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UNITED STATES GOVERNMENT

Memorandum

ACTION MEMORANDUM

TO : DAA/DS, Ms. Marjorie Belcher

THRU : DS/RES, Miloslav Rechcigl

DS/PO, Robert Simpson

FROM : DS/AGR, Leon F. Hesser

DATE: January 4, 1978

PD-AAQ-882

SUBJECT: Approval for Project Implementation for "Design of Cropping Patterns for Asian Small Farms"

Problem: The attached unsolicited proposal was submitted by Dr. Warren Vincent of Michigan State University. Authorization for project implementation and funding is needed.

Discussion: This project has been developed by Dr. Warren Vincent as an outgrowth of the IRRI "Cropping Systems Program" which has developed higher producing cropping patterns through the application of high levels of scientific skills and judgements of he and his fellow researchers. The work has now developed to where the earlier modules of the researchers' synthetic design systems simulation can now be refined to improve the simpler routines. The analysis of the labor and power component of the cropping system this proposal covers is the first and pilot undertaking. Properly developed it will lead to the refinement of the other four modules and make a better interpretation of the data through a step wise field research methodology. This simulation methodology allows the assembly and analysis of information on what labor and power is needed for sequential and contemporaneous crop combinations that fit changing economic and physical conditions for maximizing the returns to a farm system. The best combinations can be used in field and farm trials.

Objectives: The primary objective of this proposal is to expand and develop the labor and power component of the preliminary whole cropping system model that has been developed. It will (a) attempt to determine what factors cause the long delays in planting second crops when early maturing rice is grown; (b) specify and analyze the labor and power requirements that limit the farmers' choices in making timely operations; (c) determine the labor and power requirements to make cropping systems compatible with the risk, market, credit and investment components; and (d) provide a professional development opportunity for international rice researchers to increase their cooperative efforts.

5010-108

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The results will be useful in designing cropping systems which produce more output from the same land and labor inputs to improve human nutrition. It will have application for many of the rice producing regions of the world.

Capabilities of Investigators: Dr. Warren Vincent, Professor of Agricultural Economics at Michigan State University, is widely recognized as a leader in the development of simulation type research. Co-leader Price has worked with Dr. Vincent in the development of the earlier modules. They are very capable of successfully leading the graduate candidate through the project to its successful conclusion.

Reviews of the Proposed Project: This unsolicited small research project has been reviewed by the Asia Bureau, two members of DSB/AGR and DS/RES. All have made comments on specific parts of the project but recommended its approval.

The proposal has been reviewed by DSB/ESP/AGR and meets the requirements of an unsolicited proposal contained under AID PR 7-4.5301 (3). Therefore, it is recommended that a contract be awarded to Michigan State University without consideration of other sources.

Results: The research results will be published and an agreed number of copies furnished to AID.

Project Costs: The current estimate of cost on page 9 of the proposal do not reflect any inflationary increase over 1977 prices and wages. A conversation with Dr. Vincent indicated that the graduate student stipend at least should be increased to account for inflation.

Timing: Because this research project will be used for a graduate thesis, timing is very important; the student Michigan State has in mind needs to begin work in January if he is to be able to follow through. If approval is forth coming, it is hoped the project would be initiated by mid-January, 1978.

Recommendation: That the project be approved, with the inflation factor included, under the Small Research Project Program.

Approved: [illegible]

Disapproved: _____

Date: March 21, 1978

Clearances:

DS/AGR:WMerrill	[illegible]	Date	[illegible]
ASIA/TR:CMartin	[illegible]	Date	[illegible]
DS/PPU:RSimpson	[illegible]	Date	[illegible]
DS/RES:JErickson	[illegible]	Date	[illegible]
DS/RES:MRichcigl	[illegible]	Date	[illegible]

DESIGN ING PATTERNS FOR ASIAN SMALL FARMS

A PROPOSAL FOR A JOINT PROJECT
BETWEEN
THE AGRICULTURAL ECONOMICS DEPARTMENT
MICHIGAN STATE UNIVERSITY
AND
THE ECONOMICS DEPARTMENT
INTERNATIONAL RICE RESEARCH INSTITUTE

I. Background, Problem Setting and Need

II. Objectives

III. Project Leadership and Location of Work

IV. Operations of the Study

V. Budget

RICE-BASED CROPPING PATTERN DESIGN FOR SMALL FARMS IN ASIA

I. Background, Problem Setting and Need

The objective of the Cropping Systems Program of the International Rice Research Institute is to develop more intensive rice-based cropping patterns that produce more than farmers' present patterns and that are likely to be adopted by farmers.

Through a stepwise field research methodology in which prospective rice-based intensive cropping patterns are first hypothesized (the Design Phase), then tested against agronomic and economics criteria (the Testing Phase), a number of promising patterns have been introduced through pilot projects (the Extension Phase) with the initiatives and support of national agencies of the Philippines with which the IRRI research program has close ties.

The success of the cropping systems program to date in developing higher producing cropping patterns and projecting their adoptability to specific sites has been achieved through the application of high levels of scientific skills and judgement of well-trained researchers from a wide range of disciplines in the scientific community. Likewise, the program has called for the application of a wide range of analytical approaches to the solution to complex inter-disciplinary problems in cropping systems research.

The need is recognized now to augment previous research efforts with synthetic analyses that assemble sequential and contemporaneous crop combinations hypothesized to fit new combinations of physical and economic conditions in new or expanded regions where crop intensification is desired. Recent advances in developing micro-level computer simulation programs at IRRI and their potential for further development are offered as a timely and effective response to this need.

The problem of synthetic design through systems simulation is presented as an integrated, yet segmented, process. Each segment (module) of the process can be researched and mathematically simulated to yield useful intermediate results either independently of or in association with other system modules. The modular approach serves to coordinate research conducted in the several subject-matter areas and helps set priorities for the total research agenda. Components of the needed synthetic design process as currently conceptualized to include the following economic components; (1) the labor and power component, (2) the risk simulator, (3) the market and pricing simulator, (4) the credit and cash flow simulator and, (5) the income and investment simulator. Each of these components represent research areas for investigation by individual investigators each contributing to a comprehensive, integrated analytical system.

As a study, each of these components represent a refinement of a rudimentary comprehensive simulation of a typical Philippine farm (Appendix A) which was completed in April, 1976. As each refined component is completed it may be used in place of the simple routines contained in the original farm simulation. Therefore, each study may contain an analysis of both the intermediate results of the refined component, as well as their impact on the whole farm, the latter using the comprehensive rudimentary model.

The comprehensive model was constructed at IRRI and Michigan State University (MSU) by Tirso Paris, under the advisorship of Warren Vincent, Department of Agricultural Economics, MSU. Dr. Paris is now Assistant Professor of Agricultural Economics at the University of the Philippines, Los Banos. Maintenance and further applications of the comprehensive model are being conducted by Paris and Price in the joint UPLB - IRRI project described in Appendix B.

Further applications of the comprehensive model and an exploration of possible directions for its further development were presented by Warren Vincent, at the IRRI Cropping Systems Symposium held in September 1976. A part of the overall plan to refine the simulation components is in this proposal for new collaboration between MSU and IRRI. This proposal represents but a part of the large problem of cropping pattern design. Construction of comprehensive simulation model for pattern design requires the efforts of specialists in several disciplines including engineers, soil scientists, agronomists, entomologists, weed scientists, economists and possibly others. There is concensus among cropping systems and other researchers at IRRI that a comprehensive model is useful as a goal if it provides a method of assuring that individual studies are complementary -- that variable definitions are standard, that overlap is sought in terms of the input and output variables considered, and that redundance in creative effort is to some extent avoided. It is satisfactory if the fruits of a comprehensive approach are limited to these achievements, and linkages between component studies remain judgemental. Of much greater concern is that component studies individually provide methods of systematically assembling cropping patterns suited to well-defined subsets of physical and economic determinants of pattern performance.

In addition to the five economic studies identified above, certain components for the comprehensive effort will be developed by other researchers. The rainfall simulator from the original model is being re-estimated for new locations. A water balance model is being developed by staff of the IRRI Multiple Cropping Department (Appendix C). Improvement of the production component is a major task which is being undertaken as several independent studies of specific crops or crop sequences, for example a study of direct-seeded rice (Appendix D).

At present, all studies are based on experimental and farm level research data obtained in the Philippines. Long range plans call for adoptation of the synthetic systems design efforts to other Asian countries included in the network of nations involved in IRRI research.

This proposal and request for financial support is but a small part of the needed and projected "global" endeavor.

II. Objectives

In keeping with the above expressed need, the primary objective of this proposal is to develop the labor and power resources component of the comprehensive economic systems simulation model. Specific objectives include the following:

1. To specify and analyze a class of physical and economic relationships in the labor and power resources sub-system that affect farmers' choice and execution of rice-based cropping patterns.
2. To develop simulations of the labor and power resources component mutually compatible with other system components and which contribute operationally to the development of the comprehensive farm level simulator undergoing continuous development in the IRRI Cropping Systems Research Program.
3. To provide the opportunity for on-going interaction between and mutual professional development for members of both the Agricultural Economics Department at Michigan State University and the International Rice Research Institute who are actively involved in the project.

The first two objectives indicate explicitly that, of the several needed studies in the comprehensive research program, the labor and power component is of immediate concern. Although the farm power base is recognized as a

principal determinant of existing and potential cropping systems, little research on the problem has been conducted within the IRRI cropping systems program. The need for information here is increasingly apparent. For example, the long delays in planting second crops which have recently been observed following the new early-maturing and direct-seeded rice crops have been attributed to power deficiency. The viability of new multiple cropping patterns is, it now seems clear, partly dependent upon the size and type of farm power base.

The problem is complex because of rainfall and topographic variability and the related difficulty of concentrating water in a manner timely for land preparation and planting. A simulation of farmers' alternatives and selection of crop combinations may be based on a weekly evaluation of expected returns from planting a large number of alternative crop sequences on the various plots lying on different parts of the landscape of a typical farm, given rainfall to date and expected future rainfall. Preparing land and planting a specific plot would be chosen during a given week if expected net return from this action exceeded expected net return from all alternatives. With a given power and labor base, the choice of preparing land and planting a specific plot would constrain planting dates on other plots because work on the chosen plot would occupy the power and labor base until the activity is completed.

Changes in the labor and power base of the farm would alter prospective planting dates on other plots. The effect of different configurations of the labor and power base on cropping intensity and farm income will be examined in repeated simulations.

C. Research Assistance.

The researcher may obtain assistance for language translation, data collection, and retrieval, computation, and programming from the Cropping Systems staff of the Economics Department at IRRI, whose time shall be allocated to the study in the following equivalents:

Research Assistant or Aide	3 months
Statistical Clerk	3 months
Secretary	2 weeks

Following field experience in the Philippines the researcher will have programming services provided to convert data and program tapes to an operational condition for use on the computer of his own university. He/she will be provided typing services for preparation of the final report of the project (thesis) with copies made available to the cooperating institution. The number of copies will be mutually agreed upon by IRRI and MSU.

D. Researcher Living Allowances.

The researcher, if unaccompanied by immediate family to the Philippines, shall reside at IRRI dormitories and take meals at the IRRI cafeteria. If accompanied by immediate family, a living and housing allowance will be provided which, when compared with other graduate researchers at IRRI, is not preferential. Additional living allowance needs are a part of this request.

After conducting research in the Philippines, the researcher shall be provided a one-half time graduate assistantship for six months with associated privileges and responsibilities of graduate assistants at his/her home university.

E. Research Supplies and Facilities.

The researcher shall be provided work space at IRRI during his/her field research and receive study supplies through the Economics Department, use the Agricultural Resources Center (Computer), and otherwise avail of IRRI research facilities as an IRRI M.S. scholar or Post-M.S. fellow.

Likewise, work space and supplies will be supplied at his/her home university commensurate with other graduate students. However, supplies for computer use and preparation of the final report are included in the budget below.

F. Travel.

International Travel:

Co-leader Vincent shall make a supervisory visit to the researcher during the conduct of his/her field research at IRRI Los Banos, and/or other Philippine sites.

The researcher will make one round-trip from his home university to IRRI, Los Banos.

In-country Travel:

Co-leader Price shall make supervisory visits as needed to each primary researcher at Philippine sites away from Los Banos.

With approval of Co-leader Price, the researcher shall make such study trips within the Philippines as needed for execution of the study. As most data and facilities required for the study are located in Los Banos, the same shall be considered the location of the study.

V. Budget

The budget below represents the amount requested for financial support. It excludes the monetary contribution of IRRI to the project which includes research assistance, living and housing allowance, supplies and facilities and

in-country travel as described above. All funds requested below would be utilized in the final six months of the project except for those items associated with international travel of the project co-leader, those associated with one way international travel of the researcher and his/her family (if applicable) and the supplementary allowances for the researcher during the period of work in the Philippines.

Salaries:

1.	MSU Project Leader	
	International 1 week	743
	Domestic 1 month	2,700
2.	Computer Programmer (MSU) 1 month	800
3.	Graduate Research Assistant (Researcher)	
	Overseas 12 months	2,460
	MSU 6 months	2,970
4.	Typing services	200
5.	Salary overhead	2,650
6.	Fringe benefits	800
	Sub-total	13,323

Travel and Per diem:

1.	MSU Project Leader	
	1 RT East Lansing-Manila	1,510
	Per diem	200
2.	Graduate Student	
	1 RT East Lansing-Manila	1,510
	Minimal family transport allowance	2,000
	Sub-total	5,220

Other:

1.	Pre-departure expenses for overseas personnel	650
2.	Communications	800
3.	Computer use	600
4.	Supplies	407
	Sub-total	2,457

TOTAL: 21,000

APPENDIX A

IRRI Saturday Seminar
April 3, 1976

A COMPUTER SIMULATION MODEL OF UPLAND RICE-BASED MULTIPLE CROPPING SYSTEMS

Tirso B. Paris and Edwin C. Price[1/]

INTRODUCTION

Multiple cropping is an ancient practice but the scientific development of cropping systems which are appropriate to a given locality has been extremely slow. This requires intensive research on various cropping mixes and careful evaluation of its performance biologically and economically.

Rice, being the most important crop in the Philippines and the rest of Southeast Asian countries, has been considered the main crop in most multiple cropping experiments at IRRI. Because of dominance of rice, most of the cropping systems considered in this study are rice based.

The main approach of the study is systems analysis and simulation of farm level rice-based multiple cropping systems. This approach has found many applications both in industry and agriculture. The farm is conceived of as a system composed of several components which are interrelated to one another. Systems analysis implies looking at the farm as a whole, not only the discrete components and their interrelationships but also the effect of external influences both environmental and economic. If these interrelationships and influences can be modeled and expressed in quantitative terms, the effects of alternative courses of actions on the part of the farmer, as well as the effects of changing environmental and economic influences on the performance of the farm system, can be evaluated. Technically, this is termed simulation; it is nothing more than trying to duplicate the conditions that exist in the real world. Simulation can be done by simple pen and paper calculations. However, the more complex the system is, it becomes increasingly difficult to follow the various interrelationships of the system. Thus, the use of computers in simulation is almost a necessity in complex system simulation.

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1/ Post MS Fellow and graduate student, Michigan State University, and Economist, IRRI.

The main objectives of this study are:

(1) To develop a system model for simulating of upland rice-based multiple cropping systems.

(2) To evaluate by means of a computer simulation model the effects of environmental and economic influences, as well as alternative cropping mixes and cultural practices on the performance of the system.

PROBLEM SETTING

The simulation model developed in this study has been designed for upland areas. Eight upland crops are included, namely, palay, corn, sorghum, mungbean, cowpea, peanut, soybean, and sweet potato. The data used in this study were obtained mostly from the weekly economic surveys in Cale, Tanauan, Batangas, from 1973 to date conducted by the Cropping Systems, Economics Section at IRRI. In addition, agronomic experiments conducted in Cale and other Batangas barrios were utilized. Climatic data, especially rainfall, were obtained from the Ambulong Weather Station in Ambulong, Tanauan, Batangas, which is about 5 kilometers from Cale.

The term multiple cropping as used in this study refers to the growing of two or more crops in different areas at one time and/or the growing of two or more crops on the same area in sequence. As this implies, intercropping and relay cropping are not included.

STRUCTURE OF THE MODEL

Figure 1 shows the main components of a farm systems model. It can be seen that many components interplay in the performance of the farm system. Performance may be measured in terms of production, farm and non-farm income, total income, consumption, farm labor use, etc. The main components that seem to be important are the resource endowments of the farm (land, labor, and capital availability), market influences on the farm through product prices and input prices, the technology employed, and environmental influences as they affect yield of each crop. Note that many variables affect each of the above components and that their interrelationships are complex. It is then obvious that taking all variables into consideration is an unmanageable task and perhaps impractical for the purpose at hand.

In this study it was necessary to take a subset of all the components in Figure 1. After a number of revisions on the model structure consistent with the data availability and our own capabilities, a much simpler model was arrived at and this is shown in Figure 2. The major components of the revised and simpler version of farm system are:

1. Crop environment
2. Land allocation
3. Labor utilization
4. Product and input markets
5. Production component
6. Income component

These components are not independent of one another nor are they necessarily identifiable or conceptually discrete. Rather the subdivisions are for the sake of convenience in dealing with the whole farm.

Crop Environment

In an upland setting, rainfall is considered to be the most important environmental factor affecting crop yields. This fact has been emphasized by many researchers (e.g. Yoshida, 1975). Since rainfall is the only source of soil moisture for the plants, the simulation of rainfall is of prime importance in order to be able to determine the degree of drought stress to which the crops are subjected.

Other environmental influences such as solar radiation, temperature and relative humidity, while also important, were not included because of the lack of data base for deriving their relationship with yield.

Land Allocation

The land allocation component has the function of allocating limited land over time to various crop enterprises. It not only determines how much land is planted to a given crop in a given year but it also determines what crop occupies a given portion of land at a particular time. In this study, two alternative methods of land allocation were employed: (1) a linear programming model which maximizes total net returns subject to bi-weekly land, labor, and operating capital availability; and (2) an approach wherein an experimenter allocates land by specifying a cropping pattern, as well as the area and planting dates of each crop. Since it was difficult to physically link the simulation model and the optimizing linear programming model, the second approach was mainly used in specifying the land area planted to each crop.

Product and Input Markets

In the product and input markets, prices of each crop and costs of production inputs are determined. Prices and costs play important roles in determining the relative profitability of each crop. In this study, an effort was made to simulate the price movement of each crop. This was achieved by allowing price to vary both seasonally and randomly around its mean. Price could also be made to vary secularly by incorporating into the model trend lines of either linear or exponential form. In this study, prices are exogenous to the farm. That is, a farm by itself, cannot influence product and input prices.

Production Component

The purpose of the production component is to determine the yield of various crops given the environment under which the crops are grown, the management practices, and input levels. The yield of a crop

is the end result of the interaction of many biological, physiological and physical processes. The factors affecting these processes are numerous and it would be impossible to include each of them in a yield prediction model.

In this study, the factors which were considered to affect yield are (1) rainfall, through its effect on available soil moisture; (2) level of nitrogenous fertilizer; (3) level of weeding labor; (4) degree of insect control; and (5) variety of crop. The method for determining yield of a crop given the above factors is by the so-called reduction rates approach which is explained below.

Labor Component

In the present model, the labor component merely accounts for the use of labor in the production process. Labor requirements by operation and by time distribution are provided exogenously to the model. Thus, given the areas and the planting dates of each crop planted, the weekly labor utilization pattern is obtained for the entire simulated year.

Harvest and post-harvest labor are determined endogenously in the model. That is, they depend on the actual production. Likewise, fertilizing labor was made to depend on the actual amount of fertilizer applied. Weeding labor is pre-determined as a policy variable.

Labor availability was based on the assumption of 2.5 man-equivalents available 8 hours a day and six days a week, or approximately 120 manhours per week. This assumption compared favorably with actual observations in Cale, Batangas.

Labor is hired in the model when either of the following conditions are met: (1) if required labor is greater than available labor, or (2) when the operation is planting or harvesting or some other user-specified operation and the area planted is greater than 0.3 hectare and production is greater than a pre-specified level (500 kilograms in the model). The latter condition was entered because it has been observed that farmers in Cale, Batangas, hire most of their harvest and post-harvest labor, despite the availability of substantial family labor.

Income Component

The income component is really an accounting component, the function of which is to keep track of all farm income and expenses. It determines the total production, value of production, cost of production, and net returns of each crop planted and for the whole farm.

THE COMPUTER SIMULATION MODEL

The computer model, written in FORTRAN language,[1/] is composed of an executive routine (MAIN program) and eight major sub-programs. In addition, there are six minor sub-programs which service the major sub-programs as needed. Figure 3 shows the flow chart of the main program of the simulation model. Note that it carries out 3 functions, namely, job initialization, run initialization and simulation. Most of the job initialization is actually carried out in the compilation phase of the program through the BLOCK DATA sub-program which contains most of the exogenous data. However, when the sub-routine CONTRL is called, it reads in the number of simulation runs desired, the title of the job, and other data which are not possible to include in the BLOCK DATA.

Before the first simulation run is executed, the run is initialized first. Sub-routine CONTR1 reads the mode and options desired in a particular run while subroutineCONTR2 initializes the policy variables, namely, the area, planting date, fertilizer application level, weeding labor input and insect control expenditure level. These are either read from cards or set within the model depending on the mode of run.

There are four modes by which the simulation model could be run:

Mode 1 - Areas, planting dates, and input levels are specified by the user. The rainfall option is also set by the user.

Mode 2 - A desired input is varied internally in the model with increments specified by the user. The other inputs are held fixed internally either at zero, low, medium, or high levels or some other levels desired by the user. The rainfall pattern can either be fixed or allowed to vary between runs.

Mode 3 - Planting dates are varied between runs (read from cards) while input levels are held fixed. Again, the rainfall pattern can either be held fixed or allowed to vary in between runs.

Mode 4 - Rainfall is varied in each simulation run while holding input levels and planting dates constant.

With these different modes of running the model, various kinds of experimentation can be done with the simulation model. For example, yield response experiments can be done by using Mode 2 while the evaluation of the economic stability of a cropping pattern with respect to rainfall variability can be done using Mode 4. Some illustrative runs will be discussed below. Before doing so, however, the rainfall

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1/ Several simulation languages have been developed recently notably DYNAMO, GPSS, SIMSCRIPT and GASP. See Charlton (1971).

generator (subroutine RNGEN) and its various options, the yield predictor (subroutine PRODN), and the price generator are first elucidated.

Rainfall Generator (RNGEN)

The purpose of the rainfall generator is to provide to the model the rainfall pattern for the simulated year. The generated rainfall data will have some bearing on actual planting dates and yields of crops.

In the simulation model, there are five options available in generating rainfall: (1) generate rainfall based on the parameters of an incomplete gamma distribution for each week synthesized from actual data; (2) randomly select a year between 1949 and 1975 and to use the historical rainfall data of the Ambulong Weather Station for that year as the rainfall pattern for the simulation run; (3) use the historical rainfall data of a pre-determined year; (4) randomly select a high, medium, or low rainfall year on the basis of annual total rainfall and to use the historical data of selected year in the simulation run; and (5) use the average weekly rainfall of the Ambulong Weather Station from 1949-75 as rainfall pattern for the simulation run.

Of the above five options, only the first does not use historical data.1/ Rather, it generates weekly rainfall synthetically given the parameters of incomplete gamma function. The latter was used instead of certain other probability density functions such as normal and log-normal functions because it gives a better fit to actual data than the other functions. This fact was verified from goodness of fit Chi-square tests. This finding also agrees with the observation by other authors about the shape of the rainfall distribution.

In order to verify the acceptability of the synthetic rainfall generator, simulated rainfall data was compared with actual data. Tables 1-4 show a comparison of characteristics between 5 simulated rainfall figure and rainfall data from five randomly selected years. Note that they have almost similar characteristics in terms of total rainfall, average rainfall by quarter, number of dry weeks, and number of wet weeks.

Another test performed was to compare the weekly sums and standard deviations of 30 years of simulated rainfall data against the 27 years of actual data, as shown in Table 5. In terms of mean annual rainfall

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1/ The use of historical data for simulation purposes has been criticized by Phillips (1971).

totals and average rainfall per week, Tables 6 and 7 show that simulated and actual data have fairly similar characteristics.

In addition to the function of generating weekly rainfall, the subroutine RNGEN re-schedules the planting date of each crop if necessary, depending on the rainfall pattern. The rules adopted were: (1) if soil moisture is deficient during the week prior to the expected date of planting then expected planting is delayed by a week; (2) if soil moisture is deficient during the expected planting week, then expected planting is delayed by another week; and (3) if the planting of wet season crops are delayed, the dry season crops that follow are also delayed if the harvest period of former equals or exceeds the planting dates of the latter.

The subroutine RNGEN also determines the weekly available soil moisture based on a crude water balance model

$$ASM_t = ASM_{t-1} + RAIN_t - ET_t - RO_t$$

where ASM is average the available soil moisture, RAIN is the rainfall, ET is an estimate of evapo-transpiration and RO is the run-off. The use of a water balance model was deemed better than simply considering rainfall in a given week since a low rainfall or rainless week can be compensated by some carryover moisture in the previous week.

Finally, the subroutine RNGEN determines the number of drought stress weeks in each stage of crop growth based on the weekly available soil moisture and planting weeks. In most of the simulation runs done so far, drought was considered to have occurred in week t if ASM_t is less than 0.5 of an inch. The user can, however, specify another drought level desired. The number of drought weeks are then passed on to the production component.

Production component (PRODN)

The main function of subroutine PRODN is to determine the yield of each crop based on (1) fertilizer level, (2) weed control level, (3) insect control level, and (4) number of drought stress weeks in each stage of crop growth.

Figure 4 shows the flow chart of the production component used in the simulation model. The main approach used in the prediction of yield is the reduction rates approach. The approach suggests the use of potential yield as a starting point and then a series of reduction factors are applied to the potential yield to account for input levels and environmental influences which depart from optimum. Optimum levels of inputs and environmental factors are here defined as those levels which result in maximum yield. It is not to be confused with the economically optimum level which maximizes net economic returns or profit.

Several studies have employed the reduction rates approach of yield adjustment such as those of Longworth (1969) and Denmead and Shaw (1960). The latter applied the reduction rates on the effect of moisture stress on yields during various physiological stages of crop growth. Gomez (1975) also used a similar yield prediction framework in his model on optimizing returns in small farms.

The yield equation may be expressed as

$$Y = Yo\ (1 - r_1)\ (1 - r_2)\ (1 - r_3)\ \ldots\ (1 - r_n)$$

where Yo is the maximum yield and r_i is the yield reduction rate corresponding to given level of input X_i. Here, the maximum yield is a function of variety and soil type. On the other hand, the reduction rates are a function of actual and optimal input levels. When the level of input Xi is not equal to the optimum level X_o, there is a reduction in yield so the reduction rate r_i is positive.

The potential or maximum yield Yo may best be obtained from yield trials in experiment stations. Yield trials are usually done under the best crop environment such as complete weed control, high fertilizer levels, irrigation, and maximum insect and pest control.

The estimates on yield reduction rates can be obtained from various sources. The main source would be agronomic experiment either in experiment stations or in the field which used sub-optimal input levels. Other important sources of data are economic surveys as well as agronomic experiments done in various locations and seasons. Finally, when no data on reduction in yields due to sub-optimal input levels are available, a priori quantitative estimates or informed judgements from technical experts can be substituted.

Table 8 illustrates how the reduction rates of fertilizer is obtained. Given the fertilizer response function

$$Y = 1500 + 25N - .0417N^2$$

the resulting yield for various levels of nitrogen are as shown. Note that the optimum level of nitrogen is 120 kilograms per hectare, resulting in a maximum yield of 3000 kg. The reduction rates of other levels of nitrogen are then computed by

$$r\ (x_i) = 1 - Y_i/3000$$

where Yi is the yield corresponding to x_i level of nitrogen.

Price Generator (PRGEN)

The purpose of the price generator is to determine the price of a crop at any given week of the year. The basic assumption is that an individual farm's production, supply, and demand levels are a small part of the total market. Therefore, farmers are price takers. It is then sufficient to deal only with the total market rather than relating individual farm production with price level.

Since price determination based on demand and supply functions is a complicated matter, no attempt is made to build a demand and supply model. Instead a relatively simple method is employed wherein price is estimated by means of seasonal price indices and base prices. The base price is the expected annual average price which is determined by an equation derived by fitting a trend line on past annual data. Parameters of both linear and exponential trend lines have been estimated and the model can be conveniently revised to reflect either assumption for any crop. Based on tests of goodness of fit, prices of most crops in the model are presently assumed to vary exponentially according to the rates that have been estimated.

Annual base prices which have been projected by using trend equations are then adjusted for seasonal variation. The price for a given crop is varied monthly depending upon the actual seasonal variations that occurred in Manila markets, (which heavily influence markets in Cale, Batangas) from 1949 through 1974. The resulting prices thus reflect both trend and seasonal factors.

Two options are available for further adjusting prices: the random and non-random options. For random price generation, standard deviations (PSDEV) were computed for prices from which trend, cyclical and seasonal factors have been removed. Then the seasonal, trend price for a given month, X, is adjusted for irregular variation by the following steps:

(1) Generate a random number between 0 and 1,
(2) Determine the standardized normal deviate, Z, corresponding to the random number from step (1) above,
(3) Compute expected price as P - X + (PSDEV) (Z), where PSDEV is the standard deviation as described above.

Under the non-random option, the expected price is simply the seasonal, trend price. The random or non-random price is then used to compute gross returns from the crops and patterns which are simulated.

SOME ILLUSTRATIVE SIMULATION RUNS

Several simulation runs were done using the various modes and options of the model. At this stage, it must be emphasized that the model is in no way final. Part of the data particularly the reduction rates used were contrived rather than based on actual data. Moreover, some portions of the model are not working exactly as intended. Therefore, the simulation runs described below are meant to be illustrative rather than the final word.

1. Yield response to fertilizer, high vs. zero weeding, and insect control

This run was done using Mode 2 where fertilizer was incremented in steps of 20 kilograms per hectare. Weeding labor and insect control were held fixed at two levels: zero and high levels. The rainfall pattern in 1973 was used throughout.

Tables 9 and 10 show the simulated yield response to fertilizer of zero and high levels of other inputs, respectively. Note that in both cases, higher levels of fertilizer resulted in higher yields of each crop. Both tables also show the fact that legumes such as mung-bean, cowpea, peanut and soybean are relatively unresponsive to high levels of nitrogen.

It is significant to note, however, that yield levels of each crop are considerably higher in the case of high weeding and insect control levels than those at zero levels. Figure 5 shows that the fertilizer response curve of upland palay is higher for high weeding and insect control levels than at zero level.

Since these results reflect the assumptions that were incorporated in the production component, the outcome is not entirely unexpected. However, the multiplicative interactions of rainfall, fertilizer, and insect and weed control have not been foreseen and therefore are new information.

2. Yield response to weeding labor, high vs. low fertilizer and insect control

Tables 11 and 12 were obtained also by using Mode 2 and 1973 rainfall. However, this time fertilizer and insect control levels were held fixed while varying the amount of weeding labor. As expected yield levels were higher at high fertilizer and insect control levels than at low levels. Figure 6 shows the graphs of simulated yield response of upland rice to weeding labor.

3. Comparison of yields between favorable and unfavorable conditions.

The objective of this run was to determine the yield differences of each crop subjected to extremely unfavorable and extremely favorable growing conditions. Unfavorable conditions were simulated by using zero fertilizer, weed control, and insect control levels and low rainfall years. On the other hand, favorable conditions were simulated by high management levels along with high rainfall years. Unfortunately, the desired rainfall option (Option 4) did not work so random rainfall and average rainfall were used for the unfavorable and favorable conditions, respectively. It should be noted that

Table 13 shows the means of five runs of the resulting yields of each crop under both conditions. It can be seen that the yield differences are considerable. Yield differences are particularly large for cereals compared to legumes owing to the fact that in the model the former are more fertilizer responsive than the latter. While the differences in yield could be attributed to the large gap in management levels, the use of random rainfall versus average rainfall also likely contributes to the difference in yields. Weekly average rainfall figures tend to mask the large fluctuations in rainfall from week to week.

Table 14 further shows the considerable differences in gross and net returns as well as in labor utilization of each crop subjected to extreme management levels and conditions.

4. Comparison between intensive and non-intensive cropping patterns

The objective of this run was to compare the gross returns, crop costs, net returns, and labor utilization between a non-intensive and an intensive cropping pattern. The non-intensive cropping pattern consisted of one hectare of palay in the wet season followed by one hectare of corn in the dry season. The intensive cropping pattern consisted of 0.6 hectare of palay and 0.4 hectare of corn in the wet season and 0.5, 0.3, 0.1, and 0.1 hectare of corn, sorghum, mung, and cowpea respectively, in the dry season. Both cropping patterns were subjected to both low and high management levels. Nine replications or runs were done on each treatment.

Table 15 shows the results of the simulation runs. It is apparent that in both cropping patterns high management levels consistently resulted in higher gross returns, crop costs, net returns and labor utilization than low management levels. However, it is interesting to note that at low input levels, all economic measures are higher for the intensive cropping pattern. This can be attributed to several factors such as crop prices, yield levels, and labor requirements differences. Under high input levels gross and net returns were higher with the non-intensive cropping pattern. This can be attributed to the fact that the yield reduction rates of palay and corn in the model are such that they are more responsive to high management levels especially to fertilizer.

5. Comparison of planting dates and yields using two strategies for choice of planting date.

Two strategies for choosing planting dates were examined to determine their effect on the feasibility of a three-crop sequence, and the yields of the crops in the sequence. The simulated pattern was rice, followed by corn, followed by cowpea. One strategy was to prepare the land during the earliest week after March 1 when 0.5 inch of rain falls, and then to plant during the subsequent week when rainfall is .5 inch. The second strategy was similar, but with May 1 to 7 selected as the earliest planting week. The rainfall option used was to randomly select an actual year of rainfall from 1949 to 1974.

Nine runs were performed under each planting strategy, one rice crop was planted during the week March 5 - 11; all other planting dates were much later and closely comparable to the rice planting dates under the second strategy. An average difference of only 10 days, that is a planting delay from May 3 to 13, resulted from following the different strategies. An increase in palay yield of .1 ton resulted from the delay. (No fertilizer, insecticide, or weeding labor applications are assumed.) Simulated yield of the one early-March-planted crop was 1.27 t/ha compared to a high of 1.59 t/ha harvested from the later crops.

The tendency of Cale farmers to plant at about the same time each year has been noted previously by researchers working in the area, and this has been casually attributed to custom. However, it is apparent here that the physical environment, combined with the motivation to plant early, almost fully explains the tendency. In fact, if the one early March planting date that was simulated under the early planting strategy is deleted, then the average planting dates of the two strategies differ by only 2 days.

Corn yields were fairly uniform under both strategies, around 1.7 t/ha. This, and the fact that corn crops were usually planted in the earliest available week after rice harvest (i.e. no delays waiting for rain), indicate that soil moisture is usually ample during August.

The yield reductions resulting from early palay planting would be more than offset in an average year by better cowpea yields. In 8 out of the 9 years when an early rice planting strategy was followed, a cowpea crop was feasible and the average yield was .64 t/ha (over 9 years). By comparison, cowpea crop was possible in only 4 out of the 9 years when a late-planting strategy was followed, with an average yield of .32 t/ha (over 9 years).

Although an average 10 day delay in planting the rice crop is small, it is nevertheless critical to feasibility of planting a third crop. This conclusion is borne out by the results of pattern trials carried out in Batangas in 1974-75. Third crop cowpea ranked with sorghum ratoon, also a third crop, as giving lowest returns over variable costs (Garrity, and others, 1975).

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Table 3. Number of dry weeks, simulated vs. randomly selected years

Randomly selected years					vs.	Simulated years			
	Quarter					Quarter			
Year	1	2	3	4	Year	1	2	3	4
1953	12	5	2	7	1	13	8	2	10
1958	13	8	5	10	2	13	9	5	8
1961	13	6	3	8	3	13	8	7	5
1968	13	7	3	10	4	13	10	2	8
1970	13	9	5	4	5	13	8	5	9
Total	64	35	18	39	Total	65	43	18	40

Table 4. Number of wet weeks, simulated vs. randomly selected years

Randomly selected years					vs	Simulated years			
	Quarter					Quarter			
Year	1	2	3	4	Year	1	2	3	4
1953	0	0	0	0	1	0	0	1	0
1958	0	1	1	0	2	0	0	0	0
1961	0	1	0	0	3	0	0	0	1
1968	0	0	0	0	4	0	0	0	0
1970	0	0	1	0	5	0	0	2	0
Total	0	2	2	0	Total	0	0	3	1

Table 5. Comparison of weekly rainfall means and standard deviations, 30 years of simulated rainfall based on gamma parameters vs. actual data, Ambulong, Tanauan, Batangas (inches)

Week	Simulated		Actual		Week	Simulated		Actual	
	Mean	Std. Dev.	Mean	Std. Dev.		Mean	Std. Dev.	Mean	Std. Dev.
1	.17	.22	.30	.57	27	1.33	1.09	1.33	1.48
2	.10	.10	.18	.26	28	2.67	2.68	2.3	2.29
3	.05	.07	.11	.22	29	3.42	3.68	3.41	4.25
4	.07	.09	.10	.14	30	2.32	1.90	2.27	2.15
5	.06	.07	.19	.23	31	2.48	2.72	2.56	2.11
6	.10	.08	.08	.11	32	3.23	2.04	3.15	2.43
7	.04	.05	.11	.28	33	2.99	2.42	2.63	2.15
8	.07	.08	.13	.25	34	1.48	1.45	1.84	1.67
9	.12	.14	.31	.31	35	3.34	2.65	2.60	2.38
10	.07	.10	.28	.43	36	4.05	3.82	3.37	4.58
11	.08	.14	.21	.46	37	1.33	.98	1.72	1.03
12	.02	.04	.12	.34	38	2.37	1.25	2.42	1.74
13	.05	.07	.11	.33	39	1.78	1.35	1.55	1.37
14	.02	.04	.06	.17	40	2.23	1.96	2.36	2.21
15	.13	.20	.28	.52	41	2.78	2.15	2.42	2.45
16	.07	.15	.35	.56	42	1.92	1.49	2.25	2.56
17	.42	.51	.62	.86	43	.97	1.12	1.24	1.43
18	.80	1.07	.86	1.30	44	.96	1.03	1.45	2.63
19	.46	.71	1.02	1.28	45	1.56	1.58	1.22	1.11
20	1.68	1.74	1.35	1.75	46	1.60	1.96	1.32	1.48
21	1.68	2.03	1.49	1.58	47	1.84	1.94	1.85	2.30
22	2.31	2.75	1.67	2.35	48	1.74	2.20	1.53	1.82
23	2.08	2.37	1.62	1.[illegible]7	49	.87	1.25	1.1[illegible]	1.61
24	1.28	1.21	1.45	1.53	50	.80	.91	1.16	1.28
25	1.62	1.32	1.96	1.48	51	.56	.73	.90	1.49
26	3.11	2.62	2.61	3.27	52	.86	.99	1.16	1.71

Table 6. Annual totals and averages per week of 30 years of simulated rainfall based on gamma parameters computed from Ambulong, Tanauan, Batangas (inches)

Year	Sum	Avg/week
1	81.33	1.5
2	49.49	.95
3	64.97	1.25
4	80.99	1.56
5	70.78	1.36
6	72.60	1.40
7	77.19	1.48
8	61.94	1.19
9	76.95	1.48
10	51.28	.99
11	66.69	1.28
12	69.69	1.34
13	81.74	1.57
14	60.03	1.15
15	65.14	1.25
16	84.11	1.62
17	85.01	1.63
18	76.42	1.47
19	51.30	.99
20	46.41	.89
21	51.11	.98
22	65.86	1.27
23	70.59	1.36
24	91.77	1.76
25	73.61	1.42
26	71.59	1.38
27	55.38	1.07
28	59.35	1.14
29	82.07	1.58
30	60.29	1.16
Average	68.53	1.32

Table 7. Annual totals and averages per week of actual rainfall data, Ambulong, Tanauan, Batangas, 1949-1974 (inches)

Year	Annual Total	Avg/Week
1949	49.7	1.1
1950	67.3	1.3
1951	74.2	1.4
1952	84.3	1.6
1953	65.4	1.3
1954	54.1	1.0
1955	49.4	1.0
1956	80.4	1.5
1957	47.9	.9
1958	53.0	1.0
1959	70.2	1.4
1960	89.8	1.7
1961	85.9	1.7
1962	96.2	1.9
1963	53.8	1.0
1964	66.8	1.3
1965	46.8	.9
1966	81.7	1.6
1967	76.6	1.5
1968	53.8	1.0
1969	49.7	1.0
1970	71.0	1.4
1971	88.2	1.7
1972	91.4	1.8
1973	67.6	1.3
1974	87.9	1.7
All	69.35	1.33

Table 8 . Reduction rates for different nitrogen input levels, palay[a/]

NITROGEN (kg/Ha),	YIELD (kg/ha)	REDUCTION RATE
0	1500.0	.50
20	1958.3	.35
40	2333.3	.22
60	2625.0	.13
80	2833.3	.05
100	2958.3	.02
120	3000.0	.00
140	2958.3	.02
160	2833.3	.05

a/ Based on the nitrogen response function
$Y = 1500 + 25N - .0417 N^2$

Table 9. Simulated yield response to fertilizer, zero weeding and insect control (t/ha)a/

Crop	Fertilizer level (kg N/ha)						
	20	40	60	80	100	120	140
Palay	2.1	2.5	2.8	3.0	3.1	3.2	3.1
Corn 1	2.2	2.6	3.0	3.2	3.3	3.4	3.3
Corn 2	1.6	1.9	2.1	2.3	2.4	2.4	2.4
Sorghum	.9	1.1	1.2	1.3	1.4	1.4	1.4
Mungbean	.6	.7	.8	.8	.8	.8	.8
Cowpea	.9	1.0	1.1	1.1	1.1	1.1	1.1
Peanut	1.3	1.5	1.7	1.8	1.9	1.9	1.9
Soybean	1.1	1.2	1.3	1.4	1.4	1.4	1.4
S. potato	8.0	9.0	10.1	10.7	11.3	11.3	11.3

a/ Mode = 2, 1973 rainfall

Table 10. Simulated yield response to fertilizer, high weeding and insect control levels (t/ha)[a/]

Crop	Fertilizer level (kg/ha)						
	20	40	60	80	100	120	140
Palay	2.8	3.3	3.8	4.1	4.2	4.3	4.2
Corn 1	3.1	3.7	4.2	4.5	4.7	4.8	4.7
Corn 2	2.2	2.6	3.0	3.2	3.3	3.4	2.0
Sorghum	1.3	1.6	1.8	1.9	2.0	2.0	2.0
Mungbean	.9	1.1	1.9	1.2	1.2	1.2	1.2
Cowpea	1.3	1.5	1.6	1.6	1.7	1.6	1.5
Peanut	1.9	2.2	2.5	2.6	2.8	2.8	2.7
Soybean	1.7	1.9	2.0	2.1	2.1	2.0	1.9
S. potato	12.1	13.5	15.3	16.1	16.9	17.0	16.9

a/ Mode = 2, 1973 Rainfall

Table 11 . Simulated yield response to weeding labor, low fertilizer and insect control levels (t/ha)[a]

Crop	Weeding labor (manhours/ha)				
	20	40	60	80	100
Palay	2.3	2.4	2.6	2.6	2.7
Corn 1	2.6	2.7	2.9	3.0	3.0
Corn 2	1.8	1.9	2.0	2.1	2.1
Sorghum	1.1	1.1	1.2	1.3	1.3
Mungbean	0.7	0.8	0.8	0.9	0.9
Cowpea	1.0	1.1	1.2	1.2	1.2
Peanut	1.6	1.7	1.8	1.8	1.8
Soybean	1.4	1.5	1.5	1.6	1.6
S. Potato	9.9	10.3	10.9	11.5	11.5

a/ Mode = 2, 1973 Rainfall

Table 12. Simulated yield response to weeding labor, high fertilizer and insect control levels (t/ha)[a/]

Crop	weeding labor (manhours/ha)				
	20	40	60	80	100
Palay	3.6	3.8	4.1	4.2	4.2
Corn 1	4.1	4.3	4.5	4.7	4.7
Corn 2	2.9	3.1	3.2	3.3	3.3
Sorghum	1.7	1.8	1.9	2.0	2.0
Mungbean	1.0	1.1	1.2	1.2	1.2
Cowpea	1.4	1.5	1.6	1.6	1.7
Peanut	2.4	2.5	2.7	2.8	2.8
Soybean	1.8	1.9	2.0	2.1	2.1
S. potato	14.6	15.2	16.0	17.0	17.0

a/ Mode - 2, Rainfall Option = 3, Year = 1973

Table 13. Comparison of simulated yield, favorable vs. unfavorable conditions (t/ha)

Crop	Yield (t/ha)		% Diff.
	Unfavorable[b/]	Favorable[c/]	
Palay	1.53	4.23	276
Corn 1	1.61	4.56	283
Corn 2	1.56	4.71	302
Sorghum	0.82	2.73	333
Mungbean	0.66	1.44	218
Cowpea	0.88	1.92	218
Peanut	0.99	3.33	336
Soybean	1.07	2.42	226
Sweet potato	7.11	18.24	257

a/ Mean of 5 runs
b/ Random rainfall, zero inputs
c/ Average rainfall, high inputs

Table 14. Comparison of economic performance by crop simulated favorable[a/] vs. unfavorable[b/] weather and input conditions[c/]

Crop	Gross Returns		Crop Costs		Net Returns		Labor Utilization	
	U	F	U	F	U	F	U	F
	- pesos -						manhours	
Palay	1554	5489	330	1810	1324	3679	732	1008
Corn 1	1684	4860	388	1638	1296	3222	411	487
Corn 2	1734	5124	388	1638	1346	3486	411	487
Sorghum	372	2945	588	1808	288	1137	578	883
Mungbean	3374	7200	750	2000	2624	5200	710	861
Cowpea	4551	9600	600	1850	3951	7750	775	1027
Peanut	4122	10968	573	1823	3549	9145	767	923
Soybean	3029	6893	573	1823	2456	5070	566	932
Sweet potato	7861	18604	573	1823	7288	16781	632	827
Total -	29181	71683	4993	16213	24188	55470		7435

a/ Random rainfall, zero inputs
b/ Average rainfall, high inputs
c/ Mean of 5 runs

Table 15. Comparison between intensive and non-intensive cropping patterns (low vs. high input levels)

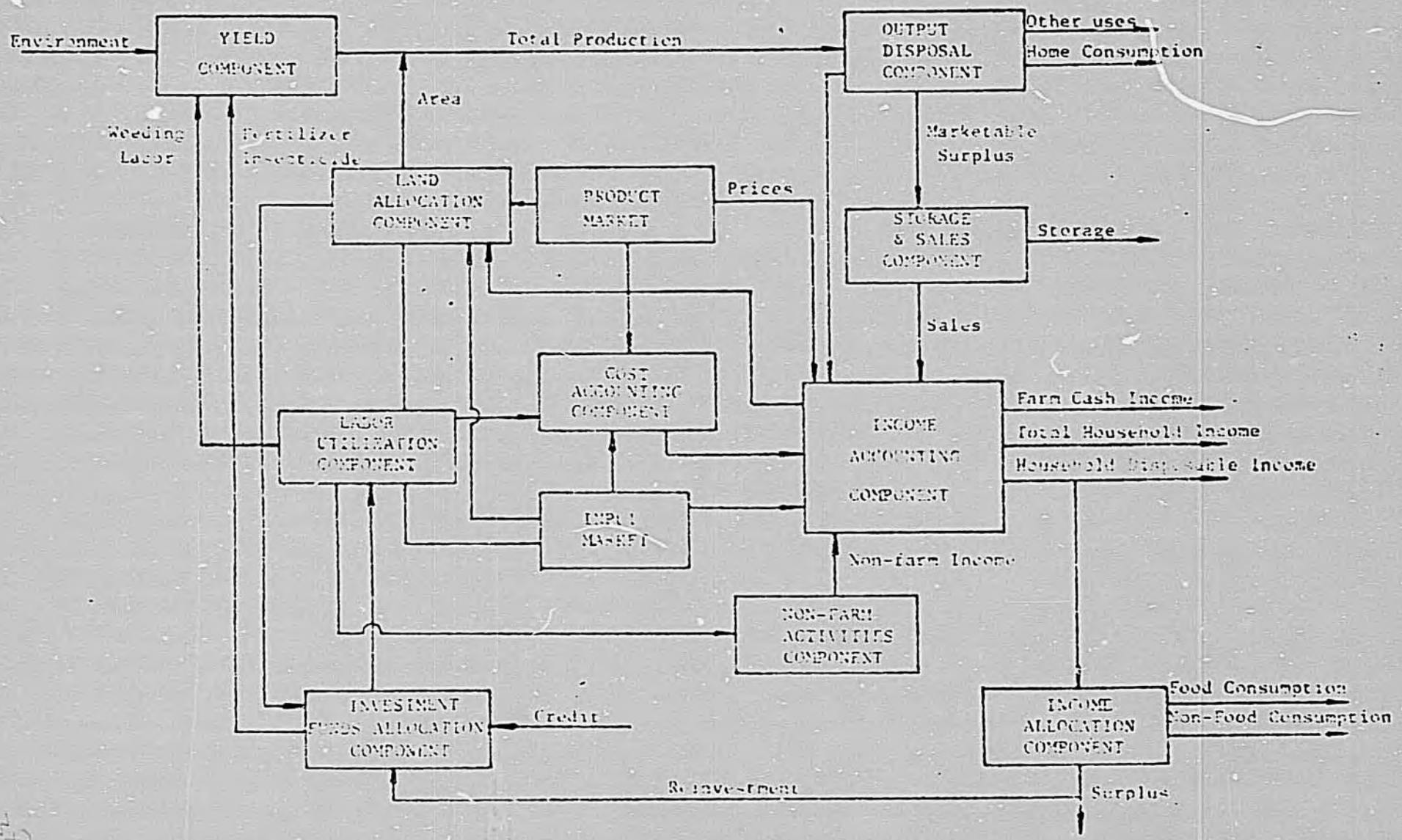
Index	Intensive[b/]		Non-intensive[c/]	
	Low	High	Low	High
Gross Returns	4819	8492	3710	8570
Crop Costs	1128	2760	948	2667
Net Returns	3691	5735	762	5903
Labor utilization (manhours)	1254	1940	1160	1460
Effective Crop Area (ha)	2.0	2.0	2.0	2.0

a/ Mode 4, Generated rainfall
b/ 1 ha. palay - 1 ha. corn
c/ Wet: 0.6 ha. palay, 0.4 ha. corn
Dry: .5 ha. corn, .3 ha. sorghum

Table 16. Comparison of planting dates and yields using two strategies for choice of planting date with low inputs

Plant ASAP After March 1			Plant ASAP After May 1		
Rainfall Years	Palay Date	Corn Date	Rainfall Years	Palay Date	Corn Date
1965	21	40	1950	26	45
1960	20	39	1966	19	38
1958	22	41	1953	19	38
1956	20	39	1957	20	39
1955	21	40	1951	18	37
1971	17	36	1975	19	38
1974	18	37	1962	19	38
1952	10	30	1963	20	39
1973	17	36	1951	18	37
Avg date	18.4	37.6	Avg date	19.8	38.8
- - - - - - - - - - - - - - - - - - Avg yield, t/ha - - - - - - - - - - - - - - - - - -					
Avg yield	1.5	1.7	1.6	1.7	

FIG. 1. GROSS STRUCTURE OF A FARM SYSTEM



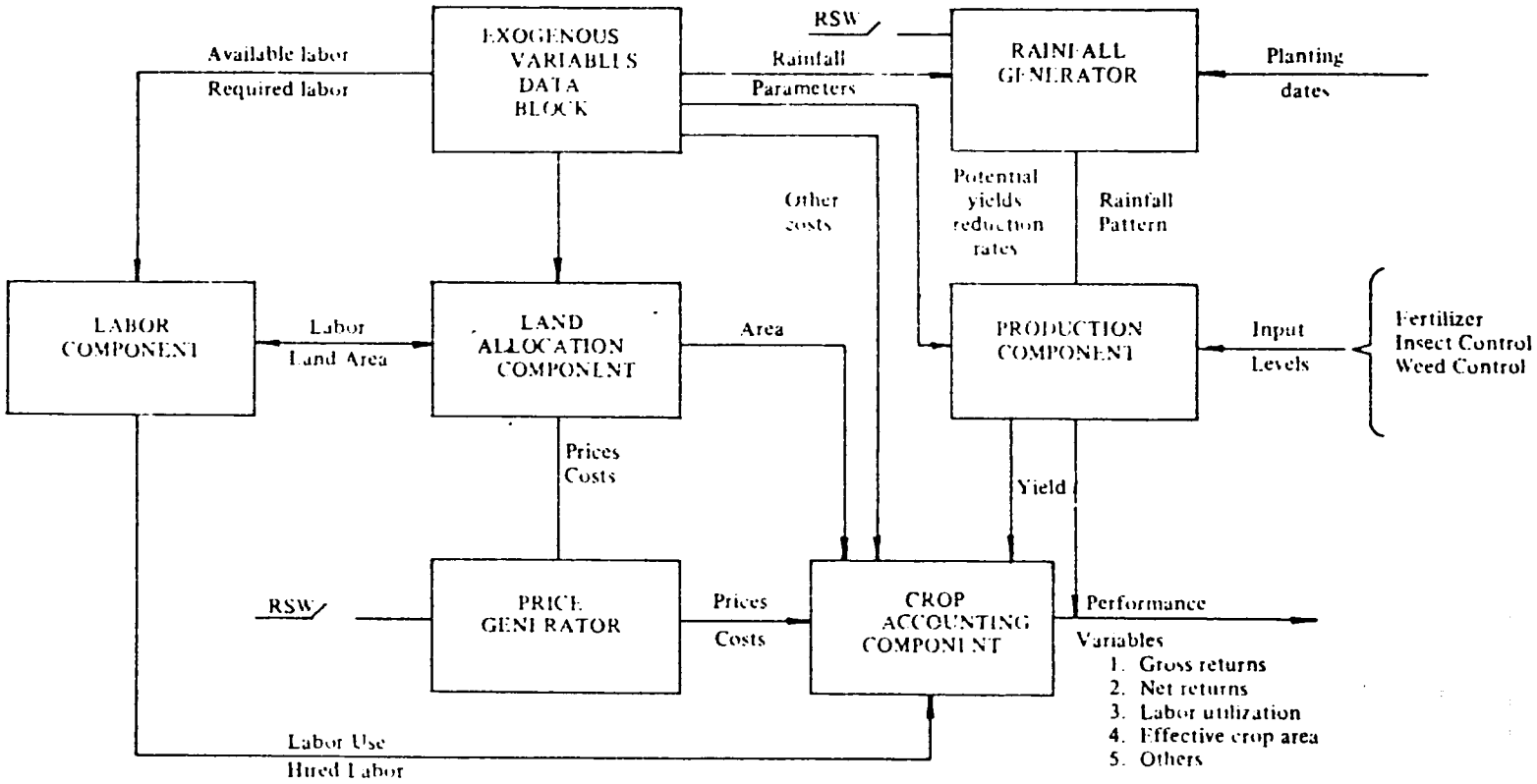


Fig. 2 Major components and interrelationships of the simulation model.

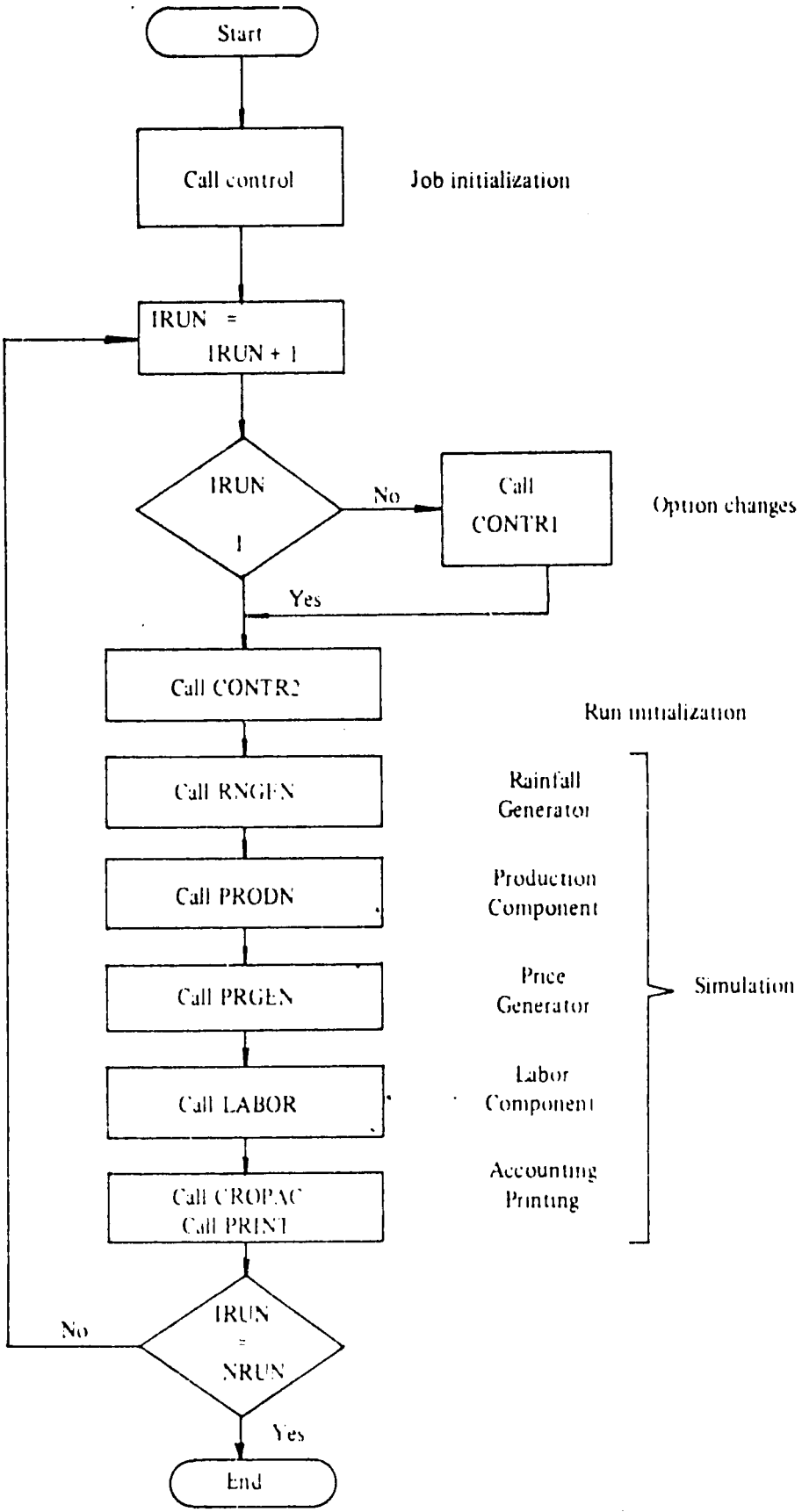


Fig. 3. Flowchart of main program, cropping systems simulation model.

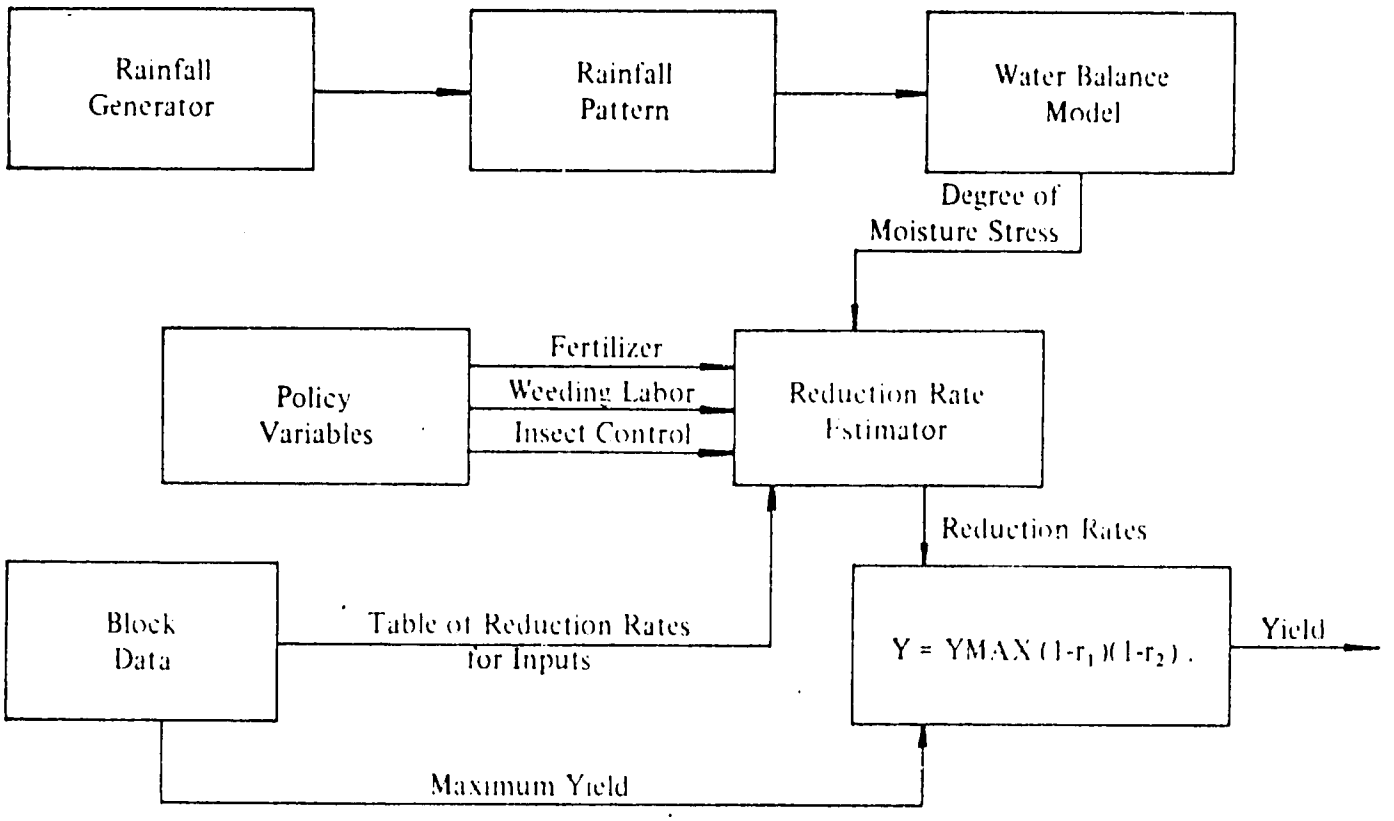


Fig. 4. Flow chart of the production component.

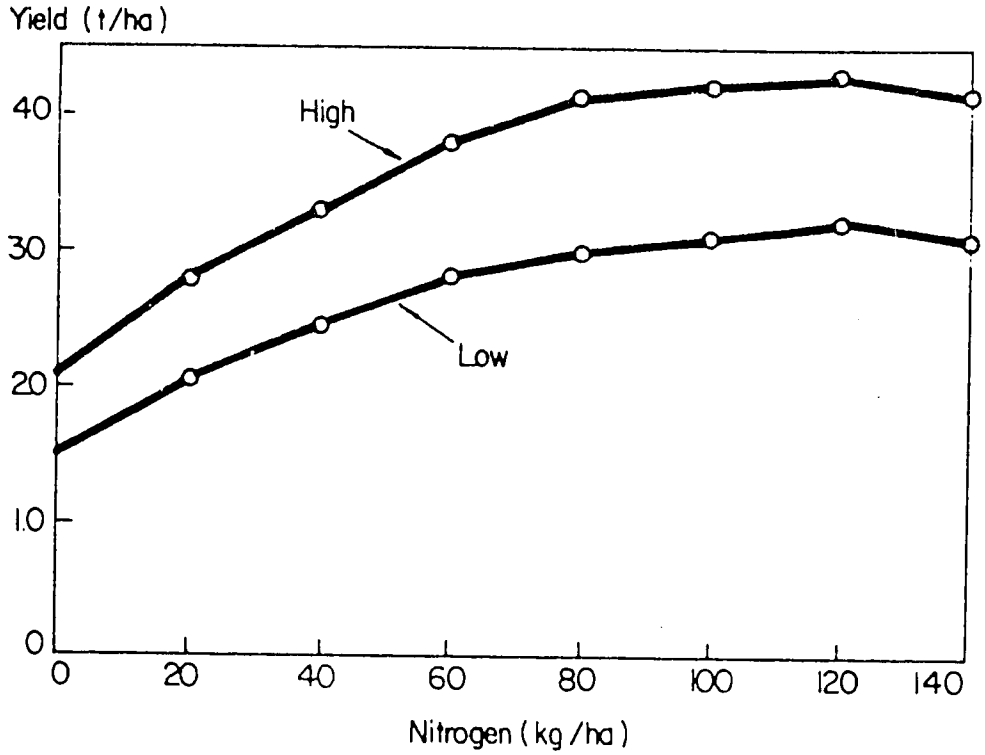


Fig. 5. Simulated yield response of upland palay to fertilizer, high vs. low weed and insect control.

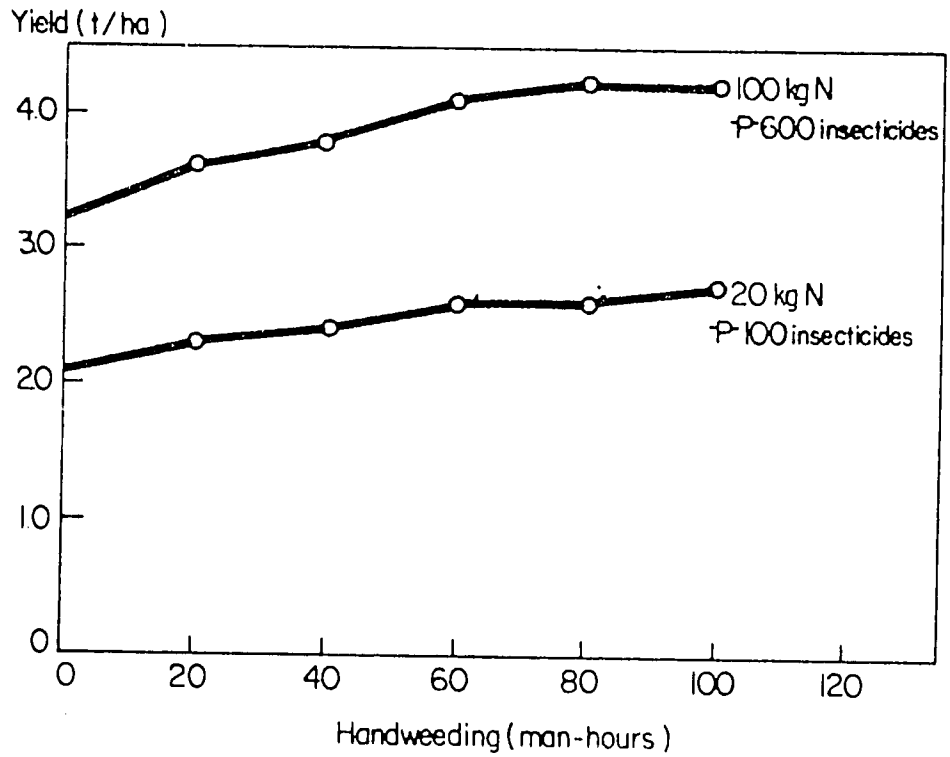


Fig. 6. Simulated yield response of upland palay to weeding, high vs. low fertilizer and insect control.

APPENDIX B

PROPOSAL

FOR A

JOINT PROJECT BETWEEN THE INSTITUTE FOR AGRICULTURAL DEVELOPMENT AND ADMINISTRATION

AND THE

ECONOMICS DEPARTMENT, IRRI

Title: Analysis of cropping pattern flexibility under variable rainfall conditions.

Objectives

1. To further develop a farm level simulation model for evaluating the economic performance of multiple cropping patterns with respect to weekly rainfall and various economic conditions at three sites in Batangas, Iloilo and Pangasinan, Philippines.

2. To compare the economic performance of cropping patterns in the three locations, including the performance of best alternatives if and when rainfall conditions necessary for execution of first choices are not fulfilled.

3. To apply the knowledge gained to the design of more productive new cropping patterns, considering fall-back alternatives.

Justification

A computerized mathematical model of a typical farm in Cale, Batangas was completed in April 1976. The model can be used to obtain estimates of crop yields, economic returns, and time profiles of input requirements for various cropping patterns

specified by the researcher. Each such prediction is based on a set of predetermined crop management techniques and exogenously determined set of output prices and weekly rainfall pattern. Simulated rainfall can be set at high, low or medium annual levels, yet randomly vary in week-to-week patterns typical of Cale, Batangas. For a number of such runs, each based on a unique but typical rainfall pattern, means variances and standard deviation of performance variables can be computed.

The model was constructed as part of the Ph.D. thesis research of Dr. Tirso Paris, and development of the model at IRRI ceased when his fellowship ended. The model, however, holds promise as a tool for cropping pattern design and testing. Furthermore, Dr. Paris, now assistant professor at the University of the Philippines at los Baños, is now in a position to continue work on the model as joint author of this proposal.

It is appropriate that a project be formulated to apply these resources to needed areas of cripping systems research. However, since crop responses to various physical and managerial parameters cannot yet be fully elaborated based on present data, applications of the model should not rely heavily upon predicted yield levels. Length of growing period, feasibility of planting with respect to rainfall, and probabilities that yields will fall within predetermined ranges, on the other hand, are comparatively more reliable items of data. This project is therefore planned to take advantage of these more accurate features, to render useful projections of pattern flexibility.

Experience of CS researchers that rainfall often forces deviations from planned pattern trials points to pattern flexibility as an issue. In Iloilo in 1976-77, only 11 percent of of pattern trials were executed as planned. Farmers' own patterns are subject to similar shifts. Initial operations for execution of first-choice patterns may favorably or unfavorably limit future alternatives within the season. With this analysis, we wish to examine robustness of alternatives once a planting strategy, i.e. first-choice pattern has been determined. We shall seek to determine which patterns provide greater flexibility for subsequent pattern shifts with respect to rainfall.

Plan of research

Additional data are now available on crop responses to various factors included in the model, rainfall, fertilizer, insecticides, and weed control measures. Weaknesses that were recognized earlier can now be partly remedied with the additional data, and this will be the initial step in the research. Also the model will be restructured to permit shifts within a simulation of the test cropping pattern, based on profit maximization, if and when rainfall does not permit timely execution of the first pattern choice. The routine would also provide an option for optimal choice and sequencing of crops based on simulated rainfall, without a preplanned sequence.

Further validation of the Calo, Batangas simulations will be carried out, in which predicted planting dates, harvest dates,

yields and yield variances will be compared to those observed under similar actual rainfall and economic conditions. Application of the revalidated model to specific research issues in Cale, Batangas will be conducted. Some of the issues are as follows:

1. Which crop sequences are feasible under Cale rainfall conditions, and which planned sequences provide the most profitable fall-back alternatives?

2. To what extent do rainfall and power and labor availability explain the observed long delays in planting second crops?

3. Do returns variability explain pattern diversity on Cale farms?

4. Why were farmer rice-sorghum pattern yields low in 1975-76 and 1976-77?

5. Why were planting dates for the sorghum crops unusually delayed?

While applications of the model to Batangas conditions are underway, the rainfall distribution parameters for Iloilo and Pangasinan will be estimated. The necessity of recomputing crop response functions for different sites will be investigated and executed if needed.

Research issues to which the Iloilo and Pangasinan models can be individually applied will be defined, then analyzed, and finally the comparative analysis across three site-models will be conducted. Labor and cash constraints can be examined at this stage, but the analysis of rainfall as a differentiating factor in cropping systems will be emphasized.

Many possibilities for further elaboration of the model are open, such as the incorporation of landscape classes and soil-related determinants. But the present project will simply help to further define these, leaving the present structure of the model intact, except for the added optimization feature.

Expected output

A quarterly, 1-3 page note on the research operations completed will be distributed to interested parties.

A paper to report methodology and major findings of the Cale, Batangas simulations will be presented in an appropriate forum by the end of one year. Another paper to present results of comparative research will be completed by the end of the second year of the project.

Other notes and discussion papers on special issues will be presented as the results permit, and these may be produced collaboratively with appropriate scientists not included among the primary researchers. The primary researchers will seek to accommodate the analysis of special issues as proposed by other scientists.

Primary researchers

Dr. Tirso Paris, Co-leader

Dr. Edwin Price, Co-leader

Assistance of other primary researchers is to be arranged on the basis of problem identification.

Operations procedures

The project co-leaders will be responsible for executing and reporting the research in a timely manner. A quarter-time econometrician will be assigned to the project and shall be responsible to the co-leaders.

Other primary researchers will critically review parameters and operational characteristics of the model, and research output, related to their respective disciplines. They will also help to formulate research issues for possible analysis using the model.

The project co-leaders shall meet regularly, and arrange between them for proper direction of the activities of the research assistant.

Duration

July 1, 1977 to June 30, 1979

Costs

Supplies, wages of research assistant, and computer time will be paid from regular budget items of the Economics Department, Cropping Systems component. An honorarium consistent with responsibilities of the co-leader and PCARR rates shall be paid to Dr. Tirso Paris, Assistant Professor, Institute of Agricultural Development and Administration, University of the Philippines at Los Baños. This shall be charged to the cooperative research item of the Economics-Cropping Systems budget. A schedule of expected costs is attached.

Budget for IADA/IPRI Project for Simulation and Analysis of Cropping Pattern Flexibility

	IADA, UPLB (P)				IRRI (P)			
	1977	1978	1979	Total	1977	1978	1979	Total
Salaries								
1. Co-Leader (Dr. T. Paris's time, 20%)	1,302	2,604	1,302	5,208				
2. Honorarium for Dr. T. Paris (at P700/mo)					4,900	8,400	3,500	16,800
3. Econometrician (1/4 time, P625/mo)					3,750	7,500	3,750	15,000
Supplies					350	600	600	1,550
Computer time					1,000	3,000	3,000	7,000
Total	1,302	2,604	1,302	5,208	10,000	19,500	10,850	40,350

APPENDIX C

2nd Draft

Crop Modeling

Accounting for Weather Influences on Corn Yields in Multi-location, Multi-season Field Studies

Weather factors are known to contribute to yield variations both between locations in any one year and between years at any one location. Therefore, weather plays an important role in the analysis of yield data obtained from field studies. However, simple meteorological measurements such as total rainfall and average temperature for selected critical periods are of questionable value for analyzing results from small plots because the conditions which precede or succeed any critical growth period can and often do have a pronounced influence on the effects of a critical period variable. This is not necessarily the case when the same critical period variable is used in a crop production study over a region as large as a province because preceding and succeeding conditions are not uniform over areas of this size. For each small component of a large region, the critical period variable will be of increased or decreased importance depending on several conditions. Because the influence of these conditions on the critical period variable for each small area tend to cancel each other when integrated over a large area, satisfactory relationships have been found between average yields of a large area and simple weather variables measured during critical periods.

If the yield variations observed on small research plots are to be accounted for by an attempt to introduce relationships between environmental factors and crop yields, complications arise. Many observations on variables such as rainfall, temperature, and net radiation must be made for each of several crop growth stages if those data are to be included in a yield analysis. Measurement of these few variables at many sites would require considerable resources in the form of equipment and time. Moreover, analysis of the resulting data, if done strictly by customary regression procedures would lead to considerable confusion because of some degree of multi-collinearity among the original or transformed weather variables. It has been shown that the inclusion of groups of correlated variables in a regression model dilutes out some of the statistical significance of the coefficients. Furthermore, pronounced and misleading shifts in regression coefficients can occur depending on the patterns of correlation among the independent variables.

A possible method of circumventing the problems described in the previous paragraphs is to develop indexes which incorporate simple weather observations into a single number or small set of numbers which represents the cumulative influences of many factors on yields. Such indexes can be obtained through the use of computer models. Through models, raw meteorological observations can be converted by appropriate computations incorporating the proper physical and biological relationships as found from other studies, into indexes which integrate the effect of weather on crop yields. Moisture stress indexes have been obtained from such models with excellent results in many instances. An appropriate model should also be able to provide information about excess moisture conditions.

It is known from other studies that the most pronounced yield reductions occur at different stages of growth. Excess moisture is most injurious in the immediate post-planting period while moisture stress becomes most harmful starting in the period just prior to anthesis and continues to affect yields during the grain-filling process.

In the general approach to computing an index or indexes to account for weather influence on yields, two requirements should be met. Firstly, the resultant index or indexes should reflect excess moisture and stress conditions simultaneously. Because these conditions affect the crop most strongly during two separate periods, and because the general responses of crop yields to abundant soil moisture in these periods are reversed, it is logical to construct a set of indexes, one for each condition. Secondly, the indexes should be appropriate for small research plots. For small plots, advantage can not be taken of the compensating conditions operative over large areas, and thus it is necessary to obtain indexes based on relationships close to known causal factors. Therefore, a moisture balance model which provides information integrated over a critical cropping period seems more likely to be successful for small plots than simple variables constructed from rainfall totals and temperature averages for different growth periods.

Dale and Shaw had developed a soil moisture budgeting technique using rainfall and Class A Pan Evaporation data to compute a stress day index which estimates the adequacy of water in the corn root zone to meet atmospheric demand. Because the Dale and Shaw soil moisture balance and stress index model had produced excellent results for several research stations within Iowa, a decision was made to modify the program to use available data in the development of stress and excess moisture indexes. Estimates of program parameters and other inputs were obtainable but

required verification. Also, model modifications necessary to calculate an excess moisture index and to improve the stress index were made to account for the impact of weather on 1200 corn yield observations collected from field plots in 7 Iowa countries over a 14 year period.

Assuming the Dale and Shaw model would prove satisfactory, literature was reviewed with the following objectives:

1. To determine characteristics of an excess moisture index
2. To seek ways to improve the stress day index
3. To find relationships necessary for estimating parameters for the root zone portion of the model from profile descriptions.

The next two sections describe the type of literature reviewed to determine the factors leading to yield reductions under conditions of excessive or inadequate soil moisture. These sections are folllowed by a third section describing the soil-plant-atmosphere continuum which served as the basis for the model. A fourth section itemizes some model data requirements and the fifth section covers the use of model-derived indexes in a regression analysis of corn yields on soil crop management and weather factors.

Corn Yield Reductions: Excess Soil Moisture

Basically, all evidence indicating the effect of excess moisture on crop yields has been derived from experiments or studies in one of the following categories:

1. Experiments incorporating high moisture treatments
2. Surface and subsurface drainage studies
3. Chemical transformations in submerged or poorly aerated soils

4. Physiological studies involving root environments with low oxygen levels
5. Disease-soil aeration studies.

As a general statement it can be said that corn yields are reduced by excessive moisture, and the critical period for yield reduction occurs in the early part of the season when the root system is small and mostly near the surface. However, the actual causes of yield decreases are not well understood. No doubt low soil oxygen levels reduce root respiration and, therefore inhibits root growth and functions. Depletion of oxygen leads to reducing conditions and alters the chemical characteristics of the soil markedly. Toxic products, either of microbial or plant origin, are important at times as are alterations in the availability of mineral nutrients. Decreases in root system extent, and changes in root morphology and function may be of major significance. Also, it is likely that many factors operate simultaneously and in interconnected ways, making simple causal statements faulty and misleading. For purposes of model development, specific causes need not be ascribed for the yield reductions. The important task is to define the conditions under which yields are reduced in order to detect them in a model simulating the air-water environment of a root system.

Corn Yield Reductions: Inadequate Soil Moisture

Corn yield reductions resulting from inadequate soil moisture are well-documented. Studies describing relationships between inadequate soil moisture and yield reduction can be placed in the following categories:

1. Corn crop analysis models using crop production data from a large area and various raw rainfall and temperature variables, or simple weather indexes, to indicate production linkages to weather factors.

2. Corn yield analysis models using average yield data from large areas and either raw weather variables or moisture budgeting models to compute satisfactory indexes which reflect weather-induced stress conditions and hence, yield reductions.

3. Stress index analysis for small plot yields using moisture balances or periodic measurements of plant available soil moisture.

4. Water treatment differences in field plot or green-house studies to induce yield losses under controlled conditions.

5. Investigations of changes in physiological processes and organ morphology in plants stressed under controlled conditions.

The investigations on the effect of inadequate moisture on corn yields generally have shown that the most severe yield depressions occur when moisture stresses arise in the periods immediately before and following silking. However, significant yield reductions do occured when stresses are suffered during other periods. Stress duration is also important in determining final yields.

As with the excess moisture case, many factors will operate simultaneously and in inter-connected ways to reduce yields. Again, for purposes of model development, specific causes need not be ascribed to the yield reductions. The important task is to define conditions under which the yields are reduced and detect them in the model simulating the soil-plant-atmosphere continuum. As a basis for further discussion about model selection and modifications, the salient characteristics of the soil-plant-atmosphere continuum are outlined below.

The Soil-Plant-Atmosphere Continuum

A discussion of the soil-plant-atmosphere continuum (SPAC) is readily divided into its three components. Reference to an electrical analogue diagram (Figure 1) will help locate each component and to determine its function in the complete system.

The analogy between water flow through a soil-plant-atmosphere system and electron flow through an electrical circuit is derived from the similarity of the flux-conductance-potential relationship which applies to both systems: between two points, the rate of flow increases with an increase in potential difference and increases with an increase in conductance.

In the soil, water moves in response to a hydraulic potential, ϕ, which is the sum of a water potential, ψ, and a gravitional potential, ψ_g. Soil hydraulic conductivity varies by soil physical characteristics such as texture and structure and also by the water content itself. Hydraulic conductivity is generally greater in light textured soils than in heavier textured soils, although this may be reversed at high soil water potentials. Hydraulic conductivity decreases with an increase in soil water potential.

Three factors pertaining to the regulation of moisture availability must be considered. Firstly, at any one instant the soil stores, as some fraction of total water capacity, a given supply of water. Secondly, the soil physical properties and the soil moisture level jointly determine the rate at which an increment of the given supply of water can be transmitted to the root system or soil surface. Thirdly, soil physical properties in conjunction with soil moisture levels, determine how rapidly and how completely

the root zone will be recharged from water located deeper in the soil including from a free water table if one occurs, and from rainfall and irrigation water. The recharging phase of the moisture regime beneath a crop is complex and dynamic because (a) the major water source, rainfall is irregular, both in frequency and amount, (b) hydraulic conductivity changes as water content changes, and (c) salient physical features of the soil profile are not uniformly distributed.

Special note should be taken of moisture changes in the vicinity of the plant root. Relative changes in (a) the reduction of hydraulic conductivity and (b) the increase in water potential gradient, determine how much water will flow to the root in response to an atmospheric demand. If hydraulic conductivity decreases more rapidly than potential gradient increases, flow will be diminished.

Once water has entered the roots, it moves through large vascular bundles to mesophyll tissue of the leaf, encountering very little resistance. Even in the mesophyll, cell resistance is generally minor. However, as water leaves the surface of the mesophyll tissue, it changes phase and moves through the substomatal cavity and stomata proper or through the cuticle under relatively high resistance. Moreover, the resistance to movement through stomata is subject to increases and decreases as leaf water potential changes.

The atmospheric conditions within and above a crop canopy influence transpiration in several ways. Water moves through the leaf boundary layer by molecular diffusion in response to a vapor pressure gradient. However, the thickness of the boundary layer depends on the wind conditions above the crop, the roughness characteristics of the crop surface and the nature

of the leaf surface. An increase in wind speed shortens the molecular diffusion path by reducing the boundary layer thickness. Because the influence of air movement on boundary layer resistance is very pronounced, the relative contribution of stomatal resistance to total diffusive resistance will depend on the degree of wind-induced alteration of the boundary layer. In still air, boundary layer resistance dominates total diffusive resistance.

An increase in wind velocity at the surface of the crop canopy causes a general velocity increase down through the canopy, which not only reduces the leaf boundary layer but also increases the potential gradient through canopy by carrying moisture away from the crop to the air above the crop. Moreover, as velocity increase turbulent diffusivity increases within the canopy. Likewise above the crop surface, water vapor flux is also proportional to the vapor gradient and turbulent diffusivity, and both these factors increase as wind speed increases. Therefore increases in wind movement lead to higher gradients and conductivities and hence to greater evaporative demand.

Model Parameter and Data Needs

Using the SPAC concept, three categories of model parameters and data are needed corresponding to three component parts. However, there are inter-relationships among the parts. These needs are discussed briefly, as they apply to a corn crop model developed to compute separate indexes for excess moisture and drought stress conditions.

Soil. Measures of plant available water capacity, total void-space, and unavailable water (water held below 15 bars) can often be estimated from soil profile descriptions which include textural classes for each horizon. Of course, the greater the amount of supportive laboratory and field test information that is available as part of soil taxonomic studies, the more reliable the estimates will be. It is more difficult to obtain information on the general rates of water infiltration and redistribution within a soil profile at different starting moisture levels. However, it is commonly accepted that water infiltrates rapidly until the void-space above the most restrictive horizon is saturated. Water in excess of the amount required to fill this space either runs off or ponds above the soil. The most restrictive horizon within the profile is usually easily identifiable from the profile description. Where the profile is relatively uniform, water is assumed to infiltrate and percolate at a rate determined roughly by the saturated hydraulic conductivity of the surface horizon. Alternatively, where only run-off is assumed, effective rainfall can be estimated based on studies which relate observed amounts of run-off to an antecedent precipitation index. This index can be based on the daily rainfall amounts for a prior defined number of days.

Recharge of the profile by side-hill seepage or from a water table at a depth sufficiently shallow to provide moisture during some crop growth stage are more difficult to deal with.

Also, reductions of moisture extraction as soil water diminishes must be estimated to determine evapotranspiration under stress conditions, i.e., when potential evapotranspiration exceeds the ability of the soil to supply water through the plants.

Several of the required soil relationships are described in Figures 2 to 6. Figure 2 shows the wilting point moisture percentage as a function of clay content. Figure 3 shows idealized water infiltration vs. time for an unobstructed profile; Figure 4 applies to a profile with an overlying restrictive layer. Figure 5 shows the general relationships used for controlling water redistribution in a profile, where the amount of downward flow is function of water-filled total pore space for 10 soil classes. In Figure 6, relative transpiration ratios as a function of soil water are plotted for different levels of atmospheric demand, before and after August 1. Table 1 shows available water holding capacity estimates which have been used to develop part of the soil parameters based on profile descriptions. In Table 2, the estimated characteristics based on a profile description have been translated into pore space description for the 10 six-inch soil layers used by the model.

Plant. The phenological dates of planting (and/or emergence if not assumed to occur a short and regular period after planting), flowering and harvest are important for tying crop growth to daily weather variables. Depth of root penetration and vertical characteristics of water extraction by stage of crop growth are also helpful, especially for crops which have an extensive and deep rooting habit. Note that the root development and moisture extraction characteristics can be modified according to restrictive profile factors. Factors relating stage of crop development and evaporative demand to potential evapotranspiration are also needed. These factors are available for most crops and are believed to be extrapolateable over a moderate range of demand conditions. Evaporation directly from a bare soil before the crop canopy covers the ground should be estimated.

Depths and fractions of water extraction as growing season progresses are given in Table 3. The ratio of evapotranspiration of corn to pan evaporation is presented in Figure 7.

Criteria must be established for excess moisture and drought stress conditions. For an excess moisture index, the criteria can be some air-filled void, which if not present constitutes an excess moisture day. There could be two or more sets of criteria to reflect the intensities of excess moisture. Furthermore, it may be useful to weigh the days according to stage of crop growth. Excess moisture during early growth stages is more critical than during later stages.

Drought stress can be determined by a turgor loss or leaf water potential function, with a minimum value set to classify a day as stress or non-stress. The turgor loss or leaf water potential values chosen as criteria are those which correspond approximately to the leaf water condition at which stomata close and gaseous exchange is greatly curtailed. If water available in the root zone is sufficient to maintain leaf water status at or above the criteria under the atmospheric evaporative demand condition, a non-stress day is recorded by the model. An alternative is to sum the relative transpiration rates over the period of interest. As with the excess moisture case, different criteria levels can be set to weigh the indexes for stress intensity.

A weighing system for stress days, based on the relative detrimental effects of stress at various stages of crop development can be helpful for improving model-derived indexes.

Atmosphere. Rainfall and evaporation or potential evaportranspiration (PET) are the main atmospheric parameters needed. PET may be estimated directly or found from evaporation by using crop growth stage factors. Pan evaporation is the most convenient and reliable measure on which to base PET, since it integrates many atmospheric factors which influence the rate of evaporation. Moreover, it is a conservative measure and can be extrapolated from a single point over a much wider area than rainfall can be extrapolated. Figure 8 shows an iso-evaporation map for one day in Iowa.

Where pan evaporation measurements are not available, PET can be estimated from temperatures, vapor pressure deficits, wind speeds and other meteorological measurements. However, there are great differences in the accuracy of these estimates, depending mainly on the appropriateness of the meteorological data the analyst has available for making estimates.

Solar radiation and direct sunlight duration are other weather factors which may be used to estimate PET, but more often these values are used to weigh the non-stress day values to indicate relative levels of photoshynthesis which should occur over different index periods.

Model Validation

SPAC crop models should be generalizable with respect to crop and environmental parameters. In other words, the model should function satisfactorily[1/] if rainfall and evaporative demand regimes are altered and soil parameters are changed. Some of these aspects were examined

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[1/] "Satisfactorily" needs to be defined in terms of the objectives of the modeling activity, i.e., the intended use of the model.

under a range of Iowa farm conditions using corn yield data from $9M^2$ field plots. The basic SPAC model could be made more general if applied to other crops.

Models can be validated on the basis of the correspondence of their component parts to measure results and/or over-all model performance to crop yield performance. As an example of the first case, a firm relationship between observed and predicted moisture profiles over the growing season indicates that the model is working satisfactorily. As an example of the later case, a strong correlation between crop yield and the stress indexes computed by the model for many sites and/or years, lends to the veracity of the model. The wiser the range of conditions over which the model works satisfactorily and the better the degree of correspondence between estimated and measured values, the more useful the model becomes. A high degress of success indicates that scientists are obtaining valid measures of the critical factors and understand their inter-related functions properly. Where models do not perform satisfactority, it can be assumed that invalid measurements of parameters have been made or that the relationships between components have not been properly established or both, and in either case further investigations are needed to better understand the system.

Use of the Model-Derived Indexes in Regression Analysis

The model described in the abbreviated flow chart (Figure 9) was used to compute excess moisture and drought stress indexes. The portions of the model marked by asterisks indicate sections in which either modi-

modifications or adaptations were made to better suit the data available or the purposes to which the results were to be applied.

In the early stages of checking the model parameters and the implied relationships within the model, smaller sets of data were used from a few of the study counties. Adjustments were made on some of the variables and on the relationships used. As an example, comparisons of methods of water redistribution are presented for 3 soils in Table 4.

After several exploratory criteria for drought stress and excess moisture index calculations were examined using smaller sets of data, five indexes for drought and three for excess moisture were retained and examined through simple correlation with the entire set of data. Except for X3, the drought stress indexes were based on a summation of relative transpiration over the period starting 21 days before and ending 42 days after 75% silk emergence.

DEFCT is a simple relative transpiration summation, DEFCTW is weighted for growth stage, DEFCTV is weighted for growth stage and energy, and X1 is weighted for grow stage, energy and the ratio of evapotranspiration to pan evaporation for the stage of crop development. X3 is a version of an index based on relative leaf turgidity weighted for energy and growth stage.

The EXMO2, EXMO3 and EXMO4 excess moisture indexes are based on criteria of 10.0%, 12.5% and 15.0% airspace in the root zone of the crop, respectively. If the model estimates that a soil layer in which the roots are growing has less airspace than these amounts in terms of volume percentage, an excess moisture condition is recorded. The excess moisture days are weighted according to growth stage, with early excess moisture being more detrimental than late.

Based on simple correlations between yield and drought stress indexes, and on partial correlations where the influence of EXMO2 and EXMO3 were partialled out, DEFCTV was selected as the appropriate variable to use in the general analysis of county data. Similarly, EXMO2 was selected as the excess moisture index to use in the subsequent regression analyses. Table 5 gives the simple correlations between yield and the indexes.

After final adjustments were made, data from the seven counties were used as a basis for the first major regression analysis using three classes of variables: soil crop management, and weather (model-derived indexes). An exploratory regression model contained 73 variables including selected interaction and quadratic terms of some linear variables. The R^2 for this model was 65.1%. As expected, many coefficients in the model were not significant and therefore the variables associated with many non-significant coefficients were discarded to form a 54-variable model. Subsets of variables from the 54-variable model were used to form four other models. Three additional variables, years, planting date, and percent barren stalks were introduced to specify four additional models. The models are outlined in Table 6 which also contains model degrees of freedom, R^2 and F-ratios for each model.

M1 represents the contribution of weather to yield, whereas M2 represents the soil and crop management factors. The weather indexes plus all interaction terms thought to be important were added to M2 to obtain M5. In M3, the drought stress indexes and some interactions were examined in conjunction with the soil and crop management variables, whereas in M4, the excess moisture index and soil and crop management

factors were examined. A model containing only two variables, planting date and percent barren stalks, was specified for M6. This model was combined with M1 to form M7. A linear time variable (years) was added to M5 to form M8, and M6 was added to M8 to form M9. F-ratios indicate that all models were statistically significant, i.e., at least one coefficient was different from zero. All coefficients in models M1, M6 and M7 were significant at the 5% level except for the interaction between EXMO2 and DEFCTV in M1, which however, was significant at the 10% level. Many variables especially interactions, in M2 were not significant and would normally have been omitted, except the analysis was aimed more at evaluation of the weather indexes, so no further consideration was given to reducing the soil and crop management components.

F-ratios from the analyses of variance of the extra sum of squares obtained by combining four sets of models are presented in Table 7. For example, R(M7/M1) designates the extra sum of squares attributable to the variables in M7 which are not also in M1. Except for the time trend (Set III), all groups of added variables increased the regression sum of squares significantly. In terms of hypotheses, the F-ratios indicate with a high probability that at least one coefficient in each added group was not equal to zero.

When added to the other variables, each group in Set II has contributed significantly to explaining variation about the mean, although the addition of EXMO2 and its interaction terms was less important in total. The combined sum of squares from R(M5/M3) and R(M5/M4) exceeded R(M5/M2) only slightly, which can be partly attributed to the stress-excess moisture interaction in M5. This result indicates that there is very little overlap

used to incorporate fertilizers; these few were, perhaps, not sufficient to give a good test of either the main effects or the interactions with stress. The stress interactions with total preplant N and total weeds were nonsignificant also. The interactions of D_v with side-dressed N fertilizer, preplant K (less disked-in K), and soil test P were all positive, indicating decreased responses rates to nutrients under conditions where D_v was less than its mean. The interactions between crop sequence code for N and D_v was negative; since the code value increased as the availability of N from the previous legume crop decreased, this negative interaction indicated that response to legume N decreased when D_v was less than its mean. For the interaction of D_v and preplant P (less disked-in P), the negative coefficient indicated that increased response rates occurred when D_v was less than its mean. Similar conclusions can be drawn for soil test N and soil test K. The coefficient for the stand level and D_v interaction was positive, indicating increased response rates for D_v values greater than its mean.

Five interactions between EXMO2 and soil and management variables were included in M5. Of these, only two were significant at the 10 percent level. The positive coefficient for the interaction between row-placed P fertilizer and EXMO2 indicated an increase in response rate to P when EXMO2 exceeded a mean value of 0.24, i.e., as excess moisture conditions increased. Row-applied P was the only row-applied fertilizer carried as a linear variable and in an interaction with EXMO2 because of the high degree of correlation between all row-applied nutrients. Therefore, the effect of row-applied P in offsetting excess moisture conditions may also be partially attributed to row-applied N and K. A positive interaction between soil test N and EXMO2 indicated an increase in the rate of response

to soil test N values when EXMO2 exceeded 0.24. The t-values for the coefficients of the interactions between EXMO2 and the transformed tile distance variable, preplant N, and total weeds were not significant at the 10 percent significant level although the t-value for the weed interaction coefficient approached it. The total weed by excess moisture index interaction is not readily interpreted because of the difficulty in distinguishing between the cause and effect of weed growth under excess moisture conditions.

As a final comment, the model worked reasonably well in generating drought stress and excess moisture indexes. Having more precise profile and evaporation information for each site undoubtedly would have improved the model. But collection of detailed information requires resources, and most significantly foresight, both of which are often lacking.

In the analysis two specific additional items would have been helpful. The first is solar radiation. Pan evaporation was used as a proxy for solar energy as an energy weight in the model. This probably caused the lower drought stress regression coefficients in the western counties in comparison to the eastern counties whereas the central county coefficients were intermediate. (Separate analyses were run for each of the seven counties). The western counties receive much more adverted energy which does not increase potential photosynthesis. Appropriate sets of relationships possibly could be worked out from historic data for solar radiation and evapotranspiration for western, central and eastern areas of the state. Better still, measurements of solar radiation could have been made directly at a few select locations.

Secondly, corn hybrids vary in their genetic potential and more significantly; in their ability to tolerate drought stress. In the analysis, no simple way had been developed to rank the multitude of hybrids used by farmer cooperators in the study. Also, information about hybrid parentage is difficult to obtain from the many private firms engaged in corn breeding.

It appears a system of rankings of the common hybrids based experiment station yield tests may be of some aid, but many of the lesser known hybrids used by many cooperators would lead to some loss of data for analysis, especially for the early years. The use of percent barrens takes into consideration some of the genetic potential and tolerance to drought conditions, but also overlaps with stress indexes.

RAM:ajas
9 May 1977

Table 1. Available water holding capacity estimates[a] for determining initial PAWC values (from SCS Laboratory, Lincoln, Nebraska)

Soil textural classes	Surface soil 0-12"	Subsoil 12-36"	Lower horizons 36-60"
	--- Inches moisture per inch of soil ---		
Coarse sand and gravel	.04 to .06	.03 to .05	.02 to .04
Sands	.07 to .09	.06 to .08	.05 to .07
Loamy sands	.10 to .12	.09 to .11	.08 to .10
Sandy loams	.13 to .15	.12 to .14	.11 to .13
Fine sandy loams	.16 to .18	.15 to .17	.14 to .16
Loams and very fine sandy loam	.20 to .22	.17 to .19	.17 to .19
Silt loams	.22 to .23	.20 to .22	.20 to .22
Silty clay loams	.21 to .23	.18 to .20	.18 to .20
Sandy clay loams	.18 to .20	.16 to .18	.15 to .17
Clay loams	.17 to .19	.15 to .19	.14 to .16
Silty clays and clays	.12 to .14	.11 to .13	.11 to .13

[a]The ranges of available water capacity shown are the estimated water-retention differences between 1/3-bar and 15-bar tensions for the medium and fine textured soils, and between 1/10-bar and 15-bar for the moderately coarse and coarse textured soils.

Table 2. An example of a soil profile transformation to a layer pore space description. Linn County, Site No. 33

Soil profile data:

Horizon thickess, in.	6	7	6	5	11	5	15	5
Clay percentage	24	26	29	30	32	20	20	33
Horizon bulk density, g/cc	1.18	1.19	1.20	1.22	1.37	1.65	1.68	1.72
Horizon PAWC, in./in	0.23	0.23	0.20	0.20	0.19	0.17	0.17	0.19
Horizon wilt percentage	7.7	8.6	10.0	10.5	11.7	6.2	6.2	12.2

Layer pore space description:

Layer number	1	2	3	4	5	6	7	8	9	10
Bulk density, in./6-in.	1.18	1.19	1.20	1.22	1.37	1.42	1.66	1.68	1.68	1.71
PAWC, in./6-in.	1.38	1.38	1.23	1.20	1.14	1.12	1.02	1.02	1.02	1.12
WILT, in./6-in.	0.46	0.52	0.59	0.62	0.70	0.65	0.37	0.37	0.37	0.67
Total pore space-WILT, in./6-in	2.87	2.79	2.70	2.62	2.20	2.15	1.87	1.82	1.82	1.45
AIRSP, in./6-in.	1.49	1.41	1.47	1.42	1.06	1.03	0.85	0.80	0.80	0.33

Table 3. Moisture extraction from soil profile during the growing season. Values for each date are given as the percentage of stressed evapotranspiration (STET) that is removed from each of the depths listed (Shaw, 1963).

Dates	Percent of STET which comes from respective depths	Depths from which water was extracted
to June 7	100	1st 6 inches
June 8 to 14	100	1st foot (equally from each 6 inches)
June 15 to 27	67.7, 33.3	1st, 2nd foot
June 28 to July 4	60, 20, 20	1st, 2nd and top half of 3rd foot
July 5 to 11	60, 20, 20	1st, 2nd and 3rd foot
July 12 to 18	60, 15, 15, 10	1st, 2nd, 3rd and top half of 4th foot
July 19 to 25	60, 15, 15, 10	1st, 2nd, 3rd and 4th foot
July 26 to Aug. 1	60, 10, 10, 10, 10[a]	1st, 2nd, 3rd, 4th and upper half 5th foot
After Aug. 1	60, 15, 15, 10[b]	1st, 2nd, 3rd and 4th foot
	60, 10, 10, 10, 10[a]	1st, 2nd, 3rd, 4th and 5th foot
	60, 15, 15, 10	1st, 2nd, 3rd and 4th foot

[a]Used only if first 4 feet all have 50 percent available moisture.

[b]Used if any of first 4 feet have 50 percent available moisture; however, after Aug. 1, the percent available is always computed on the total available water in the 5-foot profile.

Table 4. Comparisons of methods of redistribution. Periods 1, 2, 3 and 4 refer to 12, 36 60 and 84 hr after infiltration.

Soil, method, and redistribution class	Depth, inches	Percent moisture for each period 1	2	3	4
Floyd Method A	0-6	45	44	43	43
	6-12	45	44	43	43
	12-18	44	42	42	41
	24-30	39	37	37	36
Floyd Method B	0-6	40	38	38	38
	6-12	40	38	38	38
	12-18	36	35	33	32
	18-24	30	29	28	28
	24-30	28	28	28	28
Floyd - Class 8 Observed average of 4 plots (Nielsen, 1958)	3-9	41	39	39	39
	9-15	38	38	37	37
	15-21	34	33	33	33
	21-27	30	29	28	28
	27-33	30	29	29	29
Webster Method A	0-6	51	50	50	49
	6-12	50	49	49	49
	12-18	49	49	48	48
	18-24	50	49	49	49
Webster Method B	0-6	49	46	44	42
	6-12	46	44	41	39
	12-18	42	40	38	36
	18-24	40	38	36	36
Webster - Class 10 Observed average of 4 plots (Nielsen, 1958)	3-9	47	46	45	45
	9-15	40	39	39	38
	15-21	39	39	38	38
	21-27	40	39	38	38
Marshall Method A	0-6	32	31	31	31
	6-12	34	33	32	32
	12-18	34	34	34	34
	18-24	36	34	34	34
	24-30	35	34	34	34
Marshall Method B	0-6	33	31	31	31
	6-12	34	32	31	30
	18-24	34	34	34	34
	24-30	34	34	34	34
Marshall Class 4 Observed average of 5 plots (Burrows, 1957)	3-9	32	31	31	31
	9-15	33	32	31	31
	15-21	35	34	34	34
	21-27	36	34	33	33
	27-33	36	34	33	33

Table 5. Simple correlations between weather indexes and yield

Index	Coef.
DEFCTV	0.433
DEFCTX	0.405
DEFCTW	0.347
DEFCT	0.336
X1	0.434
X3	0.419
EXM02	-0.141
EXM03	-0.120
EXM04	-0.120

Table 6. AOV of models M1 to M9

Model	Variables	df	R^2	F-ratio
M1	Weather Indexes and Interactions	5	22.5	71.1
M2	Soil and Crop Management	32	49.1	36.1
M3	Drought Stress Index + Soil and Crop Management	46	63.0	43.8
M4	Excess Moisture Index + Soil and Crop Management	39	50.7	31.3
M5	Weather Indexes + Soil and Crop Management	54	64.7	39.8
M6	Planting Date + % Barrens	2	23.5	187.9
M7	Models M1 + M6	7	37.2	103.5
M8	Model M5 + Time	55	64.7	39.1
M9	Models M8 + M6	57	73.7	57.6
	Total Observations	1229	-	-

Table 7. Analysis of variance for the extra sum of squares given the indicated sub-model was present in the full model

Set	Source	df	F-ratio
I	R(M7/M1)	2	156.5
	R(M7/M6)	5	54.6
	Res(M7)	1221	
II	R(M5/M2)	22	23.5
	R(M5/M3)	8	6.8
	R(M5/M4)	15	31.0
	Res(M5)	1174	
III	R(M8/M5)	1	0.4
	Res(M8)	1173	
IV	R(M9/M8)	2	200.4
	R(M9/M6)	55	40.7
	Res(M9)	1171	

APPENDIX D

USE OF SIMULATION IN EVALUATING THE ECONOMICS OF DIRECT SEEDING IN RAINFED LOWLAND AREAS OF ILOILO, PHILIPPINES

CORAZON T. ARAGON

1. INTRODUCTION

1.1 Background of the Problem

About 75 per cent of the total rice area in the Philippines depends entirely on rainfall and most of the measures to increase rice production in the past were confined to the more stable high yielding irrigated rice areas. Approximately 45 per cent is classified as rainfed lowland (Table 1). In Western Visayas where Iloilo is located, rainfed lowland rice constitutes 71 per cent of the total rice hectarage. Most of the rainfed areas in the country, however, have low cropping intensities producing only a single rice crop with the fields left fallow during the remainder of the year. Moreover, paddy yields in these areas are also generally low, averaging only 1.4 t/ha. Recent studies conducted by the International Rice Research Institute (IRRI) revealed that the widespread practice of the transplanting method and the reluctance of government agencies to direct their research and development efforts toward risky rainfed areas are among the major causes of low yields of rainfed rice in the Philippines.[1/]

Under rainfed conditions, transplanting is considered a risky method of growing rice because of the vagaries of the monsoon rains which completely regulate the schedule of paddy activities. The amount of rainfall impounded by the paddy bunds determines when the land can be plowed and puddled and

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[1/] V.E. Ross, "Asian Rice Farmers Can Harvest 7000 Crops of Rainfed Rice by Direct Seeding". International Rice Research Institute, Los Baños, Laguna.

Table 1. Area and production of rainfed lowland rice in the Philippines, by region. Crop year 1973-74.

Region	Total rice hectarage (ha)	Rainfed lowland rice (ha)	Percentage rainfed lowland rice area	Production (mt)	Grain yield (t/ha)
Philippines	3,436,800	1,533,090	44.6	2,194,480	1.39
Ilocos	351,370	209,320	59.6	289,030	1.37
Cagayan Valley	392,570	53,250	13.6	192,000	1.35
Central Luzon	506,550	35,840	7.0	361,140	1.80
Southern Luzon	446,250	51,890	11.6	235,600	1.40
Bicol	340,530	15,460	4.5	159,450	1.29
Western Visayas	419,560	298,320	71.1	446,850	1.45
Central Visayas	79,620	51,850	65.1	76,580	1.45
Eastern Visayas	162,030	103,490	63.8	117,200	1.14
Western Mindanao	137,980	49,040	35.5	92,110	1.74
Northern Mindanao	272,790	39,630	14.5	108,680	1.10
Southern Mindanao	327,550	24,900	7.6	114,560	1.15

Source: Bureau of Agricultural Economics.

trials initiated by IRRI and BAEx (Bureau of Agricultural Extension) technical staff in Bulacan and Nueva Ecija. Experience in these experiments have shown that in establishing the first rice crop, transplanting technique which wastes 2-3 months of growing time can be substituted by direct seeding.. There are several advantages to this method of rice production. This method eliminates several farm operations such as seedbed preparation, care of seedlings, hauling and transplanting and thereby reduces labor cost.[4/] Moreover, this technology is designed to enable farmers to harvest two crops during the regular growing season. The saving in time which also results from the elimination of some farm operations enables the farmer to grow a second rice crop before the onset of the dry months. Moreover, with the use of an early-maturing variety, IR1561, which matures 95 to 100 days, a farmer is able to harvest the direct seeded rice crop in late August or early September, during lean months when he can get premium prices for his produce.[5/]

Because the potential of the direct seeding technique is so attractive, the Philippine government launched the Masagana 99 direct seeding program in May, 1974 to motivate rice farmers to adopt this new planting technique. This program was implemented during Phase III of the "Masagana 99" national rice production program and carries the same package of technology available under the Masagana 99 rice project including financing up to P1200 per hectare for rainfed areas.[6/]

[4/] University of the Philippines. 1970. Rice Production Manual. Department of Agricultural Communication, Los Baños, Laguna.

[5/] Lilia V. Ortega. "Sabog-tanim. A Method that Solves the Problem of Drought." 1975. Agricultural Newsletter 1(2), Department of Agriculture, Diliman, Quezon City.

[6/] Vernon W. Ruttan, "Research as the Economics of Technological Change in American Agriculture," Journal of Farm Economics, Vol. XLIII (4), Nov. 1960, pp. 735-756.

when the seedbed can be prepared and sown.[2/] A major drawback of the transplanting method is the need for enough water to submerge the land before planting.[3/] Consequently, in many rainfed areas, it is necessary to wait for 2-3 months of rain before enough water is accumulated for planting. Farmers impound the early rains to puddle the soil and normally transplant during the period of rainfall. When the early monsoon rain is scanty or when monsoon rains are late, transplanting often is delayed. Because of the delay in transplating, farmers are able to harvest their long season rice crops only at the end of the rainy season (November-December) which prevents them from growing a second crop. Moreover, during the months of September, October and November, rainfall is receding and drought finally occurs during the final 60-days growth period when the rice crop is urgently in need of water. Since the reproductive and ripening stages fall during the period of less intense, receding and quite uncertain rainfall, risks for drought damages are high and consequently, rice yields are reduced.

In recent years, policy makers and agricultural scientists have shown serious concern over this vast area under rainfed crops. In efforts to maximize yield and farm income per unit area, the direct seeding technology was recently developed for farmers in rainfed areas. Direct seeding is a method of planting rice wherein the seeds are sown directly in the main field (wet or dry paddy) either by broadcasting, drilling or dibbling. This technology was formulated based on the results of three years of applied research

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[2/] James R. Hoopper III, "Possibilities of Increasing Rice Production in Rainfed Areas of Central Luzon, Philippines," 1974, Unpublished Master's Thesis, University of Florida.

[3/] A. Gomez and D.A. Carandang, "Performance of Direct Seeded Rice in Farmers' Fields", Paper presented at the Annual Conference of the Crop Science Society of the Philippines at Davao City, May 10-12, 1976.

1.2 The Problem

Technological change in agriculture covers adoption of new farming techniques which have been developed through research and innovation to bring about an increase in agricultural production and greater economic returns to farmers. In the Philippines, the introduction of the direct seeding technique is an important technological development in rainfed areas. However, the direct seeding technique has to be both technically and economically feasible if it is to be adopted by the farmers and be socially acceptable.

Since its introduction, the direct seeding technology, however, failed to meet expectations for their rapid spread over wide areas. In Bulacan, for instance, despite the success of three years of applied research trials, as well as, the Pilot Extension Program on Direct Seeding of Rainfed Rice in this province, direct seeding is no longer widely practiced. Owing to the unsuitability of the rainfall pattern for the past two years, farmers in this province have found that it is not possible nor profitable to have a two-crop sequence. On the other hand, because of its favorable climate, direct seeding is widely practiced in Iloilo. This method of planting is considered an old practice in the province but Iloilo farmers in the past used this method with traditional varieties at very low management levels. In 1975, through the IRRI Cropping Systems Program, early maturing HYV's such as IR28 and IR30 were introduced and they rapidly replaced the indigenous early maturing local varieties such as Kapopoy and Speed 70 in the 1976 early wet seeded rice.

There are four new basic operations in the new direct seeding technology being introduced at present. These operations are:

1. The use of early maturing varieties;

2. Early land preparation

3. The application of pre-emergence herbicides; and

4. Early seeding.

This early land preparation technology would have a different way off from year to year depending on yearly changes in rainfall pattern. Consider, for example, the very high rainfall early in the season in 1975 and in 1976 in Iloilo and the very late rains this year, as well as in 1974. This study is, therefore, conducted to determine the effect of selected factors of which weather is the most important on the economic benefits derived from the new direct seeding technology.

1.3 Objectives of the Study

The major objective of this study is to conduct simulations to demonstrate and/or predict the effects of agroclimatic factors (e.g. variation in rainfall, landscape position, planting date, etc.) on the economic performance of the wet seeding method in Oton and Tigbauan, Iloilo. More specifically, the objectives are:

1. Given the variability in rainfall pattern, to test out the potential for double cropping of the new direct seeding technology.

2. To compare the relative economic merits of the wet seeding and the transplanting methods given the variability in annual weather conditions.

3. For selected ~~Within given~~ rainfall patterns, to determine the effect of different planting dates of the first wet seeded rice crop on the feasibility of a two-crop sequence.

4. Given a rainfall distribution, to demonstrate and/or predict the effects of several set of prime factors (landscape position, nitrogen level, weeding labor, insecticide and herbicide used) on the yield of ~~direct~~ wet seeded vs transplanted rice.

The importance of this study is that the models can serve as a basis for extrapolating to other rainfed lowland areas with similar agro-climatic characteristics.

2. RESEARCH METHODOLOGY

2.1 Source of Data

The province of Iloilo occupies the southern half of the Panay island, one of the Visayan islands which comprise the central portion of the Philippines. The climate in the area has, on the average, 5 to 6 consecutive wet months with 200 mm or more rain and 2-4 dry months with less than 100 mm of rain.

Iloilo was chosen as the study area because:

1) the rice growing environment in this province is very suitable for direct seeding and double cropping, and

2) data on rainfed lowland rice production is available due to its being one of the outreach sites of IRRI Cropping Systems Program.

The Iloilo outreach sites are located in the municipalities of Oton and Tigbauan which are adjacent coastal towns, 15 and 27 km, respectively, southwest of Iloilo City, the provincial capital. The outreach sites are composed of three villages of Oton and four villages of Tigbauan (Table 2). In these areas, the climate is characterized by an 8-month rainy season from May through December and a 4-month dry season from January through April. These villages are essentially rainfed with a small but increasing portion receiving partial and alternate irrigation. Out of 8,079 hectares of cultivated land in Oton about 95% hectares are rainfed while in Tigbauan, out 5,502 hectares of cultivated land, 99% hectares are rainfed.[7/]

[7/] N.M. Romas and M.P. Genecila, "Socio-Economic and Agronomic Characteristics of Existing Cropping Systems of a Rainfed Lowland Rice Area in Iloilo", Seminar Paper Presented to the Annual Meeting of the Philippine Agricultural Economics Association, Cagayan de Oro City, March 12, 1977.

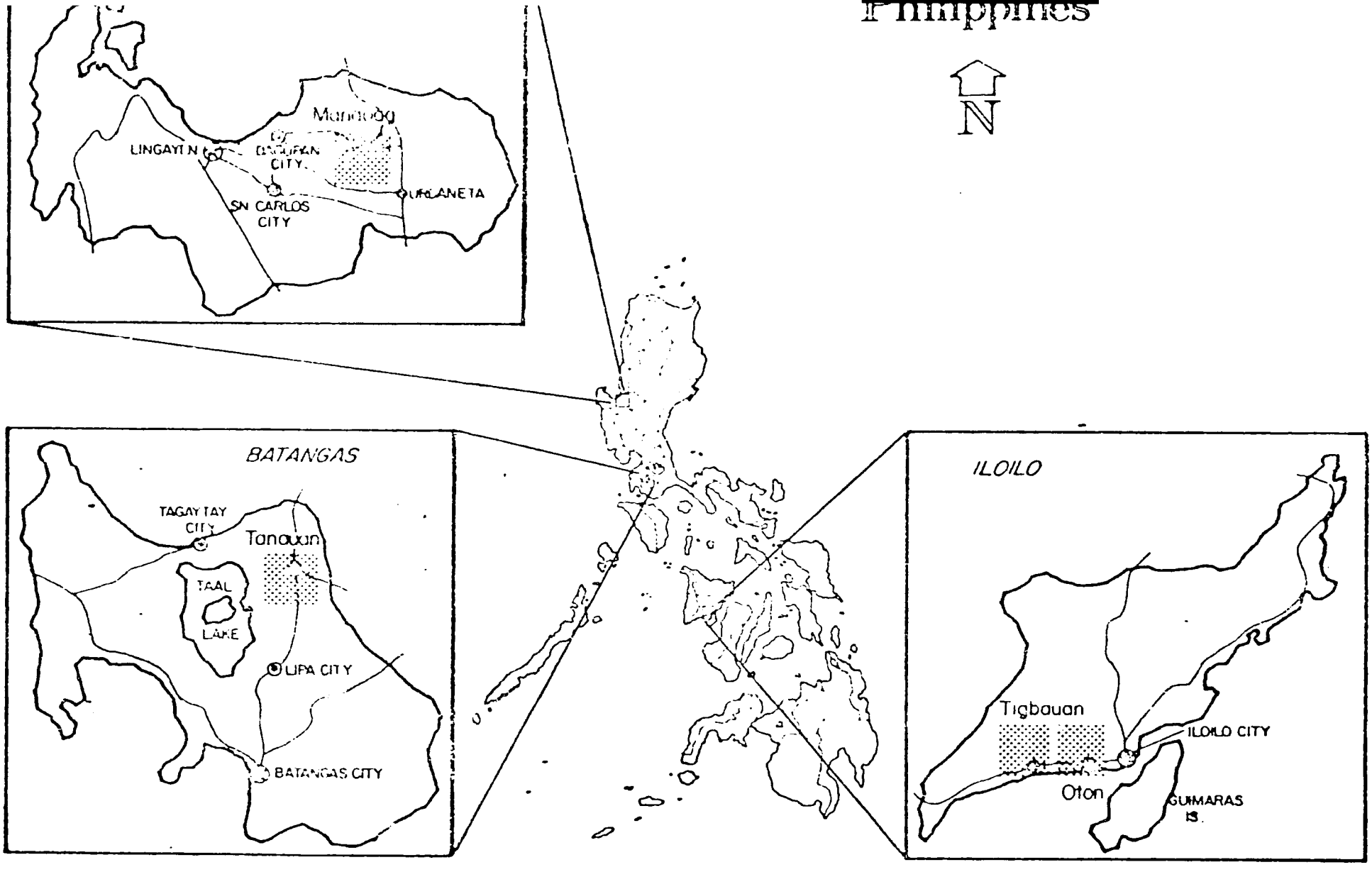

FIGURE 1. Locations of three research sites of the cropping systems program, International Rice Research Institute.

The farms of the farmer cooperators lie on a marine terrace beginning 1 km inland from the coast and extending to small foothills 8 km inland.[8/] Most of the area is level with an overall slope of 2% or less, and a deep water table that is 2 m below the soil surface during most of the rainy season. Minor variations in this landscape are composed of slightly dissected waterways, paddies which benefit from the overflow and/or interflow water enrichment, small areas of a lower terrace with shallow watertable, slightly elevated summit area which are mostly bunded and long narrow side paddies stepping up the hillsides, going into terrace levels, or stepping into waterways and creeks.

The data that will be used in this study will be obtained mostly from the 1975-76 and 1976-77 weekly economic surveys in Oton and Tigbauan, Iloilo conducted by the IRRI Cropping Systems Economics Section at IRRI. In addition, agronomic experiments conducted in these areas will be utilized. Daily rainfall data from 1961 to 1974 will be obtained from the PAGASA record book in Iloilo City. Rainfall data from 1975 to 1976 will be derived from daily rainfall readings taken from rain gauges maintained by IRRI in the monitored area. Daily available soil moisture data from water level readings will also be obtained from the Iloilo Outreach Cropping Systems Office. [illegible]

[8/] R. L. Tinsley, E. C. Price and H. G. Zandstra, "Dynamics of Land Use in Rainfed Rice Production, IRRI.

Table 2. Location of the rainfed lowland farms of economic cooperators, Oton and Tigbauan, Iloilo, 1976-77.

Location	Rainfed lowland area (has.)	Total area
Oton:		
Bunay	4.0	10.7
Sta. Monica	19.2	22.7
Rizal	26.9	28.0
Tigbauan:		
Cordova	5.8	12.4
Napnapan Norte	0.9	7.7
Napnapan Sur	1.9	6.3
Bitas	6.1	7.8
Total	64.8	95.6
Percent of total farm area	68	

Table 3. Percentage of crop land in rice-fallow and rice-rice cropping patterns rainfed lowland area of Oton and Tigbauan, Iloilo.

Cropping Pattern	Rainfed lowland area (has.)
Rice - Fallow	13.1
Rice - Rice	18.3
Total area under rice-fallow and rice-rice cropping pattern	31.4
Total rainfed lowland area	64.8
Percentage of rainfed lowland area under rice-fallow and rice-rice cropping pattern	48

2.2 The Model

The simulation model developed in this study is designed for rainfed lowland areas. Only the rice-fallow and the rice-rice cropping patterns will be considered in this study with the first rice crop established either by direct seeding or transplanting. Depending on the rainfall pattern in a given year and the rice variety used, there are, three possible cropping patterns for the first crop established as wet seeded rice (WSR) and also three patterns for the first crop established by transplanting (TPR). They are as follows:

WSR - Fallow

WSR - WSR

WSR - TPR

TPR - Fallow

TPR - WSR

TPR - TPR

In building the models of returns from direct seeding, a series of relationships among selected variables are diagrammed in considerable detail in Figures 1a, 1b and 1c. Figures 2a, 2b and 2c, on the other hand, illustrate schematically the models that will be employed to evaluate the expected benefits from transplanting. Each model consists of two parts: it combines (1) a set of biophysical data and relationships with, (2) a set of economic data and relationships.

2.2.1 Biophysical Data and Relationships

a) Rainfall Generator

The major function of the rainfall generator is to provide to the model the rainfall pattern for the simulated year. The generated

rainfall data also influences: (1) the cropping pattern through its effect on the date of planting of the first crop which consequently affects the date of harvest of the first crop and the date of planting the second crop, as well as, on the availability of soil moisture needed to produce a second crop, and (2) the yields of the first and second rice crops.

In the simulation model, there are two options that will be used in generating rainfall in this study. One of these options is to generate rainfall based either on the parameters of an incomplete gamma, normal or log-normal probability distribution for each week synthesized from actual rainfall data (1961-1976). Goodness of fit chi-square tests will be conducted to determine which among the three probability density functions will give the best fit to the actual data.

Another option that will be employed in generating rainfall is to randomly select (1) an early, regular, (2) early, irregular or a, (3) a late rainfall year and to use the historical data of the selected year in the simulation run.

Following the definitions of agronomists and rice farmers in Iloilo, early rainfall years are those years in which the first monsoon rains arrive in any of the following weeks: the second week of April (week 15) to the last week of May (week 21). On the other hand, late rainfall years are those years in which early precipitation falls during or after the first week of June (week 22 or after week 22). Using a 15-year historical rainfall data, classification of each year into a late or an early rainfall year is vitally important in determining the effect of yearly variations in the arrival of the first monsoon rains on the method of establishing and tha dates of planting the first rice crop which consequently influence the feasibility of a two-crop sequence.

Rainfall has also a pronounced influence on the timing of the second rice crop. High rainfall is necessary for starting the second rice crop. There are years in which the first rains arrive early, but rainfall is low after the harvest of the first crop so that production of a second rice crop is not feasible. Moreover, there are also years in which the first rains arrive early, but rainfall is high so that double cropping is possible. For this reason, rainfall years will be classified further into three groups: a) early, regular, b) early irregular, and c) late rainfall years. A late rainfall year has been defined previously. An early, regular rainfall year is one in which the first rains fall in any of the following weeks: the second week of April to the last week of May and one in which rainfall is high (more than 100 mm of rain per month) either during the months of August, September or October, the expected dates of planting the second crop. An early, irregular rainfall year is one in which the advent of the first rains occur in any of the following weeks: the second week of April to the last week of May and one with low rainfall (less than 100 mm per month) during the months of August, September or October so that double cropping is not technically feasible.

Aside from the function of generating rainfall, the rainfall generator also determines the daily available soil moisture (depth of water in the paddy) based on a water balance model described below:

$$AM_t = AM_{t-1} + R - ET_t - SP_t$$

where AM is the available soil moisture (depth of water in the paddy), R is the rainfall, ET is evapotranspiration and SP is seepage and percolation. Negative values of AM reflect depletion of the stored water to levels below the soil surface.

Evapotranspiration is a function of the energy available for evaporation of the water. On the other hand, seepage and percolation (S&P) losses, usually referred to togehter, account for horizontal and vertical movement of water into the soil, respectively. The sum of evapotranspiration (ET) and S & P is called net use and is considered the minimum water requirement for rice production at a particular site.

In the water balance model, daily values of rainfall (R) and evaporation (E) are porvided as input data. Daily values of ET are computed according to the equation ET = a + b (E), where a and b vary slightly for the two seasons and for different stages of crop growth.[9/] Values of a are 0.25 and 0.50 mm/day for the wet and dry seasons, respectively; b is 0.8 and 0.9 for the vegetative and reproductive growth stage, respectively. Evaporation shows less variability among weeks within a given site. In severely stressed conditions, however, ET is depressed by a factor related to AM_t. Daily values of S and P are also computed as a linear function of AM_t.

Operation of the model is possible once the maximum S and P and the initial AM are specified for the study area.

Daily AM data (from water level readings) by landscape type from 1975-77 are available in Iloilo and this facilitates estimation of S and P for each type of landscape. However, evaporation data in Iloilo are lacking. For this reason, evapotranspiration data can be approximated roughly using historical data of R, AM and the estimated values of S and P. Transposing the water balance equation, we then have:

$$ET_t = R + AM_{t-1} - AM_t - SP_t$$

[9/] Thomas Wickham, "Predicting Yield Benefits in Lowland Rice Through a Water Balance Model", Water Management in Philippine Irrigation Systems Operations and Research, 1973. pp. 155-181.

Using the rainfall data of any given year, the estimated values of S and P and the average daily evapotranspiration data, daily values of AM_t can then be calculated for each type of landscape for any given year by the model.

Another function of the rainfall generator is to determine the method of planting practiced in a given year and to reschedule the date of land preparation, as well as the planting date of each crop (DSR, WSR or TPR) depending on the rainfall pattern.

If the early rains are scanty, the normal practice in Iloilo is to establish the dry seeded rice (DSR) ~~just~~ followed by wet seeded rice (WSR) and finally by transplanted rice (TPR). However, during years in which the early rains are heavy or intense (e.g., 1975 and 1976) or during years in which rainfall is late (e.g., 1974), dry seeding is not practiced. Instead, wet seeded rice is established first followed by transplanted rice.

Based on an interview with Iloilo farmers, the earliest date of planting DSR is week 18 (~~third~~ last week of April) and the latest date is week 27 (first week of June). Fields cannot be dry seeded in July due to the heavy downpour of rain during this month. Wet seeding, however, is established starting from week 19 while transplanted rice is established as early as week 20 during early rainfall years. Majority of the farmers, however, start from week 22 until week 40 because the mid-monsoon rains are stable or intense during this period. During years in which the early rains that fall in May are intense. Very few farmers establish their first crop by transplanting during this month (Table 4). Not only is May rainfall usually low, but it is more undependable. After the onset of the early rains, subsequent rainfall is erratic.

Table 4. Number of plots established by TPR and WSR by month, 1975-76, Oton and Tigbauan, Iloilo.

	No. of plots established in		
	May	June	July
Transplanting	2	12	7
Wet Seeding	12	3	3
Rainfall (mm)	157	369	158

Table 5. Earliest dates of establishing TPR and WSR, Oton and Tigbauan, Iloilo

	Earliest Date of Planting		Rainfall	
	Wet Seeding	Transplanting	April (mm)	May
1975-76	May 12 week 19	May 15 week 20	196	157
1976-77	week 19	week 20	20	477

Data from economic surveys in Iloilo in 1975-76 and in 1976-77 for dry seeded rice are not available. This is due to the fact that dry seeding was not practiced during those years. Initial surges of rains had been heavy during these years (Table 5). In order to do dry land preparation without puddling, the monthly rainfall should be less than 150 mm (Mabbayad, 1970). In 1975, early precipitation occurred in April with a total monthly rainfall of 196 mm. On the other hand, the initial surge of rains in 1976 was in May with a total rainfall of 477 mm per month. Because the study will make use of the 1975-76 and 1976-77 economic survey data, this study is concerned only with the wet seeding and the transplanting methods of planting.

In view of the prevailing conditions, the decision strategy for choosing the method of planting is shown in Figure 4. The decision rules discussed below are closely in line with the situations that occur in the study area. From weeks 18 to 27, the choice between DSR, WSR and TPR depends on the intensity of the early rains. After week 27, the choice is only between TPR and WSR. The earliest expected date of the initial surge of the monsoon rain is week 18. So we start from week 18 or T=18 (T=week). The decision rules for choosing the method of planting are as follows: (1) if the cumulative rainfall one month prior to the expected initial surge of rain is less than 150 mm (Cum $R_{T-4} < 150$) or if the available soil moisture (AM) during the initial surge of rain is less than 1.5 cm and greater than 0 ($0 < AM \leq 1.5$) use DSR; (2) if the soil moisture does not satisfy the above water requirement, that is, if $AM > 1.5$ cm or if Cum $R_{T-4} \geq 150$, use WSR or TPR.

As mentioned earlier, this study is concerned only with WSR and TPR. Moreover, the dates of planting in each type of landscape may also differ

Landscape position reflects differences in drainage and flooding potential. Given a rainfall distribution, the dates of planting in the different types of landscape (plain, sideslope, and plateau) differ depending on the date decision rule No. 2 is satisfied. Moreover, the dates of planting in each type of landscape may also differ from one year to another depending on the rainfall pattern. For each simulated year and for each type of landscape the earliest date of preparing the land for WSR, therefore, depends on the satisfaction of decision rule No. 2. To determine the date for starting land preparation, we begin from week 18. The decision rule for scheduling the date of land preparation of WSR is as follows: (1) if available soil moisture is deficient during the expected date of land preparation, the date of land preparation is delayed by another week (1 + 1). The date of planting WSR depends on the date when the fields have been prepared or puddled. In Iloilo, farmers normally prepare their fields for two weeks. The earliest date of planting is, therefore, 15 days after the earliest date of land preparation. During planting time of WSR, it is necessary that the field should be drained. If AM = 0, the farmers can still plant since excess water can be drained through the drainage canals.

For TPR, the decision rules for determining the dates of land preparation of the seedbed and the main field are the same as in WSR. To prepare the land for the seedbed, it is necessary that the field be puddled also. The date of planting TPR on the other land depends on several factors. These factors are as follows: (1) the age of seedlings which is affected by the method of seedbed preparation (dapog or wetbed)[2] and the variety, and (2) the available moisture during the expected date of transplanting. Assuming TPR and WSR are prepared at the [illegible] since the water [illegible] for land preparation

[2] Wetbed is the [illegible] popular method of seedbed [illegible] in the study area. On the [illegible] wetbed [illegible] seedlings [illegible] 27 days for traditional [illegible] varieties, respectively. [illegible] the supply of [illegible] water [illegible]. In the dapog method, [illegible]

is the same for ~~both methods~~, the date of planting TPR compared with that of WSR is at a later date due to the seedbed preparation required in the latter. Moreover, if the available moisture during the expected date of transplanting is deficient (AM = 0), the date of transplanting is further delayed.

In order to be able to transplant, there should be standing water in the paddy. The actual moisture content during the expected planting time will determine whether the farmer can transplant or not. Given the age of seedlings, the variety and the method of seedbed preparation, the decision rule for determining the earliest date of planting TPR is as follows: (1) if available moisture is deficient (AM = 0) during the expected date of planting, transplanting is delayed by another week (T + 1).

In Iloilo, the earliest planting date in order to double crop is week 33 and the latest planting date in order to be able to produce a successful second crop is week 43 (last week of October). After week 43, or starting from the first week of November, rainfall is already receding so that a second crop is no longer feasible. For each simulated year, to determine whether a second crop is still feasible or not, the decision rule is as follows: if Am = 1.5 cm or if Cum R_{T-4} 7150 during the expected harvest date of the first crop (30 ± T ± 4) ~~(T = 43)~~, produce a second crop.

Based on the decision rule, if production of a second crop is found feasible, then the next procedure is to determine the expected date of planting the second crop. The date of planting the second crop, however, depends on the following: (1) the date of harvesting the first crop, which in turn is determined by the date of planting the first crop and the variety used, (2) the moisture content during the expected planting time and (3) the method of establishing the second crop (WSR or TPR).

In rainfed lowland areas, rainfall is considered the most important environmental factor affecting yield of rice. Since in these areas, rainfall is the major source of soil moisture for the rice plant, the simulation of rainfall is very important to determine the degree of drought stress days to which the rice crop is subjected. To measure the effect of rainfall on rice yield, stress days will be used as an index of water adequacy. The number of stress days however, also varies with landscape position. Stress periods are expected to be higher in sideslopes than in fields on the plateau and plain positions because the latter have a higher tendency to accumulate water [illegible]. Because the number of stress days varies with landscape position, it is expected that the rice yields may also differ among the different landscape types. Following Wickham's definition (1971, 1973), stress days are defined as the number of days in excess of three for which a paddy is without standing water. Thus, the rainfall generator finally determines the number of drought stress days in each stage of crop growth by landscape position based on the daily available soil moisture (derived from the water balance mode) and planting dates. The number of stress days in each stage of crop growth by landscape position is then passed on to the production component.

b) Production Component

The production component has the function of determining the yields of the first and second rice crops given the environment under which they are grown, the management practices and input levels. Rice yield depends on a complex set of factors of which weather is the most important. However, it is impossible to include all these factors in a yield prediction

model. The yield response models, in this study, are, therefore, not complete production functions. They reflect the objective of obtaining impact measures of some selected variables on the yields of the first and second rice crops. Yield prediction is based on appropriate yield response functions. The main approach in the prediction of yield in this study is multiple regression analysis. The major factors considered to affect the yield of the first direct seeded crop in this study are: (1) rainfall and landscape position through their effect on available soil moisture, AM, (Number of drought stress days); (2) nitrogen level, N in kg/ha; (3) level of weeding labor, W, in man-days/ha; (4) chemical weed control, W_c in P/ha herbicide; (5) insect control, I in P/ha insecticide; and (6) variety, V. To determine the effect of stress on the rice plant resulting from insufficient moisture during growth, early stress days and late stress days will be both tested in the response function for each type of landscape. Early stress days (S_1) are those occurring during vegetative growth while late stress days are those occuring during the reproductive stage (from panicle initiation to flowering). The duration of the vegetative phase varies among varieties while the reproductive phase is about 35 days from the date of maturity regardless of variety. Interaction variables such as nitrogen and early stress ($N \times S_1$) are also included in the model. Since most nitrogen uptake occurs during vegetative growth stress during the later stage of growth is not included. Other qualitative factors such as variety also cause variation in yield levels and response. The effect of variety has been taken into account by stratification of the sample before computing the regressions. Variety, V, however, does not only affect the yield of rice

but also the date of harvest of the first rice-crop and consequently, the possibility of double cropping. Long maturing varieties are harvested late compared with early maturing varieties. Moreover, traditional varieties are usually associated with long maturing varieties while HYV's are usually linked with early maturing varieties. In this study, however, it is not appropriate to merely classify varieties into traditional and new high yielding varieties because in Iloilo, some farmers are using early maturing traditional varieties for direct seeding such as Kapopoy, Kitsiam and Speed 70. Kapopoy and Kitsiam mature in about 90 days while Speed 70 is a 70-day old variety. For this reason, varieties will be classified into three groups:

1. HYV's
2. Short maturing traditional varieties
3. Long maturing traditional varieties

This classification is important particularly if we would like to compare the effect of each method of planting on the possibility of double cropping. In order to be able to compare the relative economic merits of each planting method, one has to use the same type of variety of the same date of maturity or growth duration (e.g. HYV WSR vs HYV TPR or early maturing local variety WSR vs early maturing local variety TPR).

For the first direct seeded rice, separate functions for each type of variety will be estimated. The yield function for direct seeded rice is as follows: $Y = L + B_1 N + B_2N^2 + B_3S_1 + B_4S_2 + B_5W_a + B_6 W_L + B_7I + B_9S_1N + B_{10}SW_L + \ldots SW_a$

To predict yield based on the yield response function, rates of nitrogen and weeding labor used and costs of insecticide and herbicide are mean values recorded for the study area which are the same for all simulated years. Only the number of stress days will vary depending on the rainfall pattern of the simulated year.

Because the direct seeding technology was developed to enable the farmers to harvest two rice crops during the regular growing season, it is also important to estimate the yield model for the second crop. The second crop, however, can be direct seeded or transplanted. For this reason, two yield models will be used for the second rice crop. For the second wet seeded crop, the same procedure and variables will be used as those employed for the first wet seeded crop (see Fig. 1b). For the transplanted second crop, the same variables will be used as those in the wet seeded second crop except with the addition of one variable, age of seedlings, (A). Old seedlings have been found to reduce yield of transplanted rice (Mandac, 1976). However, the variable A (age of seedlings) has no meaning for the direct seeded model (Cablayan and Wickham, 1977) and is therefore excluded in the model for wet seeded rice.

For the second transplanted crop, separate regression for each type of variety will also be estimated. The regression model for transplanted rice is as follows:

$$Y = L + B_1N + B_2N^2 + B_3S_1 + B_4S_2 + B_5W_c + B_6W_b + B_7I + B_9A + B_{10}S_1N$$

For the first transplanted crop (Fig. 2a, 2b and 2c) and its second transplanted crop (Fig. 2c), the same procedure and variables will be used as those employed for the transplanted second crop of the first wet seeded rice (WSR-TPR cropping pattern).

Economic Data and Relationships

a) Labor Component

The labor component merely accounts for the use of labor in the production process. Labor requirements by operation and by time distribution are provided ~~endogenously~~ exogenously to the model. Given the areas and the planting dates of each crop, then the weekly labor utilization pattern can be calculated for the entire simulated year.

Harvest and post-harvest labor depend on the actual production while fertilizing labor depend on the actual amount of fertilizer applied and therefore, they are determined endogenously in the model. Weeding labor is pre-determined as a policy variable.

b) Price Generator

Prices of rice and production inputs are exogenous to the farm and they play important roles in determining the profitability of the rice crop. Because an individual farm's production, supply and demand levels are only a small part of the total market, a farmer cannot influence product and input prices. Under perfect competition, a farmer is merely a price taker.

The main function of the price generator is to determine the price of a rice crop at any given week of the year. Since the construction of market demand and supply models for price determination is a complicated matter, a simple method will be resorted to to estimate the price of rice in this study. Paris[10/] (1976) suggested three options to estimate the price. The first option uses seasonal price indices and base prices. The base price

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10/ T. B. Paris and E. C. Price, "A Computer Simulation Model of Upland Rice-Based Multiple Cropping Systems", IRRI Saturday Seminar Paper, April 3, 1976

is the expected annual average price which is determined by an equation derived by fitting either a linear or exponential trend line on past annual data. Annual base prices which have been projected by using trend equations are then adjusted for seasonal variation. Another option for adjusting prices is called the random method. For random price generation, standard deviations (PSDEV) are computed for prices from which trend, cyclical and seasonal factors havebeen removed. Then the seasonal, trend price for a given month, X_1 is adjusted for irregular variation by the following steps:

1) Generate a random number between 0 and 1,
2) Determine the standard normal deviate, Z, corresponding to the random number from step (1) above,
3) Compute expected price as P-X + (PSDEV) (Z).

The third option is the non-random method wherein the expected price is simply the seasonal trend price. In this study, the non-random price or the seasonal trend price will be used to compute gross returns from each rice crop and pattern simulated. Since the major interest in this study is only on the effect of variations in rainfall pattern and cultural practices on the economic performance of the direct seeding method, the 1976 input and rice output prices will be used for all simulation years. The price of rice for each run will only vary depending on the date the rice crop is harvested.

c) Income Component

The purpose of the income component, which is an accounting component, is to keep track of all farm income and expenses. It determines the total production, the gross returns, cost of production and net returns of the first or the second rice crop (wet seeded or transplanted) and of each

cropping pattern with the first crop established either by wet seeding or transplanting.

2.3. Computer Language

For the first option of generating rainfall, that is based on the parameters of a probability density function synthesized from a 15-year rainfall data, the computer model will be written in GPSS (General Purpose Simulation System). On the other hand, the second option of generating rainfall, the computer model will be written in FORTRAN language.

2.4. Modes by which the simulation models will be run

Several simulation runs can be done using various modes and options of the models.

Mode 1. Planting dates are varied between runs while input levels and variety of the first WSR crop are held fixed. Therainfall pattern is held fixed between runs. The objective of this run is to determine the economic advantage of an early establishment of the wet seeded rice and the consequent possibility of an earlier establishment for the second crop vs. a late establishment of the wet seeded rice. In other words, during an early rainfall year, what is the effect of an early establishment of the first direct seeded rice on the feasibility of a two-crop sequence (double cropping)? Three strategies for choosing planting dates will be examined in this mode. The rainfall option that will be used is to select an actual year of rainfall from the early, regular rainfall group (refer to rainfall option 2 in section 2.1). The number of runs will depend on the number of early rainfall years using a 15-year historical data. One strategy is to

choose two early planting dates. The first early planting strategy is week 22. Prepare the land two weeks prior to the expected date of planting. For wet seeded rice, the farmers can still plant regardless of whether rain falls heavily at planting time because if the fields become flooded or if rain falls during seeding, canals are constructed around the plots for drainage. It is necessary that water should be drained out from the field prior to broadcasting of pregerminated seeds. The second strategy is to plant at week 26. Although week 26 is still an early planting week the second crop may be subjected to more stress compared to that planted prior to week 26. Land preparation is started two weeks before planting. The third strategy is to choose a late planting week (any week after week 26 but not later than week 37). If double cropping is feasible, the simulated patterns will be WSR followed by WSR and WSR followed by TPR using a) an early maturing HYV for both crops (first and second crops), and b) early maturing HYV for the first WSR crop and local varieties for the second transplanted crop. WSR, using early maturing varieties - WSR_2 using local varieties is not included in the analysis because this pattern is not practiced in Iloilo.

Mode 2. Landscape position is varied between runs while input levels, planting dates and rainfall pattern are held fixed. Differences in rice yields of WSR can be attributed to differences in hydrologic conditions. One reflection of this condition is expressed as the number of stress days that the rice crop has been exposed during the entire growing season. Given a rainfall distribution, the performance of wet seeded rice in terms of yield and net returns will vary on the different

a. Yield response to fertilizer, high vs. zero weeding and insect control. The rainfall pattern that will be used is 1976. Fertilizer is incremented in steps of 20 kilograms per hectare. While varying the amount of fertilizer, weeding labor, chemical weed control and insect control are held fixed at two levels: zero and high levels.

b. Yield response to weeding labor, high vs. low fertilizer, chemical weed control and insect control. Weeding is a major problem of direct seeded rice. This is especially true in Iloilo where chemical weed control is not yet widely practiced. Farmers, therefore, usually rely on hand weeding for controlling weeds. To determine the simulated yield response to weeding labor, the amount of weeding labor is varied while fertilizer, chemical weed control and insect control levels are held fixed at two levels: low and high levels. The 1976 rainfall pattern will be used throughout.

Mode 5. Rainfall is varied in each simulation run while holding input levels, variety and planting dates constant. Economic performance of HYV WSR in each landscape position, however, could be different under weather patterns occurring in different years. Comparison of the economic performance of WSR in each landscape position under different weather conditions will be made by selecting actual years of rainfall from the early, regular, early, irregular and late rainfall groups.

To facilitate comparison of the economic performance of WSR and TPR under varying rainfall patterns, the same procedure will also be conducted for TPR. Comparison will also be made using wet bed seedlings vs. dapog seedlings.

HYV WSR vs. { HYV TPR wet bed seedlings
HYV TPR dapog seedlings

local short maturing WSR vs. { local short maturing TPR wet bed seedlings
local short maturing TPR dapog seedlings

local long maturing varieties are not used for WSR.