignificant	0
18-35	43	3
19-36	85	26
20-37	36	71

[a]TPR = transplanted rice, WSR = wet-seeded rice. [b]These are technologies specified as optimal in either the *limited cash* or *more cash* solutions, or both. [c]As in Table 11, the first week given is the week of first plowing, and the last week is the week immediately after the week of harvesting.

In the more-cash solution for Bañares, the marginal opportunity cost of transplanted IR5 (weeks 23-40) is ₱209 (Table 14), and that of transplanted Kapopoy (weeks 23-29) is ₱170/ha. With the greater cash availability in this solution, the various specified areas of transplanted IR36 (weeks 17-34), in conjunction with some transplanted Kapopoy (weeks 21-36), generate a higher total surplus than the purely historical technologies.

Table 14 also shows that the marginal opportunity costs of later plantings of both transplanted and wet-seeded IR36 are substantial in the more-cash solution, mainly because of the greater concentration of their demand for harvesting labor in a peak labor demand period. The marginal opportunity costs of later plantings of dry-seeded IR36 are only minor, at least up to week 19, because a longer turnaround time is still possible.

Shadow prices of key resources

A further by-product of the linear programming solution and another aid in the wider interpretation of technology selection are the shadow prices of key resources. A shadow price is actually a *marginal value product*, which is an addition to the total surplus resulting from further addition of a unit of a given resource.

Some shadow prices generated by the optimum solution for the limited-cash situation are presented in Table 12. The values of land, labor, and cash vary according to the particular supply-demand situation. Thus, for share-tenanted rainfed land (parcels 3 and 6), the shadow price per hectare is zero up to week 25, when land is not the limiting factor in production. By week 28 the price has risen to ₱65. This is the small increase in surplus which would be generated by the added availability of 1 ha. At this stage the major limiting factors are labor and cash. The price reaches much higher levels of ₱481 in week 40 and ₱665 in week 50 because land addition in these weeks would enable more transplanted rice to be cultivated. The increases in total surplus arising from these changes would nonetheless involve leaving some share-tenanted land idle for the first crop, again because of limited cash availability and the particularly high price of this resource early in the year.

Labor attains its highest shadow price per hour during the peak cultivation period in weeks 24 and 25, and once more during the harvesting period for corn and yam bean in weeks 7-10. Early in the year, and during intermediate periods when labor demand is low and some family labor is idle, the shadow price is zero.

For the whole early part of the cropping year, up to week 31, cash has a very high shadow price of up to ₱5.20. This implies that the availability of one additional unit of cash can increase the farmer's net cash surplus by ₱5.20. (However, the rate of return to additional units of cash declines rapidly, as observed earlier when an additional ₱712 yielded only an extra ₱218.) The sale of the first crop of Singapore corn in week 31 (and of other crops thereafter) enhances the subsequent cash flow and the shadow price declines to ₱1, i.e., additional cash at this stage cannot increase the productive use of the farmer's other resources to raise the net cash surplus.

Comparison with costs and returns analysis

It is interesting to compare the preceding assessments of the economic advantages of transplanted, wet-seeded, and dry-seeded first crops of IR36 with assessments by traditional costs and returns analysis. In the case of Bañares, traditional analysis shows no significant difference in net returns per hectare between dry-seeded and wet-seeded IR36 (Table 6), and only a small advantage of these techniques over transplanting, whose higher gross

returns (due to a higher yield) are more than offset by higher labor costs. As indicated previously in the discussion of costs and returns analysis, labor (and other) inputs are charged at the same overall average rate, irrespective of whether they are from hired or family sources. In terms of returns per labor hour, transplanting gives considerably less than the other techniques, as might be expected. In terms of returns to cash spent on material inputs, dry seeding is much superior (Table 6).

These indications from costs and returns analysis provide a good overall economic assessment of the three cultivation techniques, on the basis of the physical inputs and outputs of Table 6. Dry seeding is superior when labor and cash are short; wet seeding approaches it closely in terms of economical labor usage. As noted earlier, however, costs and returns analysis does not perform well in more detailed assessments where careful pricing of inputs becomes significant. In the case of Bañares, where the usage of land by the three techniques is similar, such careful pricing is especially pertinent for labor and working capital in the form of cash. Thus, because it uses labor in a somewhat earlier period, dry-seeded IR36 is far superior to wet-seeded and transplanted IR36 than would appear from costs and returns analysis. Its lesser demand for cash is also more advantageous in absolute terms. because this input is much more expensive in the early part of the year than the application of average market prices would suggest.

It is noteworthy, however, that a considerable first crop of transplanted and wet-seeded rice is prescribed in the third solution (Table 10), with the use of labor whose shadow price is lower than would have been if all the area had been transplanted or wet-seeded. This lower price is attributed to the staggering of labor demand, which occurs where dry seeding is also practiced in earlier weeks.

It is thus evident that whole-farm analysis is superior in assessing the relative merits of different technologies in particular farm situations; it can also denote useful complementarities between such technologies in terms of overall resource use.

We believe that whole-farm analysis can also give superior assessments in the much wider regional comparisons of technologies by exploring the economic impact of technologies in a range of defined farm resource situations through empirically collected data.

APPLICATION OF THE MODEL

This paper aims to explain the approach of whole-farm analysis through linear programming, and to illustrate the approach briefly in relation to two selected farmers with differing asset levels. It introduces the concepts of activity analysis and historical and new technology vectors, which are basic elements in any mathematical modeling of cropping patterns. The paper has an explanatory purpose, but may be useful as a background to subsequent and more detailed studies that employ the whole-farm analytical approach. We believe the basic model presented (Table 7) can be applied in a variety of situations throughout the Philippines and elsewhere, provided adequate data to support it are available.

Some fundamental problems of the linear programming technique and its use in whole-farm analysis were noted. In practical applications, modified forms of linear programming appear easier to use; they have been reviewed by Anderson et al (1977). In many cases, relatively simple modifications of the basic model can be made to achieve a more realistic portrayal of the problem. Modifications of this nature will be attempted in the present series of studies, once the ranges of pertinent resource situations have been better established, and the historical and new technology vectors better estimated. The effects of risk on decision making can be usefully considered through the minimum absolute deviation (or MOTAD) approach. This approach can use the basic data arrangements described, together with measures of expected variability in performance. Again, the results of sequential decision making can be well simulated by manipulating the sets of technologies available for use by the farmers, according to assumed seasonal weather variations. Different vectors (as in Table 5) will be feasible in each set of assumed weather conditions.

The whole-farm analysis procedures are regarded as major aids in the identification of relevant new technologies. They are submitted as methodologies that should be used at central research institutes, as a means for helping research workers to identify the technologies most likely to be valuable, and to tailor such technologies to actual farm situations. Although the modeling processes involved cannot be undertaken without good basic data, it is not necessary to have elaborate historical records, and work is under way to develop a means of farm data collection through *activity statements*. These, in contrast with the activity analyses based on detailed historical records, are statements of farmers' expectations about the output and inputs of particular crops. They are based on the farmers' experience, and can be elicited through a few interviews rather than from hundreds of daily records. With appropriate adjustments, the activity statements can be used in attempts to measure the impact of new technologies in situations where no extensive records are available.

The work we report concentrates almost exclusively on mathematical modeling techniques, particularly on linear programming. We stress that these techniques complement the simpler methods of economic assessments, notably costs and returns analysis and other forms of partial budgeting. The simpler techniques will continue to have an important application at the field level where they can be applied by extension workers to get a simple assessment of the economic benefits of a new technology.

REFERENCES CITED

Anderson, J.R. 1976. On formulating advice to farmers from agronomic experiments. Misc. Publ. 3, Department of Agricultural Economics and Business Management, University of New England, Armidale.

Anderson, JR., D.L. Dillon, and J.B. Hardaker. 1977. Agricultural decision analysis. Iowa State University Press, Ames.

Banta, G.R. 1976. Information required for description of cropping systems. Paper delivered at the symposium on Cropping Systems Research and Development for the Asian Rice Farmer, IRRI, Los Baños.

Benito, C.A. 1976. Peasants' response to modernization projects in *Minifundia* economies. Am. J. Agric. Econ. 58: 143-151.

Clayton, E.S. 1965. Economic planning in peasant agriculture. Wye College, University of London.

Garrity, D.P. 1976. A test of potential cropping pattern for an upland rice growing region of the Philippines. Unpubl. MS (Agronomy) thesis, University of the Philippines at Los Baños, Philippines.

Hardaker, J.B. 1975. Agriculture and development in the Kingdom of Tonga. Unpubl. Ph D thesis, University of New England, Armidale.

Heady, E.O., and W. Candler. 1958. Linear programming methods. Iowa State University Press, Ames.

Heyer, J. 1972. An analysis of peasant farm production under conditions of uncertainty. J. Agric. Econ. 13(2): 135-146.

IRRI (International Rice Research Institute). 1977. Annual report for 1976. International Rice Research Institute, Los Baños.

Kingma, O.T., and K.W. Kerridge. 1977. Towards an analytical base for studying farm adjustment problems - a recursive stochastic model of the farm-firm. Q. Rev. Agric. Econ. 30(291):114.

Low, A.R.C. 1975. Small farm improvement strategies - the implications of a computer simulation study of indigenous farming in South East Ghana. Oxford Agrarian Stud. 14:3-19.

Norman, D.W., and R.W. Palmer-Jones. 1976. Economic methodology for assessing cropping systems. Paper delivered at the symposium on Cropping Systems Research and Development for the Asian Rice Farmer, IRRI, Los Baños.

Paris, T. B., and E. C. Price. 1976. A computer simulation model of upland rice-based multiple cropping systems. Paper delivered at the IRRI Saturday seminar.

Perrin, R.K., D.L. Winkelman, E.R. Moscardi, and J.R. Anderson. 1976. From agronomic data to farmer recommendations: an economics training manual. Inf. Bull. 27, CIMMYT, Mexico.

Price, E.C. 1976. Economic analysis of cropping systems. *In* Report of the Cropping Systems Working Group, Dept. of Agriculture, Bangkok.

Rickards, P.A., and D.J. McConnell. Budgeting, gross margins, and programming for farm planning. Professional Farm Management Guide Book 3, University of New England, Armidale.

Servano, R. 1977. Cropping systems economic study on a rainfed lowland rice area in Iloilo, Philippines.

Thodey, A.R., and R. Sektheera. 1974. Optimal multiple cropping systems for the Chiang Mai Valley. Agric. Econ. Rep. 1. Faculty of Agriculture, Chiang Mai University.

Vincent, W.H. 1976. Farmer decision making behavior with regard to cropping systems research. Proceedings of the Symposium on Cropping Systems Research and Development for the Asian Rice Farmer, IRRI, Los Baños.

Wardhani, M.A. 1976. Rational farm plans for land settlement in Indonesia: a study using programming techniques. Thesis Reproduction Series, Development Studies Centre, Australian National University, Canberra, Australia.

Zandstra, H.G. 1976. Cropping systems research for the Asian Rice farmer. Proceedings of the Symposium on Cropping Systems Research and Development for the Asian Rice Farmer, IRRI, Los Baños.

APPENDIX A: PRICING INPUTS AND OUTPUTS

Two situations should be distinguished when realistic input and output prices are sought for farm budgeting purposes:

There is an active commercial market for the farm inputs or outputs.

This is generally true of inputs like seed, fertilizer, chemicals, and hired labor. It is also true of almost all outputs. Here market prices can be accurately used.

There is no active commercial market.

This is usually true of inputs like family labor, domestic animal time, and land. Here prices should be secured by using the principle of *opportunity cost*, which is the value or price of a resource in its best *alternative use*. Thus, if family labor spends 1 day weeding rice, and a best alternative use is hilling corn, the opportunity cost of labor in weeding rice is the extra net return from the increased yield of corn (as a result of hilling). If the alternative to weeding is off-farm employment, the opportunity cost of weeding labor is the wage earned in that employment. If there is no alternative income earning activity for the family labor, its opportunity cost is the value placed on a day of leisure, which may range from zero to a level usually well below the wage payable to hired labor during times of active labor demand. Opportunity costs are also referred to as *shadow prices*.

Animal time and land are given opportunity cost in a similar manner. Thus the opportunity cost of land for a particular crop over a particular time period will be the net return earnable from the best alternative crop grown over the same time period.

For a given farm where family labor, animal time, and land are more or less fixed in supply, opportunity costs will mainly vary with changes in demand for these resources. Such costs will therefore be higher at times of high demand, such as the peak planting season.

Appendix Table A. Prices assumed for marketable outputs and purchased inputs. Budgets for Bañares and Polido farms, Iloilo, Philippines.

Outputs	₱
Rough rice, per ton	1070
Corn, 1st crop, per ton	1300
Corn, 2d crop, per ton	1000
Yam bean, per ton	420
Mung, per kg	5
Cowpea, per kg	2.76
Inputs	
Hired labor, per hour	0.62
Hired carabao plus man, per hour	1.25
Urea (45-0-0), per kg	1.70
Ammophos (16-20-0), per kg	1.38
Solophos (0-20-0), per kg	1.04
Furadan, per kg	5.61
Thiodan, Endrin, Meptox, Eradex, Hytox, Folidol, and Methyl Phosferna, per cc	0.04

APPENDIX B: A SIMPLE LINEAR PROGRAMMING PROBLEM

Consider a farm household with the following resources and possible production activities.

Resources:	Land	5 ha
	Labor	100 hours
	Capital[a]	₱100

Possible production activities:

Rice
Corn

Let the resources necessary for cultivation of 1 ha of rice be 1 ha of land, 20 hours of labor, and ₱30; and for corn, 1 ha of land, 30 hours of labor, and ₱20.

Let the surplus from 1 ha of each production activity be ₱100 for rice and ₱60 for corn.

The problem is to decide the optimal allocation of the farmer's restricted resources of land, labor, and capital between rice and corn production. (It is clear that the resource requirements in this case preclude the cultivation of rice or corn only on 5 ha.)

This can now be represented in a matrix of the form generally used in linear programming:

Surpluses per hectare of activity		100	100
Restricted resource availabilities		Production activities	
		Rice	Corn
Land	5 ha	1	1
Labor	100 h	20	20
Capital	₱100	30	20

[a]One US$ = ₱7.35.

Appendix Table B. Code of cropping weeks.

Week	Actual dates
14	2 - 8 Apr
15	9 - 15 Apr
16	16 - 22 Apr
17	23 - 29 Apr
18	30 Apr - 6 May
19	7 - 13
20	14 - 20 May
21	21 - 27 May
22	29 May - 3 Jun
23	4 - 10 Jun
24	11 - 17 Jun
25	18 - 25 Jun
26	25 Jun - 1 Jul
27	2 - 8 Jul
28	9 - 15 Jul
29	16 - 22 Jul
30	23 - 29 Jul
31	30 Jul - 5 Aug
32	6 - 12 Aug
33	13 - 19 Aug
34	20 - 26 Aug
35	27 Aug - 2 Sep
36	3 - 9 Sep
37	10 - 16 Sep
38	17 - 23 Sep
39	24 - 30 Sep
40	1 - 7 Oct
41	8 - 14 Oct
42	15 - 21 Oct
43	22 - 28 Oct
44	29 Oct - 4 Nov
45	5 - 11 Nov
46	12 - 18 Nov
47	19 - 25 Nov
48	26 Nov - 2 Dec
49	3 - 9 Dec
50	10 - 16 Dec
51	17 - 23 Dec
52	24 - 31 Dec
01	1 - 7 Jan
02	8 - 14 Jan
03	15 - 21 Jan
04	22 - 28 Jan
05	29 Jan - 4 Feb
06	5 - 11 Feb
07	12 - 18 Feb
08	19 - 25 Feb
09	26 Feb - 4 Mar
10	5 - 11 Mar
11	12 - 18 Mar
12	19 - 25 Mar
13	26 Mar - 1 Apr

Appendix Table C. Crop production vectors[a] included in the budgeting model of Bañares farm, Iloilo, Philippines.

HISTORICAL TECHNOLOGY VECTORS	*Weeks*[c]
1. *On upland, partly owned, either family or share labor*	
Singapore corn, 1st crop[b]	17-19
Singapore corn, 1st crop, without fertilizer	17-19
Singapore corn, 2d crop	45-48
Singapore corn, 2d crop, without fertilizer	45-48
Corn/yam bean, 2d crop, without fertilizer	44-46
Mung, 3d crop, without fertilizer	52-02
2. *On rainfed and share-tenanted land, either family or share labor*	
TPR, Camaros, 1st crop	25-37
TPR, IR5, 1st crop	25-37
TPR, BE3, 1st crop	25-37
TPR, Kapopoy, 1st crop	24-37
WSR, Kapopoy, 1st crop	19-30
TPR, BE3, 2d crop	34-42
3. *On rainfed and fully owned upland, either family or share labor*	
TPR, Camaros, 1st crop	25-37
TPR, IR5, 1st crop	25-37
TPR, BE3, 1st crop	25-37
TPR, Kapopoy, 1st crop	24-37
WSR, Kapopoy, 1st crop	19-30
TPR, BE3, 2d crop	34-42

NEW TECHNOLOGY VECTORS	*Weeks*[c]
1. *On upland, partly owned, either family or share labor*	
DMR2 corn, 1st crop	23-27
DMR2 corn/yam bean, 2d crop	42-45
2. *On rainfed and share-tenanted land, either family or share labor*	
TPR, IR36, 1st crop	24-29
WSR, IR36, 1st crop	21-25
DSR, IR36, 1st crop	19-22
TPR, IR36, 2d crop	38-42
WSR, IR36, 2d crop	37-40
Mung, minimum tillage, 2d crop	38-42
TPR, IR36, 1st crop/ratoon	24-29
TPR, IR36, 1st crop/ratoon per cowpea	24-47
3. *On rainfed and fully owned upland, either family or share labor*	
TPR, IR36, 1st crop	24-29
TPR, IR36, 1st crop	21-25
DSR, IR36, 1st crop	19-22
TPR, IR36, 2d crop	38-42
WSR, IR36, 2d crop	37-40
Mung, minimum tillage, 2d crop	38-42
TPR, IR36, 1st crop/ratoon	24-29
TPR, IR36, 1st crop/ratoon per cowpea	24-47

[a]Fertilizer is applied unless otherwise indicated. [b]Each crop entry has a set of vectors (see Table 5 for an example). [c]Figures show range of planting weeks covered by set of vectors.

Other papers in this series

No. 1 Recent studies on the rice tungro disease at IRRI

No. 2 Specific soil chemical characteristics for rice production in Asia

No. 3 Biological nitrogen fixation in paddy field studies by in situ acetylene-reduction assays

No. 4 Transmission of rice tungro virus at various temperatures: A transitory virus-vector interaction

No. 5 Physicochemical properties of submerged soils in relation to fertility

No. 6 Screening rice for tolerance to mineral stresses

No. 7 Multi-site tests environments and breeding strategies for new rice technology

No. 8 Behavior of minor elements in paddy soils

No. 9 Zinc deficiency in rice: A review of research at the International Rice Research Institute

No. 10 Genetic and sociologic aspects of rice breeding in India

No. 11 Utilization of the Azolla-Anabaena complex as a nitrogen fertilizer for rice

No. 12 Scientific communication among rice breeders in 10 Asian nations

No. 13 Rice breeders in Asia: A 10-country survey of their backgrounds, attitudes, and use of genetic materials

No. 14 Drought and rice improvement in perspective

No. 15 Risk and uncertainty as factors in crop improvement research

No. 16 Rice ragged stunt disease in the Philippines

No. 17 Residues of carbofuran applied as a systemic insecticide in irrigated wetland rice: Implications for insect control

No. 18 Diffusion and adoption of genetic materials among rice breeding programs in Asia

No. 19 Methods of screening rices for varietal resistance to *Cercospora* leaf spot

No. 20 Tropical climate and its influence on rice

No. 21 Sulfur nutrition of wetland rice

No. 22 Land preparation and crop establishment for rainfed and lowland rice

No. 23 Genetic interrelationships of improved rice varieties in Asia

No. 24 Barriers to efficient capital investment in Asian agriculture

No. 25 Barriers to increased rice production in eastern India

No. 26 Rainfed lowland rice as a research priority – an economist's view

No. 27 Rice leaf folder: Mass rearing and a proposal for screening for varietal resistance in the greenhouse

The International Rice Research Institute
P.O. Box 933, Manila, Philippines

Stamp

ISSN 0115-3862

22