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LINEAR ECONOMIC MODELS OF MULTIPLE CROPPING OPERATION - WITH APPLICATIONS

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INTRODUCTION

Multiple cropping is the practice of planting a crop or crops two or more times in one year. Land, as a resource, is generally a limiting factor in most cases where multiple cropping is practiced. Hence, parallel to the profit maximization objective of multiple cropping is the goal to "minimize the number of days the land is made idle (2, p. 4).

For most developing countries, particularly those in Southeast Asia, multiple cropping is viewed as a vehicle through which increases in agricultural production can be attained. In this region, the pressure of population on land is great giving rise to a low land-man ratio. Significant increases in agricultural production in this case can not take place via extensive land cultivation. The increases in agricultural production must occur through intensive use of the existing cultivated land and the extremely limited potentially arable land (3, p. 2). Multiple cropping also is a means of organizing production to better utilize water and energy resources.

The feasibility of multiple cropping to effect an intensive use of land in countries with low land-man ratio is strengthened by significant developments in the field of plant breeding during the recent years. Specifically, the emergence of high yielding, early maturing, non-photoperiodic varieties of crops, such as rice and wheat, makes it possible for farmers to plant several times in one year on a given piece of land.

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The potential output of a particular piece of land used in multiple cropping had been investigated by Bradfield (2, p. 2). He reported that in an experiment at the International Rice Research Institute (IRRI) extending over several years, an average total of 20 tons of rough rice has been produced on one hectare of land in one year by growing three crops of the new high-yielding varieties with proper cultural practices. This output is over five times as much as the average farmer produces by using traditional varieties and practices.

Programming Models of Multiple Cropping

Attempts have been made to maximize the profit of a farm practicing multiple cropping by the use of linear programming techniques (10). The first significant thrust to develop optimization models, however, was provided by Heady and Agrawal (8). Their paper laid down the fundamental steps from which an economic optimization model of multiple cropping may be developed. Heady and Agrawal advanced that operational models of multiple cropping should determine simultaneously: (1) the optimal choice of crops within a given period of the year, (2) the optimal technology for each of these crops, (3) the optimal delineation of crop production periods within the year, and (4) the optimal sequencing of crops over the year. These basic considerations provide the benchmark in the model-building aspect of this study.

The two primary objectives of this paper are (1) to construct optimization models for multiple cropping, and (2) to apply the optimization models using actual data. The first objective is attained by use of mathematical programming techniques, and the second objective by using Philippine crop production data.

To provide a systematic presentation, the rest of this paper is divided into four sections. The first section is devoted to the construction of optimization models of multiple cropping operation. Section two discusses the sources of data used in the study and section three presents the empirical results of the study. Finally, the last section provides the summary and conclusions of the study.

Optimization Models of Multiple Cropping Systems

This paper employs the linear programming techniques and the general multiple cropping model developed by Heady and

Agrawal (8). This paper will not discuss the theoretical basis of linear programming. Adequate discussions of linear programming theory may be seen in several references (4, 6, 11, 12).

To apply linear programming in the optimization of multiple cropping, the activities involved in the operation and the constraints which limit the execution of such activities to a certain range must be defined first.

Multiple cropping operation enables the farm operator to plant a crop or combination of crops a number of times in one year. The corresponding decision-making problems facing the farm operator are: (1) finding the optimal number of cropping periods into which he should divide one year and, (2) determining the crops and the combination of crops he should plant in each cropping period.

The factors that form the basis of this decision-making process are:

1. *Activities*. Five types of real activities are employed in this study, namely: (1) the alternative crops to plant in a given cropping period, (2) a borrowing activity which will enable the farm operator to obtain the services of financing organizations, (3) transfer activities which allow the shift of unused capital resources from one month to another, (4) man labor hiring activities for each month of the cropping period and (5) man-animal labor hiring activities for each month of the cropping period.

Alternative crops included as activities for different cropping periods belong to a set restricted by their adaptability to a particular cropping season, type of land, climatic conditions, etc. These crops are assumed to be competitive, independent products with constant marginal rates of substitution (7, ch. 7), implying a linear production function for each crop activity as defined for this study.

Transfer activities used in this study are assumed to be costless. The borrowing activity, however, has a negative price equal to the prevailing rate of interest. Consequently, the man-labor and the man-animal labor hiring activities also have negative prices equal to their respective minimum wage rates.

2. *Resources*. Multiple cropping requires the same kind of inputs as an ordinary single-crop enteprise. The difference

between the two operations is the intertemporal resource allocation possible in multiple cropping. Unless otherwise stated, the availability of the following factors is on a monthly basis.

a) *Land.* Two general types of land may be considered, namely: the upland and the lowland or paddy. By and large, the above mentioned land classification admits only the crops suited to it. The upland type is generally located on an elevated area; irrigation water may or may not be available. The crops grown on this type of land do not require roots or parts of stems to be submerged in water during particular stages of their biological growth. The lowland, or paddy, on the other hand, is usually located in areas with lower elevation and an adequately controlled irrigaion system may or may not be available.

It should be stated that these two types of land are reversible, that is with adequate water supply an upland type may become a paddy and with adequate drainage and water control a paddy may become an upland. This may require, however, considerable investment on the part of the farm operator.

b) *Labor*: Two sources of labor open to the farmer are considered in this study, namely: man and animal. Man labor is of two types; one is the family farm labor which includes the sum of man-days a farm family can directly engage in farm operations, and the other is hired labor which the farm operator employs whenever the family farm labor is not enough to meet the man labor needed in farm operations. The models constructed in this study require that family farm labor be exhausted first before hired labor comes in as a resource. The supply of hired labor is considered infinitely elastic at the prevailing wage rate.

Animal labor appears in conjunction with man labor used to operate the equipment pulled by the animal. Accordingly, as a constraint, this factor becomes man-animal labor in the study. Annual animal and family labor is partitioned into subsets representing the different cropping periods.

c) *Capital.* The farm operator is generally confronted with two types of capital requirements, namely: operating capital and fixed capital. Operating capital may enter into the model in two different ways: the first treats operating capital as the aggregate of monetary units used to buy the services of other factors of production needed in the operation of the farm; the second expresses operating capital in terms of the physical units of fertilizer, hired labor, etc. that enter the program as separate constraints. The latter individual restraints however, are still determined by the amount of cash money that the farmer can afford.

As a constraint, two basic approaches can be employed in the acquisition and allocation of operating capital in multiple cropping. First, if the farm operator has or expects to have a given amount of money during the projected planning horizon, he can divide it equally or proportionally among the cropping periods (predetermined). The borrowing activity of the model allows the farmer access to credit facilities separately in each period. Accordingly, transfer activities will shift the excess capital resource from one period to another. Second, the farmer can borrow for a single calendar period. A consensus among development economists is that since in less developed countries capital is so scarce relative to other factors, it is more realistic to assume that, in a multiple cropping operation, the first cropping period uses more or less the entire operating capital budget of the farmer. In the above situation, the farmer may use the services of a loaning organization for one year or two cropping seasons (as assumed in the empirical part of this study) or borrow only for one cropping season. For the latter, the operating capital requirement of the farm for the next cropping season may be entirely generated by the preceding cropping season or supplemented by another loan. The model, in this case will optimize the system by cropping period rather than for the entire planning horizon:

3. *Prices per Activity Unit.* The definition of prices differs among the real activities of the models used in this study. The prices of the crop activities are equal to their respective gross returns per hectare. Similarly, the price of the borrowing activity is equal to the prevailing rate of interest. The transfer activities are assumed to be costless, and the prices of the man labor hiring activities and the man-animal labor hiring activities are equal to their respective wage rates per day. These definitions of prices per activity unit rule out the direct interpretation of the value on the profit row of the computer output as the maximum net return above variable cost. The maximum net return above variable cost is obtained by subtracting the cost of operator's labor used by the farm from the value appearing on the profit row of the computer output.

Prices per activity unit, as used, are treated as constants and known *a priori* for the entire planning horizon.

4. *Cropping Period.* The cropping period includes the time when land is prepared for planting up to the time of harvesting. As defined, the cropping period is a function of three time elements: 1) the time spent on land preparation and planting, 2) the time needed by the crop to mature and 3) the time spent in harvesting. The length of the cropping period could either be lengthened or shortened depending upon the farmer's efficiency in doing (1) and (3).

The number of times a farmer can plant crops in one year depends on how many cropping periods can fit into his planning horizon. This can be determined by either arbitrarily dividing the length of the planning horizon into cropping periods or letting the program model determine the cropping periods. The two models that follow make use of both methods of cropping period division.

The optimization problem presented by multiple cropping requires a multi-stage program wherein each stage or cropping period is optimized such that the resulting sum of returns from all cropping periods is a maximum. A problem of this sort is often approached via dynamic programming. The multiple cropping problem in this study, however, is constructed using the static framework. As a consequence the system gives rise to a large programming problem. The two models constructed in this paper are in a standard deterministic framework.

Model 1. Deterministic with cropping periods determined by the programming model.

The following notations are employed:

X_{jt} = amount of the j^{th} activity in cropping period t where:

$j = 1 \ldots . B-1$ crop activities
$j = B$ borrowing activity
$j = B+1, \ldots . D-1$ transfer activities
$j = D, D+1, \ldots . E-1$ man labor hiring activities
$j = E, E+1, \ldots . n$ man-animal labor hiring activities
$t = 1, \ldots . T$ cropping periods

R_{ijlt} = amount of the i^{th} resource used for the production of the j^{th} activity available on the 1^{th} month of the t^{th} cropping period

where:

$i = 1, \ldots m$ scarce resources
$l = 1, \ldots 12$ months
$t = 1, \ldots T$ cropping periods

$A = (a_{ijlt})$ = input-output coefficients in expressing the requirement of the j^{th} crop activity in the i^{th} resource in the t^{th} crop period

C_{jt} = price of the j^{th} activity in the t^{th} cropping period.

The optimization problem is constructed as:

$$(1) \quad \text{Max}\, F(X_{jt}) = \sum_{t=1}^{T} \sum_{j=1}^{n} C_{jt} X_{jt} = \sum_{t=1}^{T} C'_t X_t$$

subject

$$A_t X_t \leq R_t$$
$$X_t \geq 0$$

where C_t is a vector of prices for period t, X_t is a vector of activity levels for period t and R_t is a vector of resource amounts in the same period.

This model operates essentially by selecting the optimal activity sector on the first cropping period and proceeds to replace the crop or crops that mature early by another set of crops optimal to the model. Two goals are achieved immediately by the above operation; first idling of resources especially land could be reduced to a minimum and second, any crop among the alternatives open to the farmer can enter into the optimal activity sector with profit maximization as the primary criterion.

Model 2. *Deterministic with cropping period division determined by the cropping of the primary crop.*

The same notations as in Model 1 are used. The optimization problem is constructed as:

$$\text{Max } F\ (X_{jt}) = \sum_{t=1}^{T} \sum_{t=1}^{n} C_{jt}\, X_{jt} = \sum_{t=1}^{T} C'_t X_t$$

subject to

$$\begin{aligned} A_t X_t &\leq R_t \\ X_{kt} &\geq K_t \\ X_t &\geq 0 \end{aligned}$$

where the variables are as defined previously.

$X_{kt} \geq K_t$ defines the constraint of the model wherein at least a given output of the primary crop rice, must be produced on every cropping season. (K_t is a vector of subsistence requirements in period t.). Entrance of other crops in the optimal activity vector, among other things, depends upon whether these crops have cropping period less or equal to the cropping period X_k.

This model is particularly relevant in less developed countries where the farmers are compelled to produce a certain amount of staple crops in every cropping season. Accordingly, the prescription that a certain amounut of X_k be produuced in every cropping period guarantees that at least one crop appears in every cropping season. This is specifically helpful if all cropping periods are to be optimized simultaneously. The model, however, presents one disadvantage. That is, there exists a possibility that some resources, particularly land, may be idle at times when cropping periods of the crops included in the optimal activity vector are not equal.

Models 1 and 2 have inherent flexibility in terms of real activities, resource constraints and length of time the optimization process may be conducted. Of particular interest in the resource constraints flexibility in the ability of the model to optimize by cropping period. This enables the program to let the operating capital needed in farm operation after the initial cropipng to be financed by the preceding crop. The procedure is valid regardless of whether the farmer has to borrow his initial operating capital, has the necessary operating capital or has insufficient operating capital. The necessary flexibilities in the models that insures the farm to have the optimal amount of operating capital for the planning horizon in question is carried out by the borrowing activity and the capital transfer activities of the model.

The Data

The data used in the study came from various sources. Hence, the technological coefficients derived from these data do not refer to a particular farm. The crops covered are corn, soybeans, sweet potatoes, onions and four varieties of rice. The nature of the data for soybean, sweet potato and onion crops enables us to clearly designate the input requirements of each farm operation. This, however, could not be done on rice and corn data where the input requirements of a particular farm operation are not spelled out. To solve this problem, we resorted to the use of estimates on the input requirement of a specific farm operation. When such estimates were not available, personal knowledge and judgment were used. Throughout this section, operating capital as used does not include wages to hired labor. The different crops covered by the study are discussed separately.

a. *Rice.* The data on rice came from the farm management studies of the Department of Agricultural Economics, College of Agriculture, University of the Philippines. Collection of the data was made using a simple random sample of rice farms in the province of Laguna, Philippines. The farm was conducted during the crop year 1967-1968.

Only four varieties of rice included in the sample were used in this study. The bases for selecting the four rice varieties were: 1) the number of farms using a particular variety and 2) the average return of the farm using the variety. This is done since a subsample of $n^1 = 12$ for each of the included varieties were used for the computation of the technological coefficients, and only those varieties which gave the highest returns were included.

The four varieties selected were IR-8, Intan, Wagwag and Glutinous rice. Data on IR-8 and Intan were available for both wet and dry season croppings, while Wagwag was available only for dry season cropping and Glutinous rice for wet season cropping. All four rice varieties came from farms which are irrigated during both seasons.

Table 1 presents the technological coefficients of the four rice varieties. The value for each input on Table 1 is an aggregate of one cropping period. Transformation of the aggregate values into their disaggregated form was accomplished in the linear programming matrix. The method of disaggregation employed is essentially using the average estimates of the length of time a particular farm operation can be finished (1, 5). For example, given the total man labor days per hectare used for one cropping season, the study disaggregated the total into: 2 man labor days used for seedbed preparation, 30 man labor days for transplanting, and 35 man labor days for harvesting and threshing. The rest of labor days are distributed among fertilizing, weeding and spraying. Monthly scheduling of when a particular input is expended is accomplished by approximating the actual farm operations.

Sample farms using the four varieties included in this study employed both small tractors and water buffaloes as the source of power for land preparation. To provide homogeneity on the source of power a convertion factor was employed to transform man-tractor labor days to man-animal labor days.[1] The average number of man-animal labor days for each variety are taken to be the technical coefficient of land preparation.

The operating capital item in Table 1 includes the amount spent on seeds, fertilizers, weedicides, insecticides and miscellaneous expenses. Transforming the above inputs into their money equivalent enables the capital borrowing activity of the model to become operative. Just as in the allocation of labor resource, operating capital expended monthly was computed by approximating the actual farm operations.

b. *Corn.* The source of data on corn is also the farm management studies of the Department of Agricultural Economics, College of Agriculture, University of the Philippines. The data received were already computed on a per hectare basis and were gathered via purposive sampling. The technological coefficients of corn are presented in Table 2. together with those of soybean, sweet potato and onion crops. The total man labor days for corn covers planting, fertilizing and harvesting. Total man-animal labor days, on the other hand, includes land preparation and cultivation. Operating capital expenses are for seeds and fertilizers.

c. *Soybeans.* The data on soybeans came from the Legume Committee of the College of Agriculture, University of

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[1] On the average it takes about 13 man-tractor labor days to prepare a hectare of paddy land and 21 man-animal labor days to do the same (1). Hence, to convert man-tractor labor days to man-animal labor days, a constant equal to 1.6153 is used.

the Philippines. Table 2 presents the technological coefficients of soybean. In its original form, the soybean data denoted all farm operations with their corresponding input requirements and are used directly in the linear programming matrix. The only adjustment made in the soybean data is the use of the minimum wage rate set by the government for the labor inputs. This in effect lowered the net return of soybean in this study relative to the original data.

d. *Sweet potatoes.* The data on sweet potatoes came from the Development Bank of the Philippines' Vegetable Financing Program. Adjustments on the original sweet potato data were made in this study before entering them in the linear programming matrix. The values modified were: 1) the yield per hectare, 2) the land preparation coefficients and 3) the wage rates of both man and man-animal labor. The objective of these adjustments is to bring the data to a level attainable by average farmers. Hence, the original yield of 19 tons per hectare of sweet potatoes was reduced to 10 tons. Consequently, the land preparation coefficients in the original data which used man labor were transformed to man-animal labor using the technical coefficients of land preparation of soybeans as the benchmark. Finally, the original data used wage rates which are below the minimum level set by the government and therefore were adjusted upwards.

e. *Onions.* The data on onions also came from the Development Bank of the Philippines' Vegetable Financing Program. Adjustments made on the sweet potato crop were also made in the onion crop. In this case, the original yield of 10 tons per hectare was reduced to 8 tons. Wage adjustments entailed the raising of man labor and man-animal labor wage rates to their legislative minimum. Consequently, the technical coefficients of land preparation in the original data were transformed to their man-animal labor approximations. The technical coefficients of the onion crops can be found in Table 2.

Results and Discussions

The farm subjected to optimization procedures is assumed to have 3 hectares of cropland and a controlled water resource. Total man-labor days available to the farm per month is assumed to consist mainly of operator's labor amounting to 24 man-labor days. All man-labor days needed to supplement the available operator's labor are to be hired. The farm operator,

TABLE 1
Input-output coefficients of four rice varieties on per hectare basis, Laguna, Philippines, crop year 1967-68.

ITEMS	WET SEASON			DRY SEASON		
	IR-8	Intan	Glutinous	IR-8	Intan	Wagwag
Cropping periods (months)[a]/	5	6	5	5	6	6
Yield (Cavans)[b]/	91.81	40.78	57.10	78.88	94.98	45.68
Gross return (₱)	1323.30	823.37	1355.26	1204.75	1573.75	930.19
Net return above variable cost (₱)[c]/	316.17	45.39	474.61	200.86	684.28	46.96
Total man labor days[d]/	110.83	85.52	98.83	104.29	103.18	87.89
Total man-animal labor days[e]/	12.89	13.96	14.37	15.86	9.31	15.66
Operating capital (₱)	161.22	79.88	115.79	148.07	144.43	192.99

[a] Includes time spent on land preparation and harvesting.
[b] One (1) cavan rough rice = 44 kilograms.
[c] Animal operated farms only.
[d] One (1) man labor day = 8 man labor hours.
[e] One (1) man-animal labor day = 5 man-animal labor hours.

TABLE 2
Input-output coefficients of corn, soybean, sweet potato and onion crops on per hectare basis, Philippines.

ITEMS	Corn	Soybeans	Sweet Potatoes	Onions
Cropping period (months)[a]/	5	5	5	5
Yield	41.78 cavans[b]/	2 tons[c]/	10 tons	8 tons
Gross return (₱)	514.73	1,500.00	2,000.00	6,800.00
Net return above variable cost (₱)[d]/	293.00	704.00	1,357.00	1,004.00
Total man-labor days[e]/	8.53	19.00	220.00	476.00
Total man-animal labor days[f]/	17.00	19.00	23.00	21.00
Operating capital (₱)	49.50	416.00	800.00	2,646.00

[a] Includes time spent on land preparation and harvesting.
[b] One (1) cavan of shelled corn = 56 kgms.
[c] In metric tons
[d] Animal operated farms only.
[e] One (1) man-labor day = 8 man labor hours
[f] One (1) man-animal labor days = 5 man-animal labor hours.

however, hires additional man-labor days only when his own labor is exhausted. The wage rate followed in this paper is six pesos per day.

The farmer in the above hypothetical farm does not possess any work animals. All man-animal labor days needed for farm operation are hired outside the farm. The supply of man-animal labor is assumed to be infinitely elastic at the minimum wage rate set by the government. To simplify the program, the optimization process assumes that payments to hired man labor and man-animal labor are made at the end of two cropping periods. This, however, could be easily modified and channelled to the operating capital constraint and be paid immediately as soon as the service is rendered.

At the initial stage of the multiple cropping operation, this study assumes that the farm operator has a zero amount of operating capital. The operating capital used in financing the farm operation is assumed to be borrowed at some loaning institutions at 12 per cent rate of interest per annum. (Use of the 12 per cent rate on all capital is also equivalent to assuming the farmer has an opportunity cost at this rate on any capital he might have). Assuming further that the farm operator can borrow all he needs, the above assumption enables the farmer to attain the optimal operating capital relative to his objective function.

Optimal solutions of multiple cropping operations using Model 1 and Model 2 were obtained through the use of the IBM 360 computer of Iowa State University. The specific computer program used is MPSX/360-L.P.

Table 3 presents the optimal net returns of multiple cropping operation using Model 1 and Model 2 for two cropping seasons. As shown, Model 1 exhibited a higher net returns above variable cost than Model 2. The most apparent reason for this difference may be arisen from the fact that the farm in Model 2 was constrained to produce at least 100 cavans of rice per cropping season. The effect of the constraint also can be seen in Table 4, 5 and 6. In Table 4, it is observed that Model 1 allows only the planting of 0.25 hectare of Intan during dry season, while larger cropland areas are devoted to soybean and onion crops for both wet and dry season plantings in the optimal activity vector. On the other hand, in order to satisfy the rice constraint, Model 2 requires the planting of 0.98 hectare for IR-8 and 0.25 hectare for Intan during the wet season and 1.02 hectares of Intan during the dry season. The entrance of rice in the optimal activity vector

TABLE 3

Optimal net return above variable cost of multiple cropping operation using Model 1 and Model 2 for two cropping seasons.

Net returns above variable cost (₱)	4,219.47	5,236.88
Cropland area (Has.)	3.00	3.00
Total man-labor days	515.54	404.52
Total man-animal labor days	97.52	112.86
Operating capital[a]/ (₱)	2,309.03	2,827.14

[a] If payment to labor are to be borrowed, the following operating capitals are in effect; Model 1 = 5,524.56 pesos and Model 2 = 5,280.93 pesos. The optimality of the net returns above variable cost may not hold true at these operating capital levels however.

TABLE 4

Optimal area planted to crops using Model 1 and Model 2 for two cropping seasons in hectares.

	MODEL 1[a]/		MODEL 2[b]/	
	Wet	Dry	Wet	Dry
Rice				
IR - 8	0	0	0.98	0
Intan	0	0.25	0.25	1.05
Wagwag	0	0	0	0
Glutinous	0	0	0	0
Corn	0	0	0	0
Soybeans	2.70	2.41	1.76	1.47
Sweet potatoes	0	0	0	0
Onions	0.30	0.34	0.01	0.47
Total area[c]/	3.00	3.00	3.00	3.00

[a] Equivalent to producing 5.40 tons of soybeans and 2.40 tons of onions during the wet season, and 23.74 cavans of Intan (rice), 4.82 tons of soybeans and 2.72 tons of unions during the dry season.

[b] Equivalent to producing 89.97 cavans of IR-8 (rice), 23.74 cavans of Intan (rice), 3.52 tons of soybeans and 0.08 tons of onions during the wet season and 99.72 cavans of Intan (rice), 2.94 tons of soybeans and 3.76 tons of onions during the dry season.

[c] Figures were rounded up.

TABLE 5
Optimum input requirements of multiple cropping operation using Model 1 for two cropping seasons.

Months	Operator's man labor days	Hired man labor days	Hired man animal-labor days	Operating capital (₱)
May	24.00	59.10	41.40	643.50
June	24.00	13.80	16.20	480.30
July	24.00	8.40	0	45.00
August	7.50	0	0	0
September	24.00	0	0	202.80
October	24.00	75.97	40.81	698.59
November	24.00	15.27	14.45	487.41
Deceber	24.00	13.69	0	65.24
January	11.81	0	0	0
February	24.00	0	0	204.30
March	8.75	0	0	0
TOTAL	218.29	186.23	112.86	2,827.14

TABLE 6
Optimum input requirements of multiple cropping operation using Model 2 for two cropping seasons

Months	Operator's man labor days	Hired man labor days	Hired man animal labor	Operating capital (₱)
May	24.00	25.02	35.73	191.21
June	24.00	7.47	14.05	245.27
July	24.00	0	0	65.62
August	4.82	0	0	0
September	24.00	19.42	0	84.12
October	8.75	0	0	7.69
November	24.00	130.16	38.91	875.52
December	24.00	37.36	8.83	510.24
January	24.00	35.50	0	130.24
February	18.20	0	0	0
March	24.00	0	0	209.11
April	24.00	12.84	0	0
TOTAL	247.77	267.77	97.52	2,309.03

of Model 2 reduces significantly the area planted to soybeans for both cropping seasons.

The optimal monthly input requirements of multiple cropping operation using Models 1 and 2 are presented in Tables 5 and 6. Both models were observed to utilize with comparative efficiency the available monthly operator's labor. It was observed, however, that the multiple cropping operation for Model 2 uses more operator's and hired man labor than Model 1. For both models, a larger portion of the farmers operating capital was expended during the first two months of the cropping season. The optimal amount which the farm operator needs to borrow at a 12 per cent of interest is 2827.14 pesos for Model 1 and 2309 pesos for Model 2.

The dual activity values of multiple cropping operations using Model 1 and Model 2 are presented in Table 7. A dual activity value of a resource indicates its net marginal profitability. On Table 7, the negative sign bfeore the dual value indicates the amount of reduction in the net returns above variable cost as a unit of a particular resource is withdrawn from production. In general, the higher the dual activity value of a particular resource the more scarce is that resource.

TABLE 7

Dual activity values of resources of multiple cropping operation using Model 1 and Model 2 for two cropping seasons.

LDL[a]/	May	0	0
LDU[b]/	May	0	-904.32
OPL[c]/	May	- 6.00	- 6.00
MAL[d]/	May	-14.00	- 14.00
OCAP[e]/	May	- 1.12	- 1.12
LDL	June	0	0
LDU	June	0	0
OPL	June	- 6.00	- 6.00
MAL	June	-14.00	- 14.00
OCAP	June	- 1.12	- 1.12
LDL	July	0	0
LDU	July	0	0
OPL	July	- 6.00	- 5.34

[a] LDL (month) = lower limit of land resource in hectares
[b] LDU (month) = upper limit of land resource in hectares
[c] OPL (month) = operator's man labor days
[d] MAL (month) = man-animal labor days
[e] OCAP (month) = operating capital in pesos

MAL	July	0	0
OCAP	July	- 1.12	- 1.12
LDL	August	0	0
LDU	August	0	0
OPL	August	0	0
MAL	August	0	0
OCAP	August	- 1.12	- 1.12
LDL	September	0	0
LDU	September	-920.62	0
OPL	September	- 2.73	6.00
MAL	September	0	0
OCAP	September	- 1.12	- 1.12
LDL	October	0	397.32
LDU	October	0	0
OPL	October	- 6.00	0
MAL	October	-14.00	0
OCAP	October	- 1.12	- 1.12
RICE 1		1	6.19
LDL	November	0	0
LDU	November	-929.62	0
OPL	November	- 6.00	- 6.00
MAL	November	14.00	- 14.00
OCAP	November	- 1.12	- 14.12
LDL	February	0	0
LDU	February	- 1.12	- 1.12
OPL	March	21.06	0
MAL	March	0	-029.62
OCAP	March	0	- 3.33
LDL	March	0	0
LDU	March	0	0
OPL	April	-	0
MAL	April	-	0
OCAP	April	-	- 6.00
LDL	April	-	0
LDU	April	-	0
OPL		-	2
MAL	December	0	0
OCAP	December	0	0
LDL	December	- 6.00	- 6.00
LDU	December	0	- 14.00
OPL	December	- 1.12	- 1.12
MAL	January	0	0
OCAP	January	0	0
LDL	January	0	6.00
LDU	January	0	0
OPL	January	- 1.12	- 1.12

MAL	February	0	0
OCAP	February	0	0
RICE 2	February	1 3.33	0

As expected, land gives the highest marginal net profitability for both models used in multiple cropping operation. A reduction of one hectare of land in both models will decrease the net returns above variable cost by as much as 904 pesos to 929 pesos. Hired man and hired man-animal labors as shown by their dual activity values were employed only up to the point where their marginal net profitabilities are equal to their wage rates. Accordingly, the optimal amount of operating capital borrowed from financing organizations corresponds to the points where the marginal net profitability of operating capital is equal to its rate of interest. On the other hand, the operator's labor resource may be hired up to the point where its marginal net profitability is equal to zero. This, however, is the result of the constraint placed on the use of operator's labor. It should be stated too that whenever the operator's labor for a given month is exhausted to model will not permit hiring additionl man labor if the marginal net profitability of man labor is less than the prevailing wage rate.

Potential Models

The above models were applied from relatively scarce data and available for only a few crops. We believe that such models will have their greatest utility for more complex situation where choice is among more technologies, varieties and production periods. We could readily develop and apply such models with time and the availability of data in the future. Our partitioning of the year was quite simple. Many multiple cropping problems, particularly those involving vegetables and crops with quite different growing periods, will be more complex than the one analyzed in this paper. However, the model generally is applicable to them. Similarly, it might be used to determine the payoff of a new short-period crop variety which would allow a different meshing with periods over time for the best mix other high profit crops.

Summary and Conclusion

This study deals with the construction of linear economic models of multiple cropping operation and their subsequent application using Philippine data. Two models were constructed, namely: 1) a deterministic model where cropping periods are determined by the programming model with no restriction placed on the crops that may enter in the optimal activity vector and 2) a deterministic model where the cropping periods are determined by the primary crop. The latter requires the production of a certain amount of the primary crop to be included in the optimal solution of the model.

The results of the study indicate that among others the model can:

1) determine the optimal cropping pattern for every crop year,

2) give the optimal cropland area to be planted for each crop,

3) determine the optimal operating capital to borrow at a given rate of interest, and

4) give the optimal monthly input requirements of operator's labor, hired man labor, hired man-animal labor and operating capital.

The two models may be used primarily for planning purposes with the condition that the technological and resource constraints of the farm are known.

BIBLIOGRAPHY

(1) Alviar, N. G., "A study of tractor-and carabao-cultivated farms in Laguna", Paper presented at a seminar at the International Rice Research Institute, Los Baños, Laguna, December 11-13, 1969.

(2) Bradfield, R., "Multiple cropping systems for the tropics", Paper presented at a seminar on Traditional African Agricultural Systems and their Improvement, University of Ibadan, Ibadan, Nigeria, November 16-20, 1970.

(3) Cochrane, W. W., "Agricultural and trade development in LDC's: Implications for the United States", Paper presented at the conference on U.S. Trade Policy and Agricultural Exports, CAED, Iowa State University, Ames, Iowa, June 1-3, 1971.

(4) Dantzig, G., *Linear programming and extensions,* Princeton, N. J. Princeton University Press, 1963.

(5) Deomampo, N. R., "An economic analysis of the effect of tillage, weeding and nitrogen interaction on yield of rice," Unpublished M.S. thesis, College of Agriculture, University of the Philippines, College, Laguna, 1968.

(6) Dorfman, R., P. A. Samuelson and R. M. Solon. *Linear Programming and enocomic analysis,* New York; McGraw Hill Book Co., Inc. 1968.

(7) Heady, E. O., *The economics of agricultural production and resource use.* New York, N.Y.: Prentice-Hall Inc., 1962.

(8) Heady, E. O. and R. C. Agrawal., "Prospects and problems in multiple cropping", Report of the National Seminar on Multiple Cropping, Bigyan Bhavan, India, May 2-30, 1970.

(9) Heady, E. O. and W. Candler., "Linear programming methods. Ames, Iowa: Iowa State University Press. 1963.

(10) Kahlon, A. S. and S. S. Johl., Application of linear programming to rotational planning," *Indian Journal of Agricultural Economics,* vol. 17, No. 4, 1962, pp. 45-53.

(11) Karlin, S., *Mathematical methods and theory in games, programming and economics,* vol. 1. Reading, Massachussets: Addison—Wesley Publishing Co., Inc., 1959.

(12) Vajda, S., *Mathematical programming.* Reading, Mass.: Addison-Wesley Publishing Co., Inc., 1961.