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*Mark L Esmy*  
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SIMULATION TO EVALUATE ALTERNATIVES  
IN POST RICE PRODUCTION

By

Moeljarno Djojmartono

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## ABSTRACT

### SIMULATION TO EVALUATE ALTERNATIVES IN POST RICE PRODUCTION

By

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The problems of increasing the quality and quantity of rice production consists of two large parts: first, the production problems and second, the post rice production problems. The problems within the in-field post rice production operations of harvesting, threshing, handling, and drying are viewed as complex interactions and interrelations between components within the system and the components with the environment. In this dissertation, a simulation model of post rice production operations is presented as an approach to the post rice production problems.

Field measurements of operation for post rice production performances and losses were carried out in Indonesia. The current post rice production research was reviewed. Field measurement data and reliable secondary data were analyzed and equations were developed to model the interactions and interrelations among post rice production operations.

## Moeljarno Djojmartono

Environment plays an important role in the post rice production operations. Four weather related models were developed and used to capture the influence of environment on the post rice production system. Rain and no rain condition each day and the rainfall amount on rain days were simulated stochastically. The results from the weather models were used in both the field moisture model and the working hours model. The field moisture model approximates the soil moisture status and determines the in-field working condition and efficiency. The preliminary working hours model describes the available working hours for each post rice production operation based upon the stochastically generated rainfall during working time.

Grain losses in the post rice production operations were generally influenced by the timeliness of the operations. Delayed harvesting beyond the optimum date increased shattered grain losses during harvesting, threshing and handling operations. The amount of head rice as the final product from in-field post rice production process was determined by harvesting, threshing, handling and drying dates and methods. A model to account for crop maturation times was developed, and six models in discrete time form were designed to simulate the final products and losses from the post rice production operations.

The simulation model was used to evaluate alternatives in post rice production. The influence of environment such as climate, the size of cultivated land and labor availability to the post rice production operations were also studied using the simulation model. The simulation results provided useful information to the decision makers or planners involved in the development and improvement of post rice production technology. The result of the evaluation can be used to identify the advantages, constraints and weakness in the various technological alternatives.

The simulation results using a given set of data and under alternatives in this research study indicated that the use of sickles and foot threading was the most appropriate method for producing high quality and quantity of rice. The high head rice conversion capability and lower weather dependency of a mechanical dryer suggested the use of mechanical dryers to increase and stabilize the annual head rice production. However, the cost of operating and owning the dryer resulted in less net annual income per hectare than use of sun drying methods.

Further research in improvement and modification of model or data, and extensive use of the present model



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are recommended to more realistically represent and to add to one's understanding of the post rice production system.

Approved by

  
Major Professor

  
Department Chairman

Dedicated to my late parents

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## CHAPTER I

### INTRODUCTION

The Indonesian government has been actively undertaking BIMAS (Mass Guidance), a rice intensification program, since 1963 in order to meet the increasing demand for rice. Initially the BIMAS program was designed to deal with the production problems of rice. The BIMAS program covered 43 percent of the total dry and wet land fields in Indonesia in 1976.

The introduction of the new higher yielding varieties, proper use of fertilizer and improved cultural practices, have all contributed to increased rice yields. The average yield before the BIMAS program was 2.43 tons of rough rice per hectare (BIMAS, 1972). The average yield in 1976 was 3.66 tons per hectare, which was 51 percent above the 1963 average yield. Increases in rice production technology were not, however, followed by improved post rice production technology and loss reduction.

An increasing concern about the post production losses has developed during recent years (USAID, 1978). Improved production technology provided the rice producers with increased yields, but not a comparable increase in

total production. Most of the new varieties shatter more easily. Multiple cropping has shifted much harvesting to the wet season, so drying and handling losses increase. These high post production losses have tended to nullify some of the advantages of high yields.

The total post rice production losses in developing countries are estimated to be from 10 to 37 percent (Spurgeon, 1976). BULOG (Indonesian Board of Logistics) estimated in 1971 a total of 25 percent loss after production of rice in Indonesia. A 12 percent loss was estimated within the field operations of harvesting, handling, threshing and drying.

The monetary value of post rice production losses has been more than 200 million rupiah (U.S. \$320,000) annually. This was based upon a 12 percent loss of 22,732,000 tons of rough rice produced in 1974 (CBS, 1976) and a price of 75.00 rupiah per kilogram. This loss was equivalent to 181 percent of the total Indonesian rice import of 1,509,000 tons for the year 1976/1977.

Appropriate post rice production methods and techniques are important in helping stabilize the Indonesian economy by minimizing rice imports. Also, increased returns would accrue to the producers, farmers and workers who invest in the production systems. The traditional Indonesian post rice production operations of harvesting,

handling, threshing and drying are manual, seasonal and comparatively low wage jobs. They are labor intensive operations which seem appropriate for a highly populated Indonesia. But, they are tough, tedious, in-field jobs under the hot tropical sun and often in wet soil conditions. Farm working conditions have improved little as compared to transportation with its introduction of one-half million motor bikes per year. The continuation of this imbalance with other fast growing industrial development in the urban areas, will bring about more emigration to the cities (Esmay, 1978).

The improvement of post rice production methods and techniques should be equally as important as the rice production phase. The initial post rice production operations are harvesting, handling, threshing and drying which occur mainly in the field. The post production operations all affect the quality and quantity of rice for consumption. For example, delayed harvesting will generally increase the harvesting field losses and lower the quality of that saved. Emphasis must therefore be placed on all post rice production operations as a system.

Hopefully, improved post rice production systems will provide better quantity and quality rice, minimize post production losses and improve field working conditions. An improved system might be brought about by



adoption of selective innovations. The determination of a feasible and practical system requires knowledge of its behavior under many conditions. Some of this information can be obtained by spending substantial amounts of time and money experimenting with variations of the real world systems.

Simulation modeling provides an analytical tool for extending limited experimental results and measurements to the many variations within the real world at less cost and in less time (Hillier and Lieberman, 1974). Simulation systems modeling of agricultural product harvesting of wheat and corn has been done by Campbell and McQuitty (1971), van Kampen (1971) and Holtman, et al., (1973). Fridley (1974) evaluated alternate California strawberry harvest systems. Brown (1972) has done simulation modeling on a harvest system for apples, and a simulation model for sugarcane harvest operations under stochastic conditions has been formulated by Sorensen and Gilheany (1970).

This research study was designed to obtain needed field information for the verification of a post rice production model, so that simulation could be used to evaluate and identify some feasible and practical post rice production technology alternatives. The study concentrated on the field operations of harvesting, handling,





threshing and drying. In-field data collection was carried out in a rice producing area in West Java, Indonesia, during the wet and dry season of 1978. These primary data along with reliable secondary data were employed in formulating and testing the simulation model.

### 1.1 Objectives

The general objective of this research was to identify and quantify the potential gains to be realized by the reduction of post rice production losses through improved harvesting, handling, threshing and drying technology. The specific objectives were:

1. To measure field losses and machine performance in order to formulate and verify a representative post rice production system model.
2. To use the model to estimate post rice production losses and costs, thereby identifying some feasible alternatives and practical combinations of rice harvesting, handling, threshing and drying technology for Indonesia.

This research study was designed to provide the decision maker with reliable information for the development and improvement of post rice production technology and methods.

## CHAPTER II

### A REVIEW OF HARVESTING, THRESHING AND DRYING OPERATIONS IN INDONESIA

Estimated Indonesian rice consumption per year per person in 1977 was between 123.1 and 124.6 kilograms. With a total population of 136,766,000, the estimated demand for rice was between 17,052,500 and 17,298,800 tons (CBS, 1977).

The total rice production in Indonesia was 15,884,000 tons in 1976. It was produced by both traditional and improved methods. The traditional methods were carried out under both dry land and wet land conditions. The total area of rice in 1976 was 8,368,759 hectares. This area consisted of 43 percent (3,616,089 hectares) wet land traditional, 14 percent or 1,139,342 hectares dry land traditional and 43 percent (3,613,328 hectares) under improved cultivation. Rice production included primary tillage, sowing, transplanting and weeding and/or spraying. The wet land traditional practices were subdivided into wet monsoon planting and dry monsoon planting. This amounted to 65 percent (2,345,617 hectares) and 35 percent (1,261,472 hectares) of the total wet land

traditional area, respectively in the 1975/1976 season. The wet land improved production practices were also subdivided into wet monsoon and dry monsoon planting. Each consisted of 64 percent or 2,319,294 hectares and 36 percent or 1,294,034 hectares, respectively.

The post rice production processes consist of a long and necessary series of operations to transform the mature standing field paddy into a high quality processed rice for the consumers. The post rice production systems start with the harvesting operation (cutting, bunching, laying and bundling) followed by threshing, handling and drying, milling and storage. The final operation of the in-field post rice production system is the drying operation. Drying reduces the moisture content of the wet or partially wet rough rice to a dry rough rice at 13 to 14 percent wet basis for milling and/or safe storage.

The harvesting time is determined by the maturity of the crop and thus depends on the planting date and cropping pattern, rice variety and weather conditions. A survey conducted by Biro Pusat Statistik (CBS) in 1977/1978 showed the frequency distribution of harvest time varied among provinces, but all presented a similar type of double peak distribution. The large peak was common during the wet monsoon period and the smaller during the dry monsoon period. In West Java, where the Bekasi area

is located, the frequency distribution of harvest time had a high peak of 43 percent for March and April and 44 percent for July and August (Eriyatno, 1979).

### 2.1 Traditional Methods

The post rice production operations were carried out by various methods, depending on size of the farm, surrounding conditions and labor availability. The traditional harvesting method in most Indonesian provinces was by cutting rice panicles individually with a small knife called ani-ani. Only in two provinces, West Sumatra and North Sulawesi, was traditional rice cutting with a sickle observed (BULOG, 1977 and Eriyatno, 1979). The introduction of the high yielding varieties which shattered more easily was followed by more sickle cutting in many of the provinces. Collier, et al., (1973) stated that the use of the sickle in harvesting was logical for the new rice varieties.

Traditional threshing techniques vary between regions. Beating and hand pounding are probably the most common means of threshing the indigenous varieties in many Indonesian provinces. As the new, less shatter proof high yield varieties became more popular, the manual treading and beating methods spread through the provinces. Manual treading was carried out in more than 50 percent (5 out of 9) of the provinces surveyed in 1978 (Eriyatno,



1979). Manual treading was most common in South Kalimantan. Smashing was most common in North and South Sulawesi.

The pedal thresher was not commonly used. The practice was found only occasionally in Java. Power threshers were not used by the individual farmers; rather, they were usually found at the mills.

Drying practices depend on the cutting and harvesting, threshing technique used. Traditional drying was done in the sun. With the local varieties and panicle cutting, stalk paddy drying was most common. In 1978, less than 10 percent of the farmers in most provinces were doing stalk paddy drying (Eriyatno, 1979). The stalk paddy drying of the indigenous varieties was not a major operation as the paddy was commonly left standing in the field for some time after maturity for natural drying prior to harvest (Esmay, et al., 1978).

Rough rice sun drying was done on various floor types. Bamboo or wood floors were most common for more than 80 percent of the rough rice sun drying in Indonesia. In West Java, East Java and North Sulawesi, concrete drying floors were common (Eriyatno, 1979).

The handling techniques depend on the operations that precede and follow it. Ani-ani cutting may be followed by either in-field or out-field threshing. The

harvested crop may be bundled or not, depending on the following transportation method to be used. Sickle cutting was usually followed by transportation with simple bamboo racks. Manual treading was generally preceded by bag transportation after sickle cutting. Neat transportation of harvested stalk paddy was not necessary for manual treading to get good threshing results.

The overall systems of harvesting, handling, threshing and drying varied according to the marketing system. Indonesian rice farmers traditionally marketed their surplus rice in stalk paddy bundle form (Collier, et al., 1973, and Esmay, et al., 1978).

#### 2.1.1 Panicle Harvesting (Ani-ani Harvesting)

Ani-ani is an Indonesian term for a small paddy harvesting knife, 10 centimeters long fixed crosswise on a short wooden block. The knife was used for cutting each stalk paddy (panicle) separately, approximately 20 centimeters below the panicle. Five to six panicles were cut and retained in the cutting hand, then transferred to the other hand until a large bunch of about three kilograms was accumulated. The bunches were then placed on the ground. The cut panicles were placed in a basket if the harvester brought a basket while harvesting.



The harvesters were mostly women. The harvesting method utilized a large number of persons for cutting and carrying the stalk paddy. Esmay, Soemangat and Eriyatno (1977) found that a skilled person was able to harvest 10 to 15 kilograms of panicle stalk paddy per hour. Collier, Wiradi and Soentoro (1973) and Ban (1970) reported that ani-ani harvesting might employ as many as 500 persons per hectare. The most a harvester could cut was 110 kilograms of stalk paddy a day. The author's study on ani-ani harvesting in the Bekasi area found a low capacity of 0.002 hectare per man hour for the new high yielding variety of IR-38.

The ani-ani harvesting capacity was affected by such factors as crop height, lodging and density. Other factors of precipitation, temperature, time of day (morning or afternoon), number of harvesters, soil condition and skill of the harvester also affected harvesting rate. In general, the new high yielding varieties were short with standing "flag leave" and a dense growth form, so ani-ani harvesting was not convenient (BULOG, 1976, and Collier, et al., 1973). Esmay, et al., (1978) stated that the use of ani-ani for the easier shattering varieties may increase losses.

Grist (1975) indicated that one advantage of the ani-ani method was the high degree of selection possible



in excluding immature grains and impurities and in harvesting badly lodged plants. Collier, et al., (1973) observed that the ani-ani was quite suitable for cutting the local varieties of rice that mature irregularly and whose length of stalk varies.

### 2.1.2 Sickle Harvesting

The sickle harvesting method was first used only in islands outside of Java. Some change from ani-ani to sickle harvesting in some Java provinces has been partly due to the use of new rice varieties.

There are basically two types of sickles. One has a smooth edge and the other a serrated edge. The stalks are cut about 10 to 25 centimeters above the ground with the sickle. Japanese harvesters usually cut the stalk closer to the soil surface to provide longer straw for better rope making (Stout, 1966).

The sickle harvesting rate varies by harvester, experience, plant condition and the environmental condition. Wet soil and hot climatic conditions reduce the speed and performance of the harvesters. Plant lodging also reduces the cutting rate. Djojomartono, Kamaruddin and Syarief (1979) reported that the average capacity of sickle harvesting was 0.019 hectare per man-hour for the IR-38 rice variety. Esmay, et al., (1978) reported a similar capacity of 0.010 hectare per man-hour. Khan

(1976) reported the finding of Ezaki (1963, 1969) in which the harvesting output of a skilled man in nonlodged rice was 0.010 hectare per man-hour and that of a woman was 0.006 hectare per hour.

### 2.1.3 Foot Threshing

Foot threshing was the traditional rice threshing method in Bekasi, West Java, Indonesia. Human feet were used to tread and rub the stalk paddy against each other and on the concrete floor or bamboo mat until most of the grain kernels were separated. Stalk paddy may come from either panicle or sickle harvesting. Foot threshing was usually carried out in the yard of the farmer's house. Stalk paddy was transported from the field to the threshing site on bamboo racks or in plastic bags.

The rate of foot threshing was affected mainly by the condition of the stalk paddy. Very easily shattering varieties require less time for threshing. Threshing is usually done by the same men or women who do cutting. Esmay, et al., (1978) estimated that foot treading had a low capacity of 30 to 40 kilograms per man-hour. BULOG (1976) indicated that 80 kilograms per hour was the maximum threshing capacity for a woman. The average threshing rate in Bekasi area was 28.41 kilograms per man-hour when done by trampling an easy shattering variety, IR-38.

The rubbing action of threshing can be done in various ways. In Sri Lanka, threshing has been done by animals or tractors (Ilangantileke, 1978). There were two other manual threshing methods besides foot threshing: one was beating the stalk paddy on the edge of tubs, threshing board or racks; two was flail threshing (BULOG, 1976 and Eriyatno, 1979). BULOG (1976) also reported that there were two kinds of beating threshing in North Sumatra. The threshing equipment was made of bamboo. The bamboo sticks were arranged in the form of a bed, 1 by 0.4 meters for the small type and 1 by 2 meters for the large type. Mats were placed below and on three sides of the bed to prevent the grain from scattering. The threshing capacity was approximately 200 kilograms per hour for three people with the small thresher and 600 kilograms per hour for six people with the large sized thresher. A flail method was commonly used in Krawang, West Java, when the paddy condition was not suitable for ani-ani harvesting. Sickles harvested stalk paddy was often threshed on a woven bamboo mat by beating with a piece of wood about one meter long. The capacity and resulting quality were both lower than from foot threshing. The type of wood for beating varied by area.

#### 2.1.4 Sun Drying

Most paddy was sun dried in Indonesia. The drying was generally done in the farmer's yard or at a drying site of the cooperation or local mill. Farmers have traditionally done only limited drying when marketing the harvested indigenous varieties in bundle form. The adoption of improved varieties made threshing possible immediately after the cutting operation and the drying of rough rice was then carried out. A Post Harvest Survey of CBS in 1978 indicated that no more than 10 percent of the farmers in each province were drying their paddy in the bundle form. Two exceptions were a 20 percent finding in East Java and 73 percent in South Kalimantan.

Rough rice sun drying was commonly done on a woven bamboo mat, wood layer or concrete floor. Rough rice was spread at a depth of from 2 to 10 centimeters, depending on the volume of the rough rice to be dried. A 100 square meter floor area handled approximately one ton of rough rice at 2 centimeters. Drying was usually done between seven o'clock in the morning and five in the afternoon. The rough rice was stirred regularly to bring about even drying between layers.

The sun drying rate was affected by layer thickness, grain moisture content, floor type, amount of radiation, air temperature and relative humidity. Measurements

by BULOG (1976) in the West Java province, indicated that from 4 to 8 hours were necessary for drying rough rice from a moisture content of 17 to 19 percent down to approximately 14 percent wet basis. Sumardi and Setiawati (1978) reported that 14 hours and 4.5 hours were necessary to dry 250 kilograms of IR-34 rough rice from 28-30 percent and 20-22 percent, respectively, to about 14 percent moisture content. 7.25 and 4.75 hours, respectively, were needed to dry 250 kilograms of bulu (an indigenous variety) from the same initial moisture content. The high sun drying rate at Bekasi area was an average of 1.5 percentage points per hour (Djojmartono, et al., 1979). IRRI (1974) reported that the use of an unperforated clear polyethylene sheet for the drying surface resulted in a longer drying time than for a surface of woven mats or concrete floor.

Technically, good weather is necessary for successful sun drying. Stirring frequency and good judgement as to grain moisture content are also necessary for good drying.

## 2.2 Mechanical Methods

Institutions and experimental stations, mostly from rice producing countries, have developed new methods of agricultural operations. The International Rice

Research Institute (IRRI) in the Philippines, for example, has produced some semi and fully mechanical methods for tillage, planting and post production operations (IRRI, 1969). Agricultural Engineering Research Institutes, experimental stations and private manufactures in Japan, have developed various types of mechanical tools and machinery for agriculture. They range from simple, manually operated tools to sophisticated, large machines. IRRI and Japanese designs have been introduced into many Asian countries.

The Food and Agricultural Organization of the United Nations has cooperated in several agricultural mechanization projects with the International Institute of Tropical Agriculture, Ibadan, Nigeria; The Central Rice Research Institute, Cuttack, India; L'Institute de Recherches Agronomiques Tropicales et des Cultures Virieres, Bombay and Richard-Toll, Senegal; and the Agricultural University of Wageningen, the Netherlands (Unonimous, 1976). The Regional South East Asian Cooperative Post Harvest Research and Development Programme in the Philippines is also carrying out extensive research and extension programs on post harvest technology and losses.





### 2.1.1 Manual Dropper

The manual dropper consists of a pair of 20-30 centimeter long serrated sickle blades facing each other and set on the end of a one to one-half meter long wooden handle. A simple wire platform was attached to the handle to bunch the cut stalk paddy temporarily (Stout, 1966 and Ezaki, 1972). Figure 2.1 shows the manual dropper schematic diagram.

The manual dropper operator pushes the blades against rice stalks in the cutting operation. The slicing and sawing action cuts the stalks close to the soil surface. This action is continued until a bunch of stalk paddy is accumulated on the platform. The bunch is then laid on the ground.

The operational capacity of the dropper is not much above sickle harvesting, but the operator can cut while standing. A better job than the traditional sickle can be expected. Ezaki (1972) reported that the capacity of the manual dropper was between 0.10 to 0.16 hectares per hour.

### 2.2.2 Mechanical Reaper

The basic principle of the walking mechanical reaper is similar to the manual dropper. A Japanese reaper uses a planetary system to rotate a circular cutting blade. The paddy stalk was then simultaneously

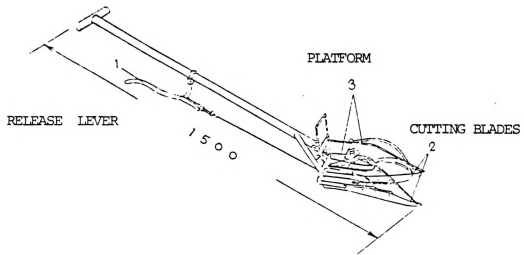


Figure 2.1.--Manual Dropper Schematic Diagram

transported to a side platform. Nine to sixteen bunches of stalk paddy were collected on the platform, and then the large bunch was automatically laid on the ground. A 3-hp two cycle engine provided power for both the cutting operation and forward movement. The operator walked behind the machine to direct the machine in the cutting operation.

The reaper capacity depends on operator skill and control. The operator controls the cutting width and forward speed. The maximum cutting width of the walking mechanical reaper was 75 centimeters. The operational judgement had to be based on the plant and soil conditions. Djojomartono, et al., (1979) reported that the average capacity of a rotary type reaper under "optimum maturity"



and dried soil surface was 0.046 hectare per man-hour on IR-38. A certain plant height was necessary for proper operation of the reaper. A small modification of the bunching mechanism was possible.

### 2.2.3 Manual and Mechanical Binders

Binders cut, handle and bind the stalk paddy in one operation. Mechanical binders usually used a reciprocating cutter bar (mower type cutter). A plastic nail type pick up device worked better than a reel for gathering stalks. The cutting width varied from one row (25 centimeters) to three rows (75 centimeters).

The manual binder was usually a smaller one row type. A cutting device similar to the manual dropper was used. The binding device was manually operated. The attachments were all set on a two wheeled frame for ease of handling. The capacity was double that of sickle cutting and ranged from 0.020 to 0.035 hectare per hour (Ezaki, 1972).

The mechanical binder was usually powered by a 3.5 to 5 horsepower engine. The mechanical binder was usually supported by two or four wide tires for mobility in wet soils. The old binder design required a preliminary field cutting prior to the binder cutting. The mechanical binder capacity varied with the operator's skill and plant and soil conditions. The average capacity



under "optimum maturity" and dry soil conditions was 0.046 hectare per hour for a three row binder on IR-38 including the time for field preparation and preliminary cutting. Ezaki (1972) reported that a mechanical binder can harvest 0.06 to 0.13 hectare per hour.

#### 2.2.4 Pedal Thresher

The foot pedal drum thresher was first developed in Japan for threshing the nonshattering Japanese variety in the field or at the building site after short stalk paddy drying on bamboo racks. The foot pedal drum thresher has also been used nearly exclusively in Taiwan since the 1950's (Esmay and Wu, 1975).

The foot pedal thresher consists of a threshing drum, a foot pedal and accessories. Pedaling was done at a rate of 100 times per minute to provide drum rotation of 400 to 450 rpm (Niko, 1948). Figure 2.2 shows a pedal thresher schematic diagram. The impacting teeth on the threshing drum separate the grain from the panicle while the stalk paddy is held firmly by hand.

There were one-man and two-man pedal threshers. The operational procedure for the most common two-man pedal thresher was quite simple but must be followed closely. Three or four persons were necessary for continued operation. The one-man units were generally





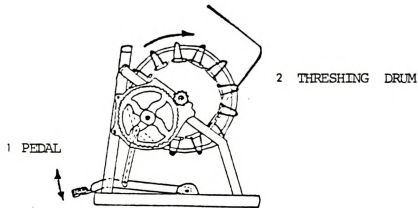


Figure 2.2.--Pedal Thresher Schematic Diagram

unpopular. Some foot pedal threshers were produced locally in Indonesia.

BULOG (1976) and Eriyatno (1979) reported several pedal threshers in Indonesia, mainly in Java. Many of them in West Java were locally made. The pedal threshers were limited to large farmers or cooperatives. Only 26 percent, 5 percent and 2 percent of the farmers surveyed in East, Middle and West Java respectively had threshed paddy with pedal threshers.

IRRI (1968) tests indicated that the performance rate of foot pedal threshers was 68 kilograms per hour for a two-man team. A similar rate of 70 kilograms per hour was found in thresher tests carried out in West Java on IR-38 (Djojmartono, et al., 1979). The pedal thresher capacity was double or triple that of beating or treading.



Furthermore, the pedal drum thresher was simple and light weight, so that stalk paddy threshing could be done in the field after harvesting to minimize handling losses.

#### 2.2.5 Power Thresher

There are many types of power threshers. Khan (1976) stated that threshing paddy by treading them under tractor tires has been used in some Asian countries. The method was used occasionally in Sri Lanka for custom threshing. The mechanically powered threshing cylinder is more typical. Threshing cylinders can be classified as for only panicles or the through type. For panicle threshing, the stalk paddy was held by hand over the rotating drum, while the through type takes the stalk paddy through the machine.

The engine-driven drum threshers have been adapted from the pedal threshers in Taiwan (Esmay and Wu, 1975). Some large old through type threshers have been used at the mill level in Indonesia. Some cooperatives and large farmers utilized small powered threshers of the panicle type. These panicle threshing type threshers could be imported or locally manufactured. Recently, one manufacturer in Middle Java introduced locally made IRRI designed through type powered drum threshers equipped with a cleaning mechanism.



The result of thresher tests conducted by IRRI in 1968, indicated that the performance of IRRI drum panicle threshing power threshers varied from 126.8 to 252.1 kilogram per hour depending on the feeding rate. A small, walking combine-harvester threshing capacity was 463 kilograms per hour for IR-38 (Djojmartono, et al., 1979).

#### 2.2.6 Small Combine-Harvester

A rice combine-harvester does cutting, feeding, threshing, cleaning and bagging simultaneously. The panicle threshing rice combine-harvester was initially designed as a walking type combine. This panicle threshing rice combine-harvester consisted of a 50 centimeter width reciprocating cutter bar (mower type), a plastic nail type pick up device, chain stalk handling and a panicle threshing type thresher. The cutter bar, pick up device and threshing units were set in a frame and supported on crawler tracks to provide mobility in wet paddy fields. There were 200,000 combines in Japan in 1973 (Esmay and Wu, 1975). Several improved riding type panicle threshing rice combine-harvesters have been designed in Japan and adapted for wet fields in Malaysia. The combines, manufactured in 1975, were equipped with a 1.5 meter cutter bar and operated at an average rate of 0.200 hectares per hour. The capacity was affected by soil conditions (Ano., 1977).



One walking panicle threshing type rice combine-harvester with a 50 centimeter cutter bar width provided a harvesting capacity of 0.040 hectare per hour on IR-38. During the tests, the soil condition was dry, the paddy was at its optimum maturity with 18 percent grain moisture content and it yielded 5.028 tons per hectare.

#### 2.2.7 Mechanical Drying

Rice is a biological material with hygroscopic qualities. It must, therefore, be dried down to 13 or 14 percent wet basis to prevent spoilage during long period storage. Sun drying systems are dependent on weather and can be a problem during wet seasons.

Mechanical grain drying can be done by blowing air through layers of grain with fans. Esmay, et al., (1978) classified the moisture reduction methods into four categories: (1) ultra low temperature, (2) low temperature, (3) high temperature and (4) ultra high temperature. Brooker, Bakker-Arkema and Hall (1974) gave a complete discussion of cereal drying principles and systems. De Padua (1976) also discussed the rice drying principles and systems.

A thermal convection solar flat-bed rice dryer was tested in Thailand by Exell and Kornsakoo (1978). A solar air heater consisted of a layer of burned rice husk and a clear plastic sheet was used. The paddy reached

moisture content of 14 percent wet basis from about 20 percent in two or three days while protected from rain. The flat-bed type dryer commonly used in many Asian countries was small in size with a one ton bin. The fan to blow the oil-fired heated air through the grain was driven by a three or five horsepower engine.

There were 873 batch type and 7 continuous type dryers located throughout Indonesia in 1972 (Weitz-Hettelzater, 1972). They were owned by millers or cooperatives or BULOG. The result of a BULOG and IDRC survey project in 1976 indicated that the high operational cost, the need of high operational skill and difficulties of maintenance and repair were the main problems of using the mechanical dryer in Indonesia. The mechanical dryers were only used as supplemental dryers during the rainy seasons.

The batch type dryer may take from 5 to 20 hours to dry a ton of rough rice, depending on the amount of water removed from the rough rice, climatic conditions, heated air temperature, and the rate of air flow through the grain (Esmay and Wu, 1975). The new design dryer with an improved holding bin construction was developed by IRRI and is now produced locally in Indonesia. A simple divider can separate several varieties of rough rice. The loading and unloading of the rough rice is easier,





and the cost of the bin construction is lower with the vertical bin than with the flat-bed bin with a perforated metal floor.

The average temperature and moisture content reduction of three experiments using the new high yielding variety (IR-32), on IRRI designed rice hull flat-bed dryers is shown in Figure 2.3. The results indicated that the rough rice achieved about 12 percent wet basis moisture content from about 25 percent moisture content in ten hours.



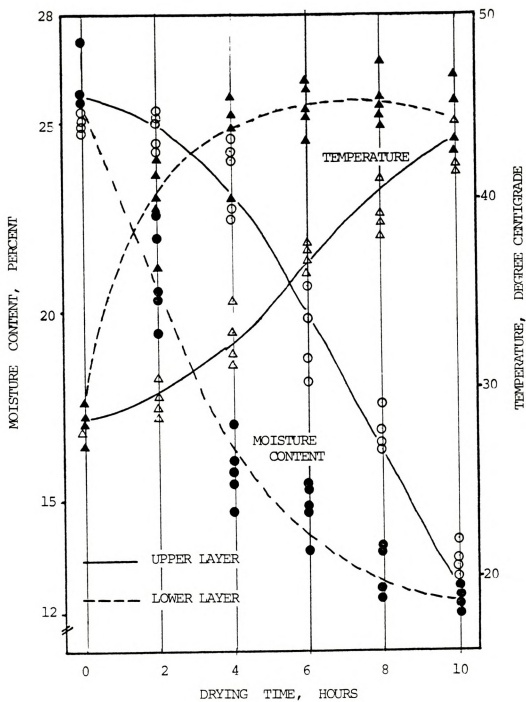


Figure 2.3.--Grain Moisture Contents and Temperatures at Different Drying Times



### CHAPTER III

#### FIELD STUDY

Rice differs from other cereal crops in that the grains are normally cooked whole rather than processed into flour. The number one objective of the post rice production operations is to transform the standing mature rice paddy crop into the highest possible quality and quantity of head rice--good whole polished rice kernels. Many different harvesting, threshing, handling and drying methods have been used in attempts to achieve the objective. However, numerous varying technical, biological, physical and environmental conditions contribute to the post rice production losses of quantity and quality.

Post rice production operation losses include:

(1) mechanical shattering and broken kernel losses from the mechanical operations of cutting, handling, threshing and drying; (2) biological losses of over or under maturity, lodging; (3) rodent, bird, insect and micro-organism losses; (4) environmental losses caused by extreme temperatures, humidities, winds and sun light.

Measurements of post rice production losses were carried out in the field using several types of tools and



machines at several crop maturity levels. The study concentrated on harvesting, threshing, handling and temporary storage operations. The field research was carried out in a rice producing area in West Java, Indonesia in 1978, on two high yielding rice varieties, IR-36 and IR-38. The results of the field research along with available reliable secondary data were employed as a base in formulating the simulation model in Chapter V.

### 3.1 Methodology

#### 3.1.1 Harvesting Losses

Three randomly located plots, each one hundred square meters in area were used for ani-ani and sickle harvesting on scheduled harvesting dates. Three larger plots ranging from four hundred to eight hundred square meters in area were randomly chosen for the rice reaper, rice binder and walking rice combine-harvester operations. Five one square meter plots were randomly chosen within the harvested plots to measure the grains left after the harvesting operations. These were collected and referred to as harvesting losses when converted to kilograms per hectare at 14 percent moisture content.

#### 3.1.2 Packing and Transportation Losses

The harvested stalk paddy were packed and transported using bamboo racks, plastic bags or bamboo baskets





to the threshing location, 600 meters away from the field. Plastic sheets were laid under the bamboo rack while packing. The bamboo rack was covered by a plastic sheet during transportation. The amount of shattered grains on the sheet were counted and converted to kilograms per hectare to provide packing and transportation losses.

#### 3.1.3 Threshing Losses

Stalk paddy harvested by ani-ani and sickle were then threshed using manual foot threshing or a pedal thresher. The stalk paddy harvested using mechanical harvesters were threshed using a power thresher from the walking rice combine-harvester.

The grain which was blown off, husked or left unthreshed in the straw after the threshing operation was referred to as threshing losses. These were collected and converted to kilograms per hectare. The threshing operations were done only at one maturity level, assumed as the optimum maturity level judged by the farmers.

#### 3.1.4 Temporary Storage Losses

A portion of the harvested stalk paddy and threshed rough rice were used for temporary storage study. Harvested stalk paddy and threshed rough rice were left fresh and undried inside a storage room for five days, to imitate the delay of threshing and drying operation.



Spoiled grain was examined every day and judged from the outside appearance as to losses of stalk paddy and rough rice from temporary storage.

### 3.2 Results

#### 3.2.1 Harvesting Losses

Regression equations were fitted to field data collected on the harvesting operation for the IR-36 rice variety. Losses due to ani-ani and sickle harvesting operations were used as dependent variables against the number of days before or after the "optimum maturity" date judged by the farmers as the independent variable.

Equation 3.1 illustrates the predictive equation fitted to the field data of ani-ani harvesting.

$$PHL = 57.7 + 0.16*ND \quad 3.1$$

Equation 3.1 had a r value of 0.93.

Equation 3.2, with a r value of 0.94 represents the prediction equation of sickle harvesting losses.

$$SHL = 52.14 + 1.37*ND \quad 3.2$$

In equations 3.1 and 3.2,

PHL = the predicted ani-ani harvesting losses  
in kg/ha



SHL = the predicted sickle harvesting losses  
in kg/ha

ND = the independent harvesting time variable,  
number of days before or after the optimum  
harvesting time.

Regression curves for ani-ani and sickle harvesting operations varying with the number of days before and after the optimum harvesting date are illustrated in Figure 3.1.

The mechanical rice reaper, rice binder and rice combine-harvester could not be operated properly on the IR-36 rice variety, because of the plant's short height to the canopy of 77.5 centimeter. The IR-38 rice variety with an average height of 20 centimeter more than the IR-36, was better adapted to the Japanese mechanical rice reaper, rice binder and walking rice combine-harvester.

The grain shattering losses after harvesting IR-38 rice by ani-ani, sickle, rice reaper, rice binder and rice combine-harvester are shown in Table 3.1. The measurements were made at the "optimum maturity" level, with a grain moisture content of 18 percent and dry soil condition.

### 3.2.2 Packing and Transportation Losses

The packing and transportation losses with bamboo racks for IR-36 varied with the harvesting date, before



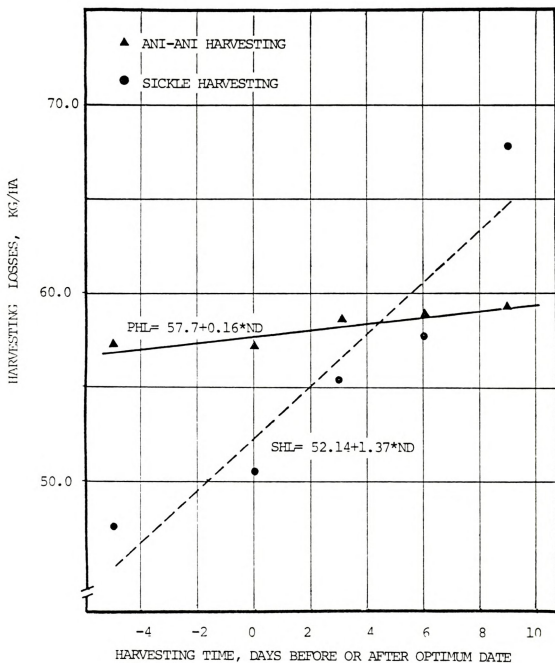


Figure 3.1.--Harvesting Losses at Different Harvesting Times (IR-36)





TABLE 3.1.--Grain Losses for Different Harvesting Methods and IR-38

| Harvesting Methods     | Losses    |         |
|------------------------|-----------|---------|
|                        | Kg per ha | Percent |
| Ani-ani Harvesting     | 158.8     | 3.2     |
| Sickle Harvesting      | 135.1     | 2.7     |
| Mechanical Rice Reaper | 111.6     | 2.2     |
| Mechanical Rice Binder | 100.5     | 2.0     |
| Rice Combine Harvester | 121.1     | 2.4     |

and after the "optimum maturity" as depicted in Figure 3.2. The total amount of packing and transportation losses referred as to handling losses was used as a dependent variable against the independent harvest date variable in obtaining the fitted prediction equation:

$$\text{BRTL} = 7.82 + 0.54 \cdot \text{ND} \quad 3.3$$

where:

BRTL = the predicted handling losses for  
600 meters, kg/ha

ND = the number of days before or after the  
optimum harvesting time.

The handling losses equation had a high coefficient of determination of 0.98. Packing and transportation of stalk paddy with plastic bags or bamboo baskets



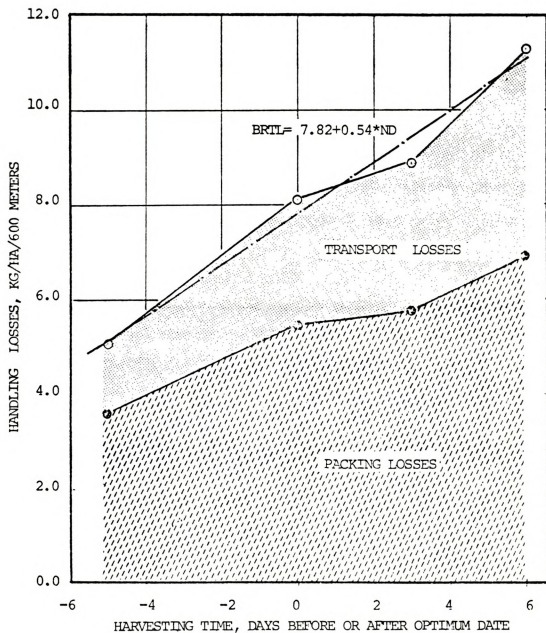


Figure 3.2.--Handling Losses for Different Harvesting Times (IR-36)



were assumed to avoid the shattering losses, and measurements were not made on these cases.

### 3.2.3 Losses During Threshing

The amount and percentage of unthreshed grain and husked grain losses after threshing operations on IR-36 and IR-38 rice varieties are shown in Table 3.2. The measurements were done on stalk paddy harvested at optimum harvesting time. A power thresher could not be used to thresh the IR-36 stalk paddy properly due to the short stems.

TABLE 3.2.--Unthreshed and Husked Grain Losses for Different Threshing Methods

| Threshing Methods       | IR-36 Variety |         | IR-38 Variety |         |
|-------------------------|---------------|---------|---------------|---------|
|                         | Kg per ha     | Percent | Kg per ha     | Percent |
| <u>Unthreshed Grain</u> |               |         |               |         |
| Foot Threshing          | 17.5          | 0.6     | 22.9          | 0.5     |
| Pedal Threshing         | 143.2         | 4.8     | 29.2          | 0.6     |
| Power Threshing         | *             | *       | 0.0           | 0.0     |
| <u>Husked Grain</u>     |               |         |               |         |
| Foot Threshing          | 2.6           | 0.1     | 0.0           | 0.0     |
| Pedal Threshing         | 6.8           | 0.2     | 0.0           | 0.0     |
| Power Threshing         | *             | *       | 6.3           | 0.1     |



### 3.2.4 Temporary Storage Losses

The percentage of deteriorated grain losses after stalk paddy and rough rice temporary storages were used as the dependent variable against the independent variable of the number of temporary storage days. Regression equations were used to fit the data obtained.

Equation 3.4 represented the model used to fit the predictive equation to the collected data on stalk paddy temporary storage.

$$\text{SPTSL} = -2.43 + 8.47 \cdot \text{NDTS} \quad 3.4$$

where:

SPTSL = the predictive percentage of deteriorated grain losses, percent.

NDTS = the independent number of temporary storage days variable, day.

had a  $r$  (coefficient of determination) value of 0.97.

Equation 3.5 is the predictive equation for rough rice temporary storage losses,

$$\text{RRTSL} = 5.5 + 14.73 \cdot \text{LN}(\text{NDTS}) \quad 3.5$$

where:

RRTSL = the predictive percentage of deteriorated grain losses, percent





NDTS = the independent number of temporary  
storage day variable, day

The coefficient of determination for equation 3.5 was 0.92.

The curves of the predictive equations representing the variations in percentage of spoiled grain losses to the independent number of temporary storage day variable NDTS, are illustrated in Figure 3.3.

### 3.3 Discussion

Shattering losses after harvesting as well as after handling operations showed an increase after optimum harvesting time and a decrease before the optimum harvesting date. Rice paddy plants continue their biological process until maturity. The grain becomes more susceptible to shattering at harvesting and handling operations as it matures and dries. At optimum harvesting time, IR-36 had lower shattering losses after ani-ani and sickle harvesting than IR-38. This difference in shattering losses reflected the behavior of varietal characteristics.

The percentage of unthreshed and husked grains varied with the methods of threshing. Table 3.2 illustrated the influence of the threshing method on the percentage of unthreshed and husked grains. Foot threshing



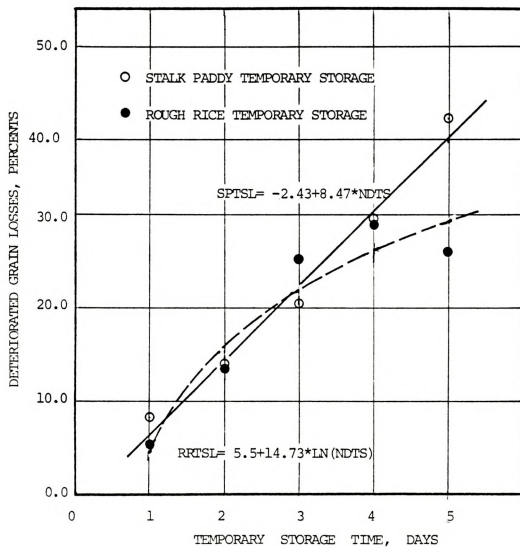


Figure 3.3.--Deteriorated Grain Losses in Temporary Storages (IR-36)



with a rubbing action for threshing the grain from the straw showed a low tendency to produce husked grains. The high speed rotating drum teeth from the power thresher, on the other hand, caused husked grain losses. The unthreshed grain losses may result from improper feeding of stalk paddy.

Deteriorated grain losses due to delay in threshing of stalk paddy or delay in drying of rough rice were seen to increase with the increase in the number of days in temporary storage. High moisture grain will ferment, germinate and generally deteriorate in quality, if it is not stored under proper conditions.



## CHAPTER IV

### FEASIBILITY ANALYSIS

The systems approach consists of five major phases (Manetsch and Park, 1976): (1) Feasibility Evaluation, (2) Abstract Modeling, (3) Implementation Design, (4) Implementation and (5) Operation.

The feasibility evaluation generates a set of viable alternative solutions capable of satisfying the needs of the people for whom a development program is being designed. The first step of a feasibility evaluation is the needs analysis. Based upon the current situation, an analysis of the needs was made to determine the real need (Asimow, 1962).

Having established the real needs, the next step is system identification. This step includes the system boundary, output desired to meet the real need, input necessary to accomplish desired outputs, inputs from environment, undesired outputs resulting from the inputs, and system parameters.

After the real needs have been stated and the system has been identified, an explicit statement of the





problem can be made. Included in the problem formulation is a statement of the criteria for evaluating alternative solutions.

Generation of a broad range of alternative solutions follows the problem formulation. These alternative solutions should then be analyzed to determine those that do not seem to be feasible with current knowledge.

The set of feasible solutions were then studied in more detail in an effort to predict which systems have good potential for reduction to practice. A simulation was developed to aid in this study.

#### 4.1 Needs Analysis

The traditional post rice production techniques in Indonesia have evolved through the years as a result of climatic, economic, social and cultural factors. Evolution often provides an appropriate technique for the prevailing conditions. Thus, the traditional methods and techniques were probably most appropriate for the indigenous varieties. But once the balance of traditional operations is disturbed, changes must follow.

The BIMAS program has introduced new high yielding varieties which, along with other cultural practices, increased the rice yields. Besides the high yielding characteristics, the new grain varieties have a much shorter growing season and are more susceptible to



shattering losses than the indigenous varieties. With the proper mix of resource inputs, the new grain varieties increase the opportunity for multiple cropping. The harvesting season then, often has to be handled in the wet season. Traditional sundrying is more difficult if not impossible and increases quality losses. The increased quantity of rice requires more harvesting capacity than the traditional method to harvest the paddy during its optimum harvesting time and reduce excessive losses. As described in Chapter III, shattering losses of new rice varieties increased significantly beyond its optimum maturity.

An imbalance between rice production and post production factors was created by the focus only on rice production practices through the BIMAS program. New varieties may justify some new techniques or methods. Alternative post rice production systems may be appropriate for the new higher yielding varieties to reduce excessive losses and thus, to save the increased rice yields for marketing and consumption.

Esmay (1977) stated that the limited effort previously directed towards improving post production operations has been scattered piecemeal and ineffectively. Isolated attempts have been made from time to time in different countries to improve specific tools, machines



or methods without consideration of the total post production phase. In other cases attempts have been made to import modern technology directly from the industrialized countries. In most cases, appropriate attention has not been given to minimizing losses with appropriate technology that is labor intensive, simple and locally made.

The evidence indicated a need for an improved post rice production system for Indonesia to minimize losses and increase total rice production.

#### 4.2 System Identification

Figure 4.1 illustrates a system schematically. The post rice production system included the field operations involved in transforming a standing rice crop into a storable commodity for market and consumption. The operations involved were cutting, bunching, transporting, threshing and drying. The system constraints were:

- a. One new high yeilding variety was used
- b. One geographical region was considered. The total simulated area was assumed to be within the one geographical region and with the same climatic conditions
- c. The total acreage was assumed to be well irrigated and with good drainage. A good dry soil condition was always assumed for the day before the first day of harvesting



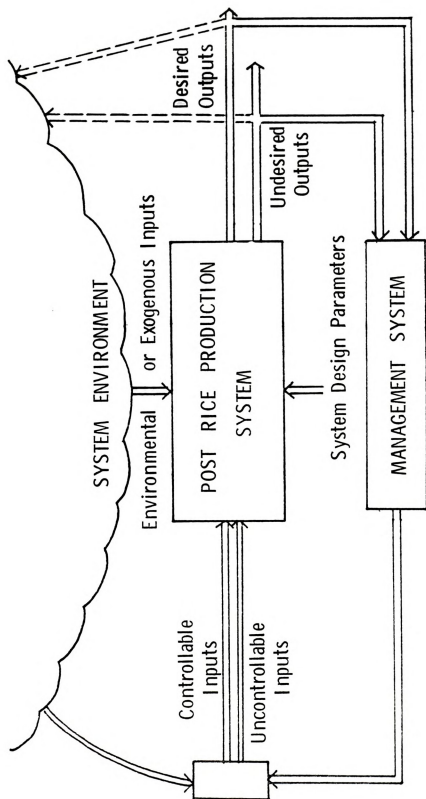


Figure 4.1.--Schematic Diagram of a System





- d. The one main objective in the post rice production operation was to achieve maximum production and minimum losses

Employment and financial evaluations were imposed when feasible, and practical alternative systems in reducing losses were evaluated.

Based upon the needs and identification of the system, the following outputs, inputs, and constraints were considered:

Desired Outputs:

- a. Minimize quantity and quality losses as measured in individual operations and/or in the overall system (kg/ha or %)
- b. Increase rice to the consumer as measured in total tonnage and/or yield per crop area (kg/yr or kg/ha)
- c. Improve grain quality as measured by percentage of head, broken and cracked kernels and foreign material (%)
- d. Minimize operation costs and improve the producers profit position (rupiah/system/hr or rupiah/system/yr)

Environmental Input Variables:

- a. Climatic and weather variables
- b. Prices of post rice production tools and machines



- c. Government policies, i.e., rice price and grading
- d. Wage and interest rate
- e. Fuel and lubrication prices

Controllable Inputs:

- a. Operations rate (ha/hr)
- b. Working hours (hr/day)
- c. Post rice production systems or combinations of various types of harvesting, handling, threshing and drying.

Uncontrollable Inputs:

- a. Total acreage (ha/season)
- b. Production practices; cropping pattern, rice variety, planting date and harvest date (number of harvest seasons/yr)
- c. Crop condition at harvest time, e.g., moisture content and lodging
- d. Credit availability
- e. Rural technical level

System Design Parameters:

- a. Performance characteristics of post production technologies and machines
- b. Labor input (number of people per operation)
- c. Planning horizon (yrs)

All of the outputs and inputs listed were considered to be a part of the system under study; however,



some were not included in the simulation model. Justification for omitting these factors (i.e., credit availability and rural technical level) was based upon the lack of available data to include a meaningful consideration, and that for the purpose of this study, an inordinate amount of time would have been required to develop the needed data.

#### 4.3 Problem Statement

Evaluate traditional and alternative methods for post rice production in Indonesia under alternative cropping patterns and farm sizes, to:

- a. Minimize qualitative and quantitative losses
- b. Increase consumable grain production in quantitative and qualitative terms
- c. Maintain labor utilization at an acceptable level
- d. Improve financial feasibility
- e. Provide technical and cultural feasibility

#### 4.4 Measure of System Performance

The main objective of improving the post rice production operations was to maximize the quantity and quality of rice production by the minimization of losses. The performance of alternative post rice production methods were compared to the traditional methods.



Negative incremental performance in terms of production was not desired. Similarly, positive incremental performance in terms of losses was not desired.

Accumulation of some desired outputs was considered necessary to evaluate a system which might show effectiveness in the long run. Evaluations of performance for a post production system where machines were involved were made at five year periods.

The cost-benefit ratio for incremental production through alternative post rice production operation methods was compared to the performance of traditional operations under given conditions.

#### 4.5 Alternatives of System Concepts (Solutions)

The types of changes which might be made in post rice production techniques to bring about the desired outputs were classified as follows:

- a. Changes in harvest practices only
- b. Changes in threshing practices only
- c. Changes in drying practices only
- d. Changes in harvesting and threshing practices
- e. Changes in harvesting and drying practices
- f. Changes in threshing and drying practices
- g. Changes in harvesting, threshing and drying practices





The traditional post rice production method in the Bekasi area, West Java Indonesia was:

- Harvesting: panicle harvesting with ani-ani, unbundled short stalk paddy
- Handling: bamboo basket handling
- Threshing: manual foot threshing (treading threshing) of wet stalk paddy
- Drying: Sun drying

Cleaning was usually done after drying. The sun drying operation was to dry rough rice to 14 percent moisture content wet basis.

The possible changes of post rice production operation are shown schematically in Figure 4.2. The walking rice combine-harvester was also considered as one of the post rice production alternatives.

There are 23 possible post rice production operation combinations resulting from the possible changes of harvesting, handling, threshing or drying operations. However, only twelve combinations, including traditional post rice production operation, were studied using the simulation model. These twelve combinations are shown on page 53.

#### 4.6 Experimental Design

The twelve combinations of post rice production operation alternatives were then studied in more detail



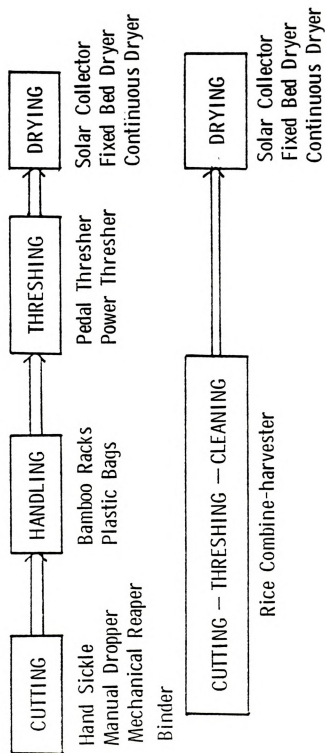


Figure 4.2.--Schematic Diagram of All Possible Post Rice Production Operations Changes



Operation Combinations

| No. | Code     | Operation Combinations |          |           |        |
|-----|----------|------------------------|----------|-----------|--------|
|     |          | Harvesting             | Handling | Threshing | Drying |
| 1   | PHBBFTS* | Panicle                | Basket   | Foot      | Sun    |
| 2   | PHBBMTS  | Panicle                | Basket   | Power     | Sun    |
| 3   | PHBBFTD  | Panicle                | Basket   | Foot      | Dryer  |
| 4   | PHBBMTD  | Panicle                | Basket   | Power     | Dryer  |
| 5   | SHBRFTS  | Sickle                 | Racks    | Foot      | Sun    |
| 6   | SHNHPTS  | Sickle                 | --       | Pedal     | Sun    |
| 7   | SHBRMTS  | Sickle                 | Racks    | Power     | Sun    |
| 8   | SHBRFTD  | Sickle                 | Racks    | Foot      | Dryer  |
| 9   | SHNHPTD  | Sickle                 | --       | Pedal     | Dryer  |
| 10  | SHBRMTD  | Sickle                 | Racks    | Power     | Dryer  |
| 11  | CS       | Combine-harvester      |          |           | Sun    |
| 12  | CD       | Combine-harvester      |          |           | Dryer  |

\* Traditional post rice production operations.



to predict which systems were most practical and had the greatest potential for reduction of losses. The four constraints described in system identification were applied in all simulations. The variables that reflect the changes in farming practices are:

a. Multiple cropping schedule:

- i. two crops per year
- ii. twelve crops per five years. It was assumed, in this cropping schedule, the harvesting seasons were in March and August in the first year, in January, June and November in the second year, in April and September in the third year, in February, July and December in the fourth year and in May and October in the fifth year. The following five years would have the same harvesting schedule

The harvesting schedule for both cropping patterns is illustrated in Figure 4.3.

b. Seven different farm sizes:

- i. 1 hectare per crop
- ii. 2 hectares per crop
- iii. 3 hectares per crop
- iv. 4 hectares per crop





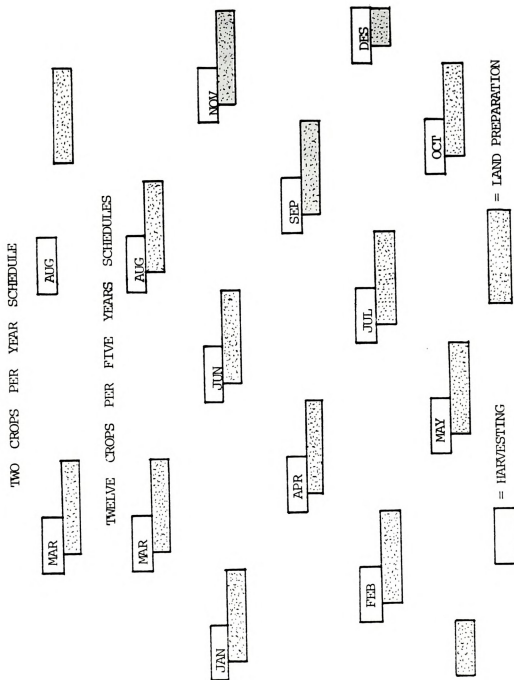


Figure 4.3--Cropping Patterns and Harvesting Schedules



- v. 5 hectare per crop
- vi. 7.5 hectare per crop
- vii. 10 hectare per crop

The shorter growing season of the higher yielding varieties and their ability to mature with less regard to day length increased the opportunity for multiple cropping. Esmay (1973) stated that an equivalent of 50 kilograms of rough rice per hectare is lost each day the land is idle with 120-day rice capable of yielding five tons per hectare. One of the BIMAS program objectives for high production was to maximize the number of crops per year. Harvesting was then necessary during two or three seasons per year.

The farm size determination was based upon the average size of the individual farmers and the financial condition of cooperative organizations. Individual farm sizes ranged from one to five hectares. Larger farms, 7.5 hectares and 10 hectares were hypothesized as at the cooperative level (BUUD).



## CHAPTER V

### THE SIMULATION MODEL

A computer simulation model was formulated to simulate the various combinations of post rice production operations. The simulation approach was chosen because of the system complexity and the stochastic aspect of the post rice production operations (Holtman, et al., 1970).

Simulation models may be formulated in either the discrete or continuous time form. The choice between the continuous or discrete time model depend upon: (1) the level of detail necessary to answer relevant questions, (2) the frequency of events or the flow rate of objects relative to the minimum time interval, and (3) the cost of programming and operating the models (Manetsch and Park, 1974). The outputs should provide all seasonal, annual and planning period information. After considering all of the input information, the discrete time form was selected with a simulation time increment of one day. Submodels and components of the post rice production model are described in the following sections.



### 5.1 Weather Model

The weather or climatic condition is described by numerous parameters such as: rainfall amount and duration, barometric pressure, dry-bulb and wet-bulb temperatures, evaporation, solar radiation, wind speed and direction. The rainfall, temperatures, radiation and evaporation parameters are critical to harvesting, handling, threshing and drying operations. Rain, nonrain days and the rainfall amount determine the work or no work status of the in-field post rice production operation of harvesting, in-field threshing and sun drying. Temperature, radiation and evaporation directly affect the sun drying operation (i.e., the drying period), and the soil moisture status which in turn affects the capability of various in-field post production operations. Temperature, radiation and evaporation parameters, however, were not included in this study. The judgement for omitting these factors was based upon the lack of available data to appropriately account for the effects of these factors on operational performances.

The output of weather--the rainfall occurrences and rainfall amount--were used as an input to the in-field post rice production operations in the overall model. The weather component of the "environment" for the post rice production activities can be obtained in two ways:





One is by using historical weather records. This method provides an exact replication of historical occurrences, but in a series of limited length and requires a large number of cards and long computation time. Two is a method that generates daily weather factors for larger time series than available from historical records. This second method uses historical records for the base of probability occurrence, and then stochastically generates the parameters. The method is thus called the stochastic weather simulator.

#### 5.1.1 Weather Data

Fifty year weather records for rainfall, temperatures (mean, maximum and minimum), pressure, sunshine hours, relative humidity and wind (velocity and direction) were available from 52 weather stations in Java. Smith (1973) felt that data before 1939-40 were probably more reliable than afterwards. The effect of the Second World War and subsequent political disturbances in Indonesia resulted in the loss of considerable meteorological data.

There were 20 meteorological stations in West Java, but none was located in the Bekasi area. The closest station to the Bekasi area was in Jakarta. It was located at an altitude of seven meters, which was similar to the Bekasi area. Eighteen years (1959-1976) of Jakarta



weather data were then used to stochastically generate weather factors representative of the Bekasi area.

#### 5.1.2 Weather Model Development

Considerable research has been reported on weather parameters. Some reports included evaluations for only one typical location, while others were for many locations and several weather parameters.

Sorensen (1967) constructed a generalized weather model to simulate regions with gradient extremes of annual rainfall from five to fifty inches for any given year. Iowa rainfall probabilities were evaluated and used in an agricultural production analysis by Link (1968). Jones (1970) developed a weather simulation model to use the Markov Chain method to simulate daily rainfall, temperature and evaporation for Mississippi. A spatial correlation between the simulated weather in the Manapla and Victorias areas in the Philippines was maintained with the weather simulation model developed by Panol (1973). In Panol's study, one day lag auto-correlation among the weather variables was also used. Dumont and Boyce (1974) described methods of simulating five weather variables for any location for which data was available. Oldeman (1975) evaluated the climatic condition and constructed an agro-climatic map of Java.



### 5.1.3 Rainfall Model

A day was defined as wet in this study if 0.1 millimeter or more rainfall occurred during that day. A probability of rainfall was described as a probabilistic process. It was assumed that the conditional probability of rainfall at the  $i$ th day was determined by the weather sequence until the  $(i-1)$  days.

- Let:  $FD_i$  = event that was sequentially dry for  $i$  days
- $DD_{i+1}$  = event that  $(i+1)$  day was dry
- $RD_i$  = event that was sequentially wet for  $i$  days
- $WD_{i+1}$  = event that  $(i+1)$  day was wet
- $P(DD_{i+1}/FD_i)$  = conditional probability that  $(i+1)$  day was dry, given  $i$  sequential dry days
- $P(WD_{i+1}/RD_i)$  = conditional probability that  $(i+1)$  day was wet, given  $i$  sequential wet days.

$FD_i \cap DD_{i+1}$  was the event that  $(i+1)$  days were sequentially dry and therefore,

$$FD_i \cap DD_{i+1} = FD_{i+1} \quad 5.1$$

$RD_i \cap WD_{i+1}$  was the event that  $(i+1)$  days were sequentially wet and therefore,



$$RD_i \cap WD_{i+1} = RD_{i+1} \quad 5.2$$

From equation 5.1 and 5.2, the conditional probability  $P(DD_{i+1}/FD_i)$  and  $P(WD_{i+1}/RD_i)$  are:

$$P(DD_{i+1}/FD_i) = \frac{P(FD_i \cap DD_{i+1})}{P(FD_i)} = \frac{P(FD_{i+1})}{P(FD_i)} \quad 5.3$$

$$P(WD_{i+1}/RD_i) = \frac{P(RD_i \cap WD_{i+1})}{P(RD_i)} = \frac{P(RD_{i+1})}{P(RD_i)} \quad 5.4$$

$P(FD_{i+1})$ ,  $P(FD_i)$ ,  $P(RD_{i+1})$  and  $P(RD_i)$  were obtained from historical records of daily rainfall. The conditional probability, then, was calculated by using equations 5.3 and 5.4. The probability of a day being wet was determined by  $P(DD_{i+1}/FD_i)$ ,  $P(WD_{i+1}/RD_i)$  and a random number generated using program  $RN = \text{RANF}(-1)$ . The process is depicted in Figure 5.1.

The rainfall distribution during a given wet day was described by a method with two random numbers. The total rainfall for each ten day period was divided into ten categories. A cumulative probability distribution was made for each ten day period from the eighteen year weather records. Figure 5.2 shows the cumulative probability distribution of three ten day periods in March. The first random number determines the rainfall category





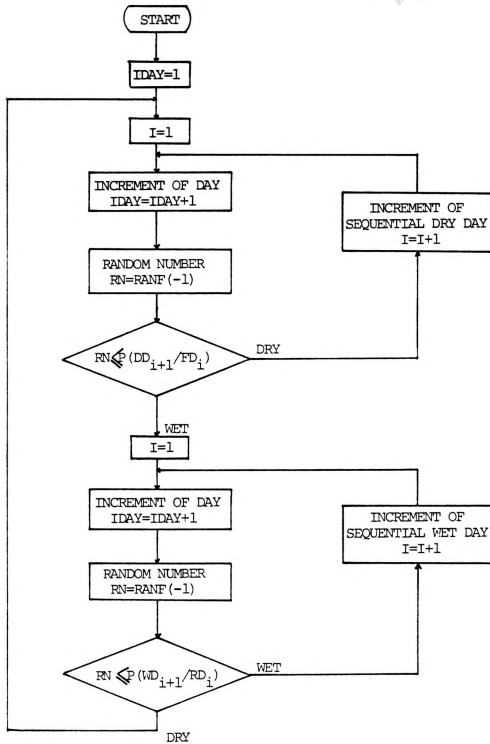
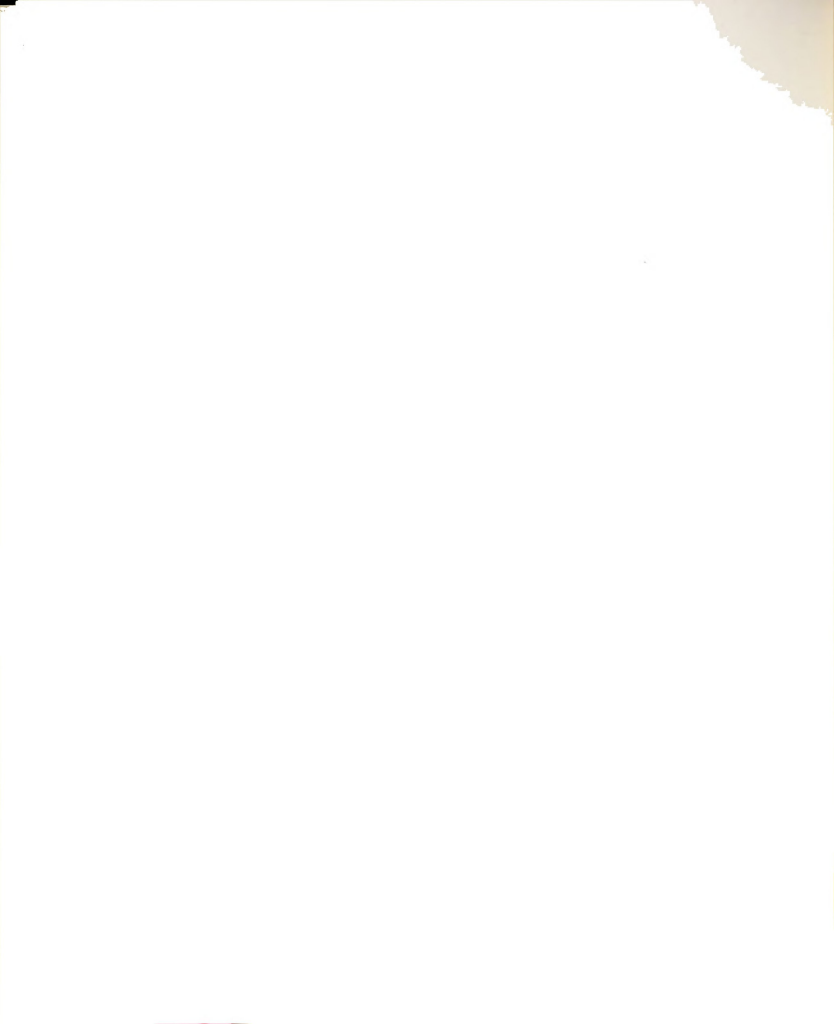


Figure 5.1.--Rainfall Model Flow Chart



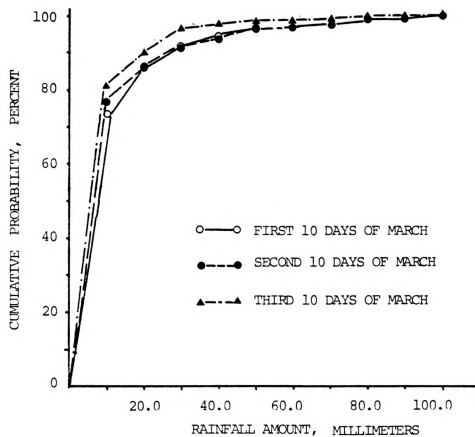


Figure 5.2.--Cumulative Probability of Rainfall Amount in March



of the distribution, and the second one defines the specific rainfall amount. The process is shown in Figure 5.3.

### 5.2 Working Hours Model

The maximum working hours per day for in-field post rice production operations was assumed as eight hours. The drying operation using a mechanical dryer can be over eight hours, and its maximum can be set by changing the value of a parameter from the overall model.

Threshing wet paddy directly after the cutting operation was a common threshing practice in the Bekasi area, West Java, especially when the foot threshing method was used. The persons who were doing the threshing operation were the persons who cut the paddy. Only two hours or less of available working hours per day were assigned to the harvesting operation in the working hours model. If more than two working hours were available on a particular day, and it was not a combine harvesting method, the available working day was divided into two similar hours. One half of the available working hour was assigned to harvesting and handling operations and another to the threshing operation.

The available working hours per day were defined by the rainfall amount on a particular day, between six



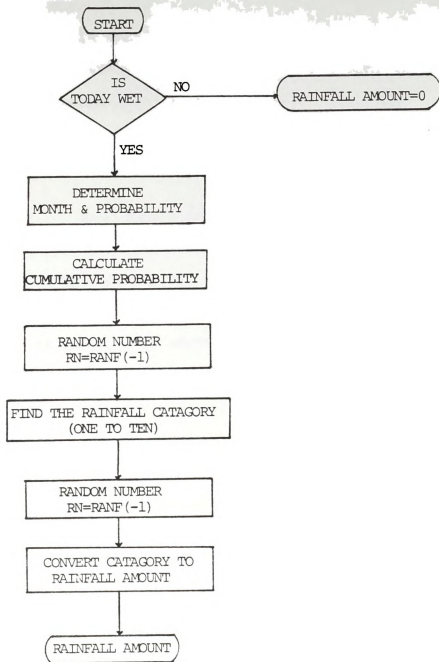


Figure 5.3.--Rainfall Amount Model Flow Diagram





o'clock in the morning and six o'clock in the evening and the type of in-field operation.

The relationship of the working hours and the rainfall amount was assumed as shown in Figure 5.4. The available working hours for the combine-harvester on rain days were assumed to be one-half that of other operations.

### 5.3 Field Condition Model

The field condition which greatly affects post rice production operations was described by the top soil moisture status. Wet soil or standing water reduces the tractability of harvesting machines. The soil condition also affects traditional or manual harvesting operations. Standing water or wet soil is critical for sickle harvesting because: (1) the cut grain will draw moisture from the wet soil; (2) the mobility of the harvester is reduced under wet soil condition whether using a sickle or ani-ani. Observation during the course of this study in the Bekasi area showed that harvesters prefer doing the cutting job on dry soil rather than on wet soil. There was a tendency for the harvesters to leave panicle uncut on wet and badly lodged paddy fields.

Many soil moisture studies have been done for areas where complex machines are used. The moisture distribution in the soil surface layer as well as soil type



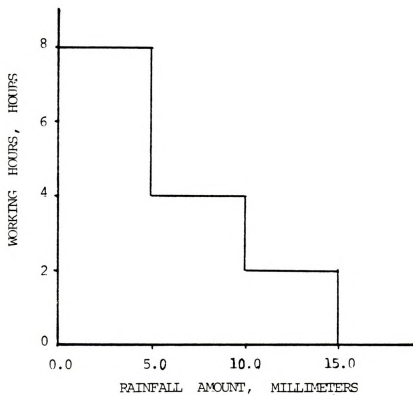


Figure 5.4.--Relationship Between Working Hours and Rainfall Amount



determines the machine's tractability. Shaw (1963), and Baier and Robertson (1966) developed a soil moisture budget model which considered soil type, evaporation, evapotranspiration, rainfall and run off. Shaw (1965) developed and tested a work day model which transformed climatic observations into work day sequences. Frisby (1970) described a technique for predicting the number of good days available for primary tillage in the spring and fall for soil types in Central Missouri. Tulu, et al., (1974) developed models to analyze timeliness costs for corn production.

Research data on soil moisture in Indonesia was too limited for a meaningful analysis. It was therefore decided not to develop a model of the effect of climatic conditions and soil moisture status on in-field post rice production operations. Instead, a simpler model was developed to estimate a working day base upon sequential rainfall occurrences for several days. This model was considered adequate for predicting the field condition resulting from excessive rainfall and its effects on the performance of mobile type machines (i.e., combine-harvester).

#### 5.3.1 Field Moisture Model

The soil moisture model estimated the soil moisture status on particular nonrain days, preceded by wet days. The model assumptions were:



1. A non-rain day for a well-drained field was considered as a working day when less than 10.0 millimeters of rainfall on the previous day.
2. A rain day with a precipitation of less than 10.0 millimeters was combined with the capability of evaporating 50 percent of the rainfall in excess of 10.0 millimeters on the previous day.
3. A nonrain day was defined as a work day for the combine-harvester when there was less than or equal to 10.0 rainfall in excess on the previous day with less or equal to 10.0 millimeters precipitation. Up to 20.0 millimeters of rainfall may be in excess on a work day before it affects the manual harvesting rate. More rain in excess of 20.0 millimeter would reduce the harvesting rate by 20 percent.
4. One nonrain day is necessary to evaporate the excess rainfall resulting from 10.0 millimeter on the previous day.

The model was used to check if a nonrain day was a work day based upon the soil moisture status. The model based





its decisions on rainfall and climatic conditions of up to three days before the particular day of concern. The model flow chart is shown by Figure 5.5.

#### 5.4 Plant Condition Model

Robertson and Weille (1973) reported that rice yields varied from farm to farm and from country to country. The lowest yields were about 1400 to 2000 kilograms per hectare in the developing countries where traditional production practices were used, and the high yields ranged from 4500 to 5300 kilograms per hectare with high yielding varieties and optimum crop inputs and management. The yield variation was a result of interactions and interrelations of many factors such as weather, variety, fertility of soil, farm management practices and prevalence of diseases and insects. Among these factors, the weather parameters were the most significant contributing factors. Owen (1971) reviewed studies on the effects of temperature on the growth and development of rice. He concluded that adverse temperature, acting either alone or through the interaction of day length and other factors from sowing to floral initiation, largely determine the maximum potential yield. Rainfall amount and distribution were also found critical for rainfed rice



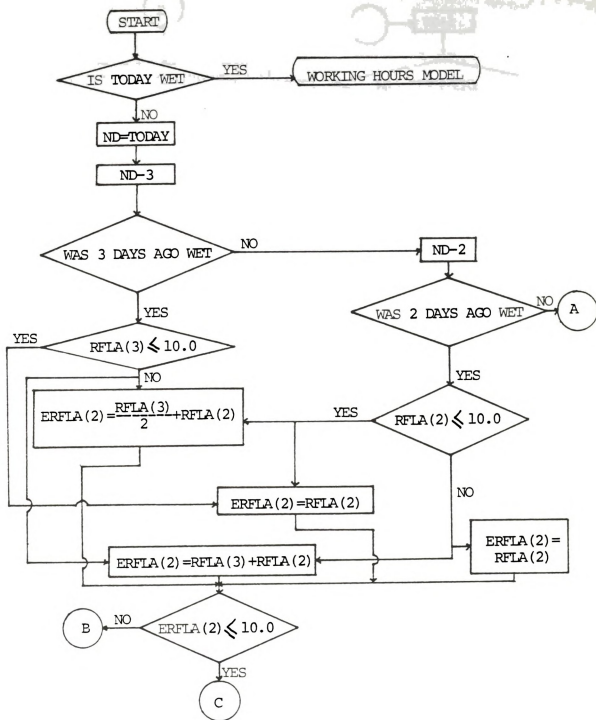


Figure 5.5.--Soil Moisture Status Flow Chart (Part 1)



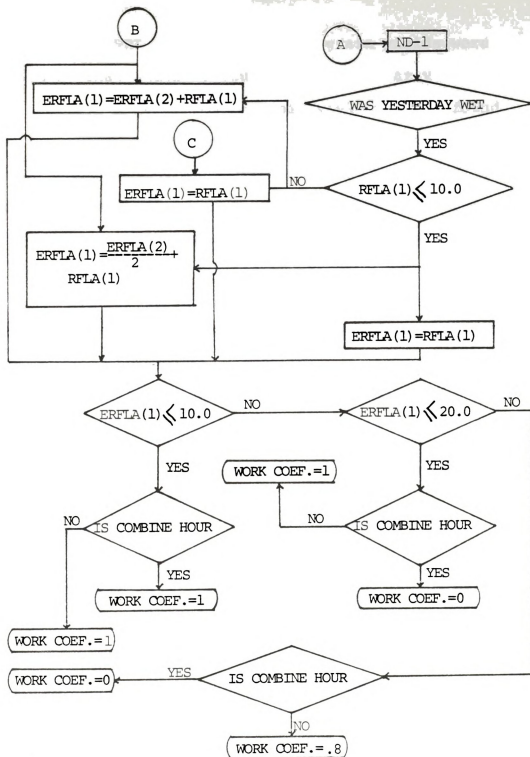


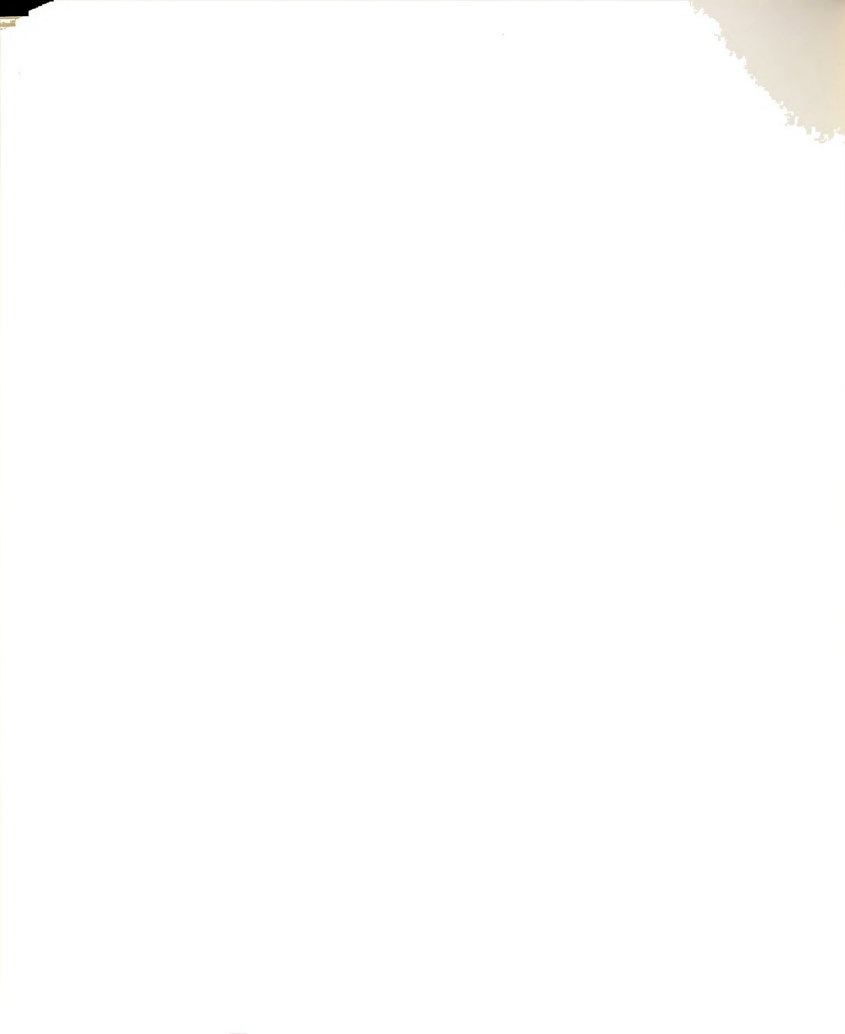
Figure 5.5.--Soil Moisture Status Flow Chart (Part 2)



production. IRRI (1969) found that grain yields were reduced by inadequate moisture during the early stage of crop growth. A reduction in grain yield was not found when the reproductive and ripening stages of the paddy growth were preceded by continuous flooding. IRRI (1967) also found that solar radiation during the last 30 to 45 days before harvest was highly correlated with grain yields. Murata (1975) simulated the rice yield from climatic factors, solar radiation, sunshine hours and temperature. Nitrogen application was another example. IRRI (1970) data indicated that the nitrogen absorbed at flowering was closely related to the grain yield of improved varieties.

Three models were necessary to adequately reflect the plant conditions during harvest. The first model determined the potential yield on the season. The second model took into account the yielding or maturing time. The second model did not allow all of the paddy to enter the maturity stage at the same time. The planting schedule along with weather factors (i.e., temperature) influence the maturity time (IRRI, 1975). The third model consisted of a crop moisture reduction model. Three types of moisture reduction take place in the rice crop. First, the grain loses moisture in the field while attached to the paddy plant; second, the stalk paddy loses moisture





after harvest; and third, grain loses moisture after it is threshed. Many researchers have worked on these problems. Philips and O'Callaghan (1974) modified the wheat moisture content vs. days since ear emergence, from Geslin and Jordan's data, to identify the wheat moisture content when harvested. The relation between climatological variables and field moisture of corn was modeled by Schmidt and Hallauner (1966). Ano. (1976) used the days after 50 percent heading as the characteristic which determines the stage of maturity rather than the moisture content. The grain moisture varies within the day and between days, especially during the wet season.

A yield model and a rice maturing time model were developed for this study. From Anonymous (1976), the optimum harvesting date was used as the determinant for losses, rather than as a function of moisture content.

#### 5.4.1 Crop Yield Model

The yield model was built to describe the relation between the effect of the tillage season's weather condition and accomplishment of the harvesting operation in the previous season to the next season yield. Mathematically, the yield of the next season was described as:

$$OY_{t+1} = AOY * YLDC_{t+1}$$

5.5



$$YLDC_{t+1} = f(SHDAR, AREA, STTLC, TTILD) \quad 5.6$$

where,

- OY = potential yield at season (t+1), ton per hectare
- AOY = average potential yield, ton per hectare
- YLDC = yield coefficient for season (t+1)
- SHDAR = harvested area at previous season (t)
- STTLC = standard tillage capacity, for particular method, ha/hr
- TTILD = total tillage working day for previous season (t), days.

Available tillage working days were determined by the total tillage working days and the weather conditions during the period. The area prepared for planting was determined by the standard tillage capacity and available tillage working hours. The yield coefficient was assumed a function of the fraction of the area harvested and the fraction of the area prepared for planting. The yield model, however, was used only for determining the yield of the second and the following seasons with twelve crops per five years of production practice.

#### 5.4.2 Crop Maturing Model

The reality that all of the rice fields in a particular area would not mature at the same time was accounted for by utilizing the SEASONALIZATION Subroutine



(Manetsch, 1977). The total yield in a given area was indicated by OPY. It was distributed over the maturity time span between TSM (time of starting maturity) and TFM (time of final maturity) as shown in Figure 5.6. The determination of yield was accomplished by using the DELAY Subroutine of the FORDYN simulation language (Llewellyn, 1965).

The portion of mature crops entered as input into the overall post production model, in terms of optimum mature crops. It was specified in the overall model, that about 60 percent of the yield matured on the first day of the harvesting period. When the harvesting operation had to be done either in advance or at delay time, the field (potential) yield of that particular area was not at its optimum level. The in-field yield reduction, due to immature kernels or pre-harvest shattering losses, was calculated by using a modified formula for IR-8 (Bhole, et al., 1970), given as, (equation 5.7)

$$YFLF = 1.0 - \frac{0.32 + 0.428*(OPD+i) - (0.007*(OPD+i)**2)}{0.32 + 0.428*OPD - 0.007*OPD**2}$$

where:

YFLF = yield loss coefficient on day i

OPD = optimum day of harvest (= 30.57), day

i = specific number of days, before or after

OPD.



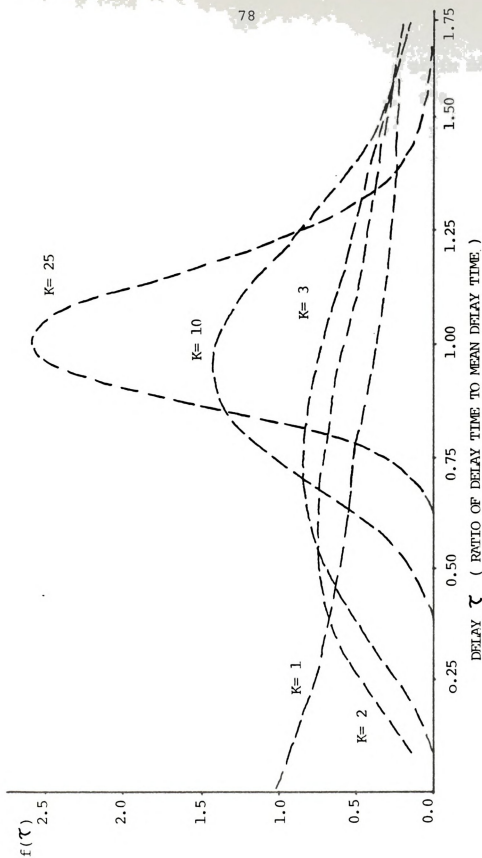


Figure 5.6.--Continuous Delays of Different Orders (Orders =  $k$ )





Equation 5.7 was derived from field yield vs. grain moisture content data collected by Bhole, et al., 1970. The conversion from moisture content to number of days after 50 percent heading used the predictive equation fitted to the moisture content vs. days after 50 percent heading collected by Anonymous (1976).

### 5.5 Loss Models

Losses under various conditions were simulated with predictive equations fitted to the field data.

#### 5.5.1 Shattering Losses During Harvest Operation

Less shattering losses occurred for most varieties before and during the optimum maturity period. Grain harvested before complete maturity increases losses of immature kernels as modelled in Section 5.4.2. Similarly, grain harvested after the optimum maturity date increases shattering losses. The amount of shattering losses after harvest was influenced by the harvesting method. The predictive equations 3.1 and 3.2 fitted to ani-ani harvesting and sickle harvesting were used to simulate the shattering losses. The cracked grain loss due to ani-ani or sickle harvesting was set equal zero in the simulation model.



### 5.5.2 Packing and Transportation Losses

Transportation with bamboo baskets or plastic bags can avoid most transportation shattering losses. The model then,

$$\text{BBTL} = 0.0 \qquad \qquad \qquad 5.8$$

The predictive equation 3.3 was used to model the handling shattering losses with bamboo racks.

### 5.5.3 Losses During Threshing

The losses during stalk paddy threshing can be unthreshed grain, husked grain or cracked grain losses. The amount of unthreshed, husked and cracked grains were influenced by the crop maturity level, varietal characteristics and the threshing methods.

The unthreshed and husked losses models in this study assumed that unthreshed and husked losses were constant over maturity stages. The cracked grain losses model used in the overall model was derived from the equations used by Ilangantileke (1978) and Anonymous (1976), given as:

a. Foot threshing:

i. Unthreshed grain losses,

$$\text{FTULP} = 0.005 \qquad \qquad \qquad 5.9$$



## ii. Husked grain losses,

$$\text{FTHLP} = 0.0 \quad 5.10$$

## iii. Cracked grain losses,

$$\text{FTCLP} = 0.0 \quad 5.11$$

## b. Pedal threshing:

## i. Unthreshed grain losses,

$$\text{PULP} = 0.006 \quad 5.12$$

## ii. Husked grain losses,

$$\text{PHLP} = 0.0 \quad 5.13$$

## iii. Cracked grain losses,

$$\text{PCLP}(i) = \frac{10.106 - 0.3773 * (\text{OPP} + i) + 0.00724 * (\text{OPP} + i) ** 2}{10.106 - 0.3773 * \text{OPP} + 0.00724 * \text{OPP} ** 2}$$

$$- 1.0 \quad 5.14$$

## c. Power threshing:

## i. Unthreshed grain losses,

$$\text{PWULP} = 0.0 \quad 5.15$$

## ii. Husked grain losses,

$$\text{PWHLP} = 0.001 \quad 5.16$$

## iii. Cracked grain losses,

$$\text{PWCLP} = \frac{86.702 - 5.493 * (\text{PPD} + i) + 0.09277 * (\text{PPD} + i) ** 2}{86.702 - 5.493 * \text{PPD} + 0.09277 * \text{PPD} ** 2}$$

$$- 1.0 \quad 5.17$$

All of the values of threshing losses are fractions of the threshed grain amount. Thus, the threshing losses were in kilograms. OPP in equation 5.14 is optimum harvesting time, (26.06) days after 50 percent heading. PPD in



equation 5.17 is also optimum harvesting time, with the value of 29.61 days after 50 percent heading.

#### 5.5.4 Combine-Harvester Losses

The grain shattering losses after harvesting IR-38 with a 50 centimeter cutting width walking rice combine-harvester were 121.1 kg/ha at the optimum harvesting time. Because the data for shattered grain losses with the combine-harvester for different harvesting dates were not available, the model for estimating the shattering loss was derived from the data collected at optimum harvesting time and the data from sickle harvesting. The equation was:

$$\text{CHL} = 46.6 + 1.37 \cdot \text{NDD} \quad 5.18$$

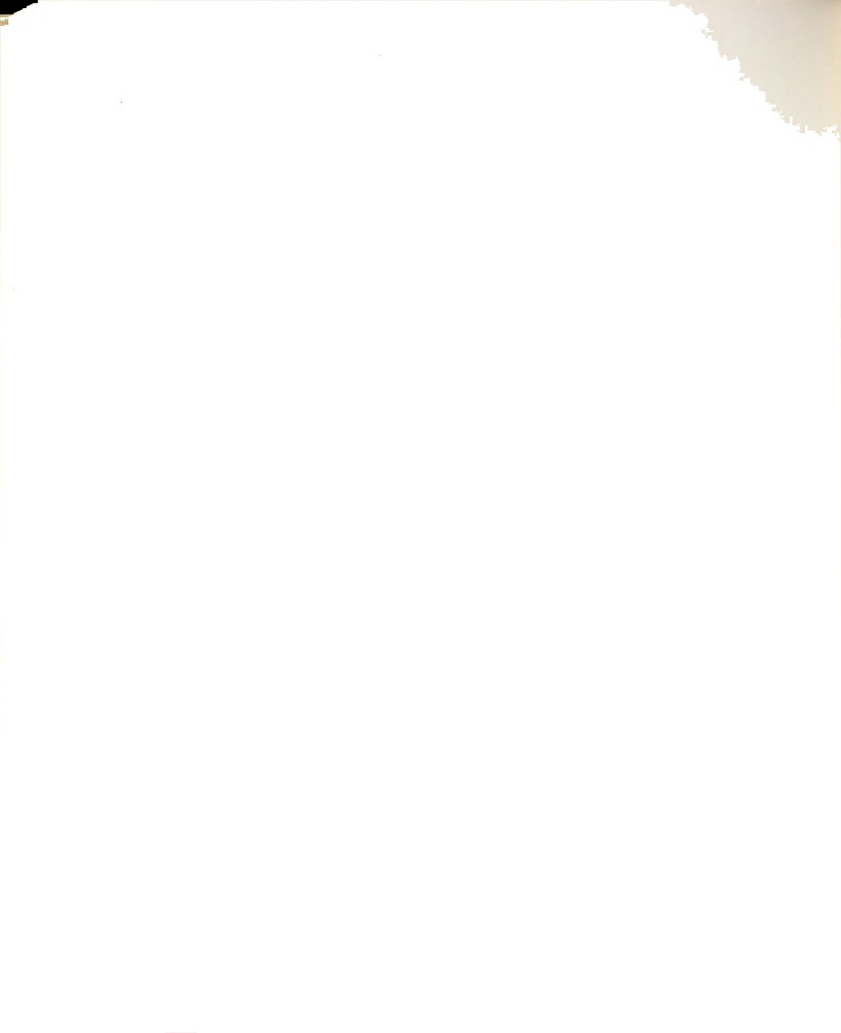
where:

CHL = combine-harvester shattering losses, kg/ha

NDD = number of days after or before the optimum  
harvesting date, days

The threshing operation within harvesting with a combine-harvester would also result in cracked grain losses. Equation 5.17 was used to predict the cracked grain losses due to harvesting with a walking rice combine-harvester.





#### 5.5.5 Temporary Storage Losses

The predictive equations 3.4 and 3.5 fitted to stalk paddy temporary storage data and to rough rice temporary storage data were used to model the losses which occurred in these threshing or drying operation delays. The model should be used for the number of temporary storage days more than or equal to one day. The use of a zero day temporary storage would create negative losses.

#### 5.5.6 Drying Losses

Bhole, et al., (1970) found that mechanical drying gave different head yield from sun drying. The percentage of head yield would be the same if the rough rice were harvested after the optimum harvesting date when sun-cracked grain had developed while the paddy was left standing in the field. The model for predicting cracked rice grain losses after drying with sun drying or mechanical drying methods was derived from Bhole, et al., (1970) data. The conversion from moisture content to the number of days after 50 percent heading was based upon the data collected by Anonymous (1976).

The predictive model for cracked grain losses with sun drying time was,



$$SCLP(i) = 1.0 - \frac{-28.13 + 4.13*(OSD+i-7) - 0.058*(OSD+i-7)**2}{-28.13 + 4.13*(OSD) - 0.058*OSD**2} \quad 5.19$$

where:

SCLP = the percentage of cracked grain losses with  
sun drying on day i, percent

OSD = optimum harvesting date (35.8), day

i = number of days after or before the optimum  
harvesting date, days.

The predictive model for cracked grain losses from  
mechanical drying was given as:

$$DCLP(i) = 1.0 - \frac{-1.0 + 4.10*(DSD+i+1) - 0.07*(DSD+i+1)**2}{-1.0 + 4.10*DSD - 0.07*DSD**2} \quad 5.20$$

where,

DCLP = the percentage of cracked grain losses  
with a mechanical dryer on day i, percent

DSD = optimum harvesting date (29.29), day

i = number of days after or before the optimum  
harvesting date, days

### 5.6 Operation Costs and Income Model

The total operation costs over the planning period  
were calculated by summing all of the fixed and variable  
costs associated with post rice production operations.  
The gross return over the planning period was calculated  
by adding the gross return from head rice production and  
the gross return from production of rice other than head



rice. The income, before subtracting the rice production costs, was assumed as the gross return minus the total post production costs.

The average annual net income was computed by multiplying the net income by a capital recovery factor,

$$CRF = \frac{(1+r)^n - 1}{r(1+r)^n} \quad 5.21$$

where,

CRF = capital recovery factor

r = rate of return per time period

n = planning period or number of specific  
time periods.

### 5.7 Model Verification

The weather model and rainfall model were verified using actual weather and rainfall data in March and August. The distribution of rainfall from the simulation and the actual records in the first ten day period of March for ten years are shown in Figure 5.7. It is shown in Figure 5.7 that the simulation results agree very closely with the actual data.

Another important consideration in comparing simulated rainfall data with actual rainfall data is the frequency of occurrence of wet days, or the distribution of the number of consecutive nonrain days. The results of



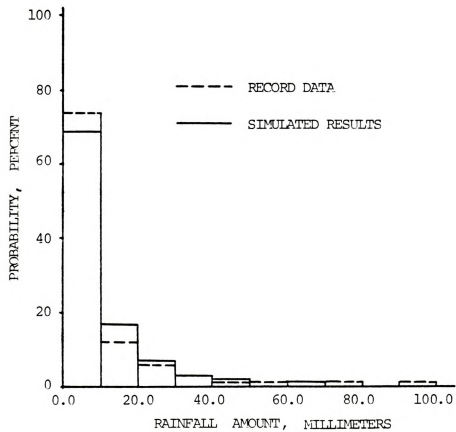


Figure 5.7.--Histogram of Record and Simulated Rainfall Amount in the First 10 Days of March





simulated nonrain days for 18 years agree very closely with the actual data for the same 18 year period, as summarized in Figure 5.8.

Since the field moisture model and the working hours model were basically preliminary models based upon assumptions, no attempt was made to verify these models. No verification were made for the loss models which were predictive equations; however, the logical and theoretical consistencies of all these models within the overall model are discussed in the results (Chapter VII).

#### 5.8 The Overall Model

A specific high yielding variety with a known optimum maturity date and known shattering loss grown on particular land was used as an input to the model. The crop maturing model determined the portion of mature crop on a particular day of the total known area. The portion of mature crop entered available optimum mature crop at the day of harvesting. The harvesting was initiated if it was a work day (nonrain) for that particular post rice production operation combination. After the available area was harvested, the next operation, such as threshing or drying, followed if there was rice crop (stalk paddy or rough rice) available and the operational condition permitted. Otherwise, there were operational delays which caused post rice production losses. The total simulation



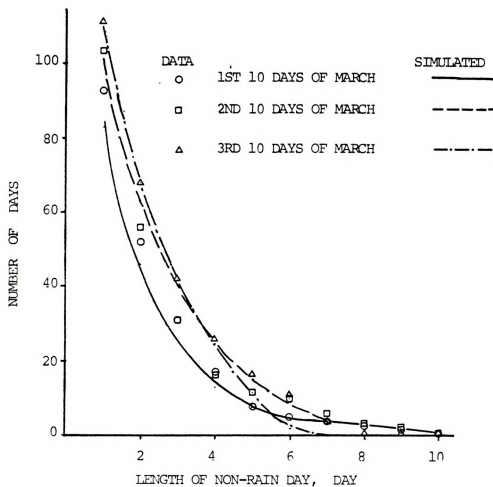


Figure 5.8.--Comparison of Nonrain Sequence Lengths from Actual Data and Simulated Results for 18 Year Period



model continued until all operations were completed or until the maximum post rice production period was achieved. The initial condition of the farm and the post rice production operation were defined in the beginning of each run.

Two different cropping patterns, seven different farm sizes, a planning period and a number of simulations could be controlled by changing the data set. The overall model also provided the means and standard deviation for the average annual net income from several simulations.

Figure 5.9 shows the overall model's flow chart, and Figure 5.10 shows the overall block diagram.

#### 5.8.1 Overall Model Outputs

The outputs from each post rice production operation combination were:

1. The total grain production (quality and quantity)
2. The total operation costs and net income; seasonal and annual
3. The total grain losses

These outputs were used as a basis for a comparison analysis of various alternatives in post rice production.



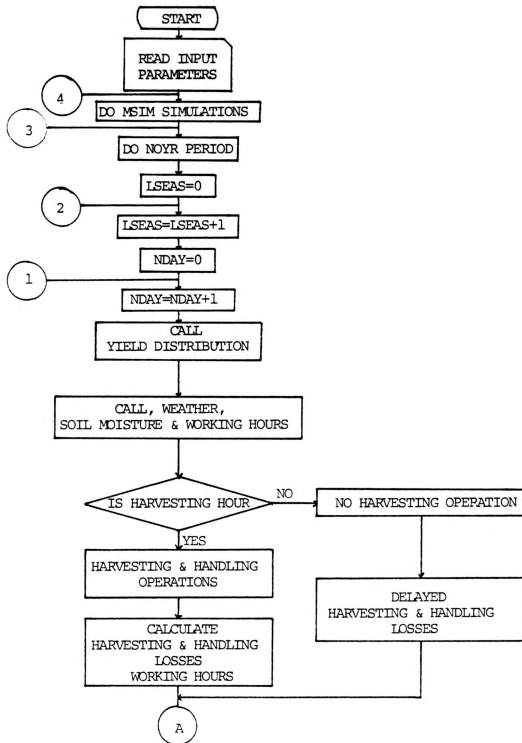


Figure 5.9.--Overall Model Flow Diagram (Part 1)





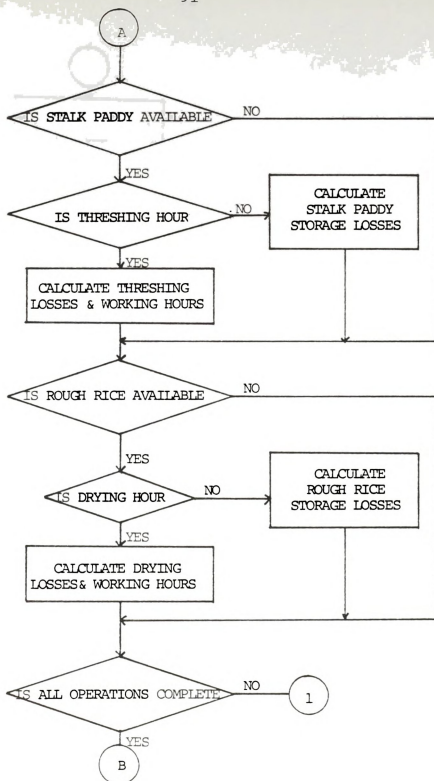


Figure 5.9.--Overall Model Flow Diagram (Part 2)



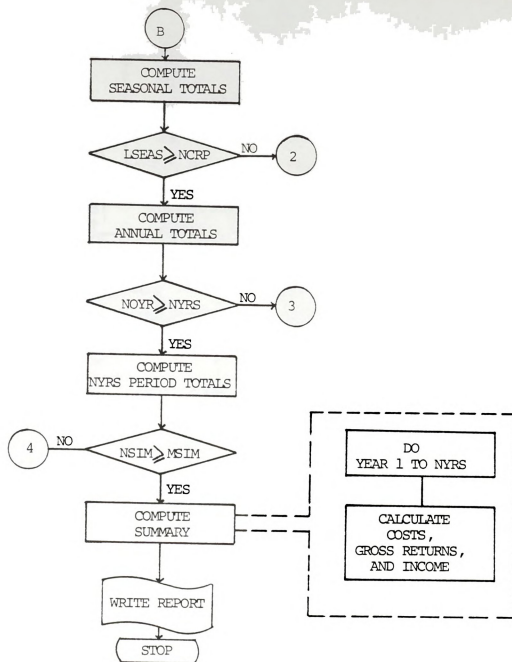
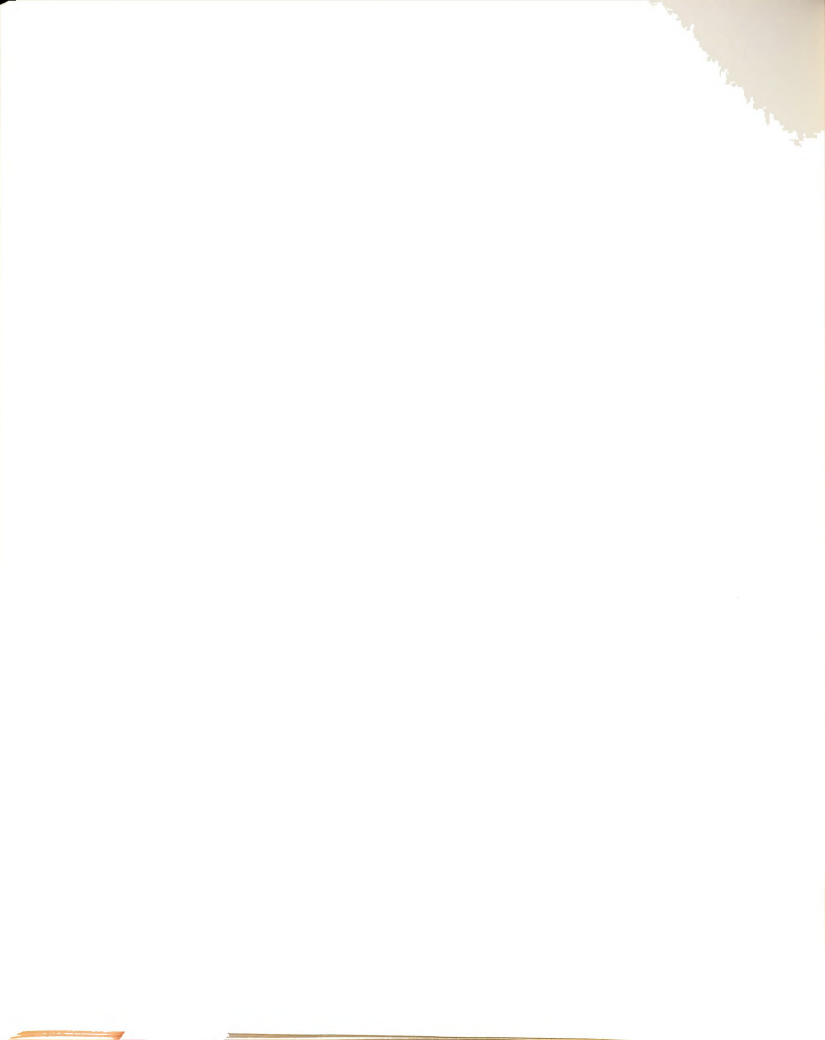


Figure 5.9.--Overall Model Flow Diagram (Part 3)



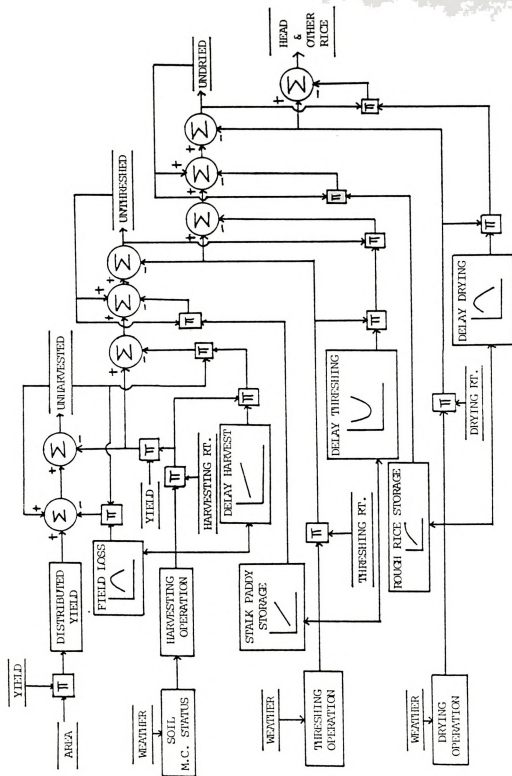


Figure 5.10.--Overall Model Block Diagram



## CHAPTER VI

### SIMULATION RESULTS AND DISCUSSION

A series of simulation runs were made. Simulation periods of two years were used for traditional and manual operations. Five year simulation periods were used for the evaluation of alternative machines. Twenty simulations were made for each run to provide representative statistics for important performance variables.

Several input variables and parameter values were evaluated according to the alternatives analyzed. The yield was assumed to be 3.25 tons per hectare of 14 percent rough rice. The total rice yield and maximum milling head yield was based upon Bhole, et al., (1970) data. The post rice production operation data was taken from field study results described in Chapter III. All of the input variables and parameter values are listed in Table 6.1. Seven different farm sizes were used to evaluate the performance (production and losses) of the technological alternatives.

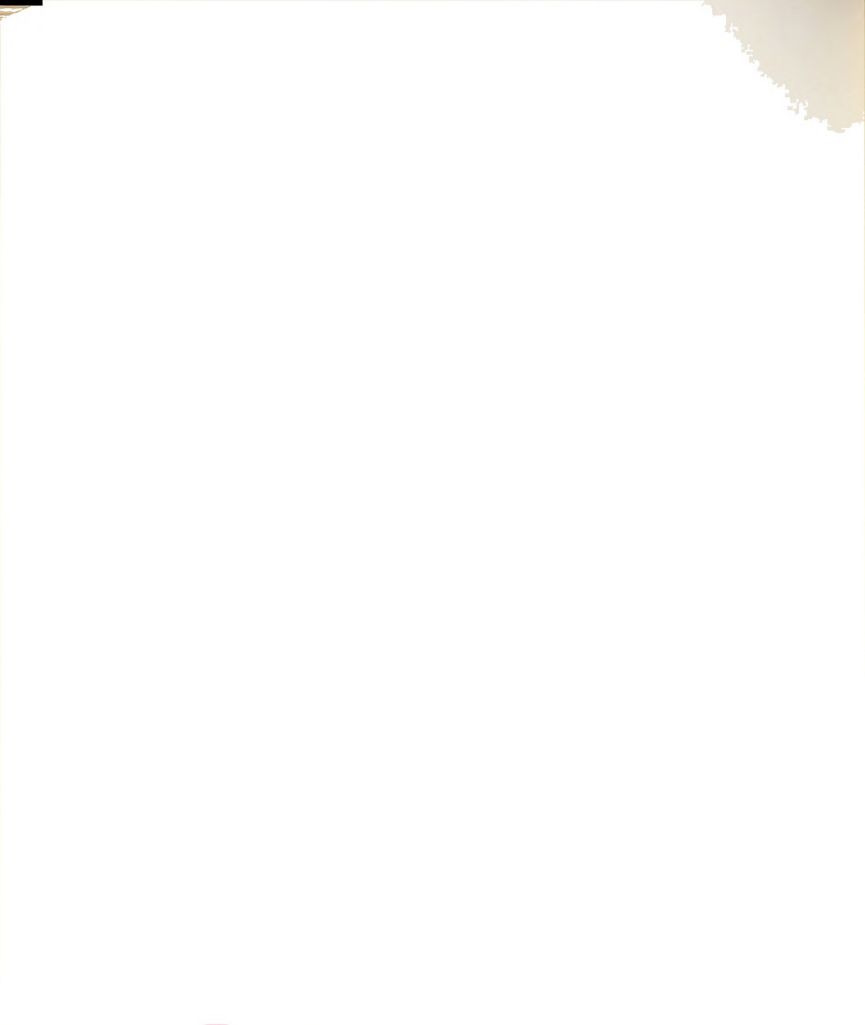
Evaluations were also conducted to observe the effect of several variables such as: number of laborers in manual operations, maximum harvesting period per





TABLE 6.1.--Input Variable and Parameter Values Used in the Simulation

| Parameters                                            | Values |
|-------------------------------------------------------|--------|
| Yield (Ton per hectare)                               | 3.52   |
| Rough rice to rice conversion                         | 0.72   |
| Mechanical dryer head rice conversion                 | 0.59   |
| Sun drying head rice conversion                       | 0.46   |
| Ani-ani harvesting capacity<br>(hectare per man-hour) | 0.002  |
| Sickle harvesting capacity<br>(hectare per man-hour)  | 0.019  |
| Rice combine-harvester capacity<br>(hectare per hour) | 0.040  |
| Foot threshing capacity<br>(kilogram per man-hour)    | 28.4   |
| Pedal threshing capacity<br>(kilogram per 2-man-hour) | 70.3   |
| Power thresher capacity<br>(kilogram per 4-man-hour)  | 463.0  |
| Sun drying capacity<br>(ton per hour)                 | 0.125  |
| Mechanical drying capacity<br>(ton per hour)          | 0.100  |
| Maximum mechanical dryer working hours<br>(hour)      | 10.0   |
| Transport distance (meters)                           | 600.0  |



season and the yield factor of losses and production for several technological alternatives. The operation costs and income per hectare were evaluated for each operational alternative. For calculation of the costs, gross returns and income, appropriate input parameters were required. These parameters included initial cost of machines or tools, miscellaneous costs, repair and maintenance costs, fuel costs, lubrication costs, labor costs, salvage values, interest and prices of head rice and rice other than head rice.

Initial cost for ani-ani and sickle harvesting were assumed to be zero because the tool cost was minimal. The assumed costs for the ani-ani and sickle harvesting operations were based upon payment in kind after threshing. Seven parts for the owner to one for the harvester was the most common share basis. Costs for other post rice production methods were assumed based upon data from BULOG (1976) and Tarmana (1978). The values are listed in Table 6.2. The costs and income over the simulation period were converted to present value.

### 6.1 Two Crops Per Year Schedule

#### 6.1.1 Ani-ani (Panicle) Harvesting

The traditional method of ani-ani harvesting, bamboo basket or plastic bag handling, foot threshing and



TABLE 6.2.--Parameter Values for Cost and Income Calculations

| Parameters                                                | Values |
|-----------------------------------------------------------|--------|
| Miscellaneous costs (fraction of initial price):          |        |
| Pedal thresher                                            | 0.05   |
| Power thresher                                            | 0.30   |
| Sun drying floor                                          | 0.001  |
| Mechanical dryer                                          | 0.30   |
| Rice combine-harvester                                    | 0.30   |
| Repair and maintenance costs (fraction of initial price): |        |
| Pedal thresher                                            | 0.05   |
| Power thresher                                            | 0.12   |
| Sun drying floor                                          | 0.005  |
| Mechanical dryer                                          | 0.12   |
| Rice combine-harvester                                    | 0.12   |
| Fuel consumption : (liter per hour)                       |        |
| Pedal thresher                                            | 0.0    |
| Power thresher                                            | 1.0    |
| Sun drying floor                                          | 0.0    |
| Mechanical dryer                                          | 1.0    |
| Rice combine-harvester                                    | 3.1    |
| Lubrication (liter per hour):                             |        |
| Pedal thresher                                            | 0.001  |
| Power thresher                                            | 0.1    |
| Sun drying floor                                          | 0.0    |
| Mechanical dryer                                          | 0.1    |
| Rice combine-harvester                                    | 0.31   |
| Salvage value (percent of initial value):                 |        |
| Pedal thresher                                            | 0.0    |
| Power thresher                                            | 10     |
| Sun drying floor                                          | 0.1    |
| Mechanical dryer                                          | 10     |
| Rice combine-harvester                                    | 10     |



TABLE 6.2.--Continued

| Parameters                              | Values    |
|-----------------------------------------|-----------|
| Initial prices (Rupiah):                |           |
| Pedal thresher                          | 80,000    |
| Power thresher                          | 250,000   |
| Sun drying floor                        | 100,000   |
| Mechanical dryer                        | 380,000   |
| Rice combine-harvester                  | 5,000,000 |
| Labor costs (Rupiah per man-hour):      |           |
| Ani-ani harvesting                      | 30        |
| Sickle harvesting                       | 30        |
| Sun drying                              | 100       |
| All other operations                    | 250       |
| Interest (percent)                      | 10        |
| Fuel price (Rupiah per liter)           | 100       |
| Lubrication price (Rupiah per liter)    | 350       |
| Head rice price (Rupiah per kilogram)   | 150       |
| Broken rice price (Rupiah per kilogram) | 90        |





sun drying were simulated to provide a basis for comparison. Three different ani-ani harvesting crew sizes of 25, 50 and 100 people were simulated. Results of a two year simulation period of traditional operations are depicted in Figure 6.1. The highest head rice and broken rice productions of a 25 person harvesting and threshing crew were achieved for a farm size of 1.0 hectare, and ani-ani harvesting rates with 50 and 100 persons provided maximum head rice and broken rice productions for farm sizes up to 3.0 hectares, as shown in Figures 6.1(a) and (b). The decrease in rice production of a 25 person harvesting and threshing crew for farm sizes over 1.0 hectare was due to the limited harvesting capacity. Doubling and quadrupling the ani-ani harvesting crew size increased the harvested area per day; however, the limited drying capacity caused a decrease in rice production.

Figure 6.1(c) shows the annual shattered grain losses of the three different ani-ani harvesting crew sizes for various farm sizes. The shattered grain losses of a 25 person and of a 50 person harvesting and threshing crew increased for farm sizes over 1.0 hectare and over 4.0 hectares, respectively. The limited harvesting rates resulted in delays harvesting and thus, caused an increase in shattered grain losses.



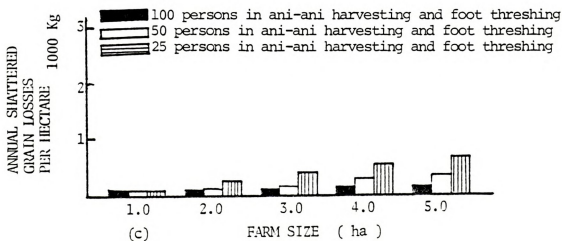
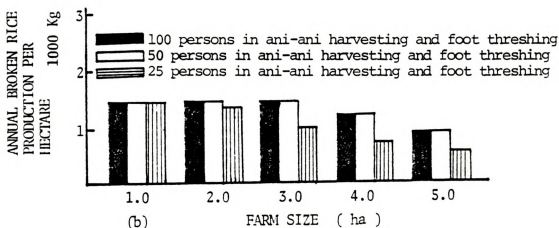
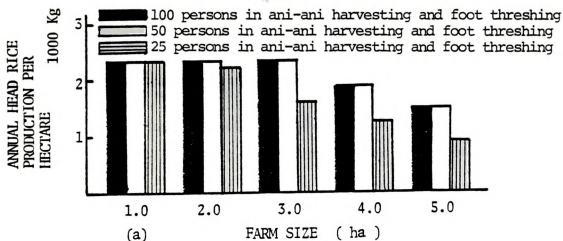


Figure 6.1.--Comparison of (a) Head Rice Production, (b) Broken Rice Production and (c) Shattered Grain Losses on Three Different Ani-ani Harvesting, Foot Threshing and Sun Drying Alternatives



### 6.1.2 Harvesting with Sickles

Ani-ani and sickle harvesting were compared over 10 day maximum harvesting period (Figure 6.2). An ani-ani harvesting rate of 0.050 hectare per hour and sickle harvesting rate of 0.480 hectare per hour, both for a 25 person crew size, were used in the simulation.

The lower ani-ani harvesting rate resulted in less head rice and broken rice production than sickle harvesting for farm sizes over 1.0 hectare [Figures 6.2(a) and (b)]. The reason for the lower rice production was due to the limited ani-ani harvesting capacity, such that the harvesting operation was delayed or not completed. The maximum annual rice production of sickle harvesting with 25 persons started declining at the 4.0 hectare farm when the rice production limit was set by the drying capacity.

With sickle harvesting, it was possible to harvest a 5.0 hectare farm without appreciable delay. The shattered grain loss was always at its minimum because the paddy was harvested nearer to the optimum harvesting time. The delays in harvesting with ani-ani for farm sizes over 1.0 hectare caused an increase in shattered grain losses.



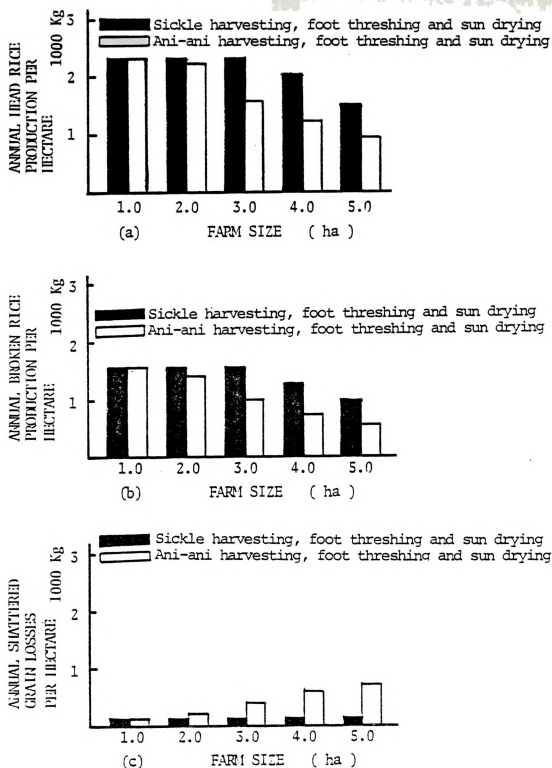


Figure 6.2.--Comparison of (a) Head Rice Production, (b) Broken Rice Production and (c) Shattered Grain Losses on an Alternative with Sickle Harvesting and an Alternative with Ani-ani Harvesting





### 6.1.3 Changes in Threshing Methods

A comparison of the threshing practices of the foot treading method and power threshing in combination with 50 persons doing the ani-ani harvesting and with sun drying is shown in Figure 6.3. A comparison of the different threshing method of foot treading, pedal threshing and power or mechanical threshing with sickle harvesting and mechanical drying are depicted in Figure 6.4.

The use of a power thresher, as defined in the model, will result in higher broken rice production than other threshing methods due to the impact of the rotating power threshing drum teeth. As shown in Figures 6.3(a) and (b) and 6.4(a) and (b), the use of a power thresher resulted in lower head rice production and higher broken rice production than foot threshing or pedal threshing, for all farm sizes. Combined effects from delay in harvesting and the impact of power thresher drum teeth increased the broken grain production for 2.0 hectare, 3.0 hectare and 4.0 hectare farm sizes with ani-ani harvesting and sun drying methods [Figure 6.3(b)].

The broken rice productions from using a power thresher for 1.0 hectare, 2.0 hectare and 3.0 hectare farm sizes were constant [Figure 6.4(b)]. With the use of sickle harvesting, it was possible to harvest the paddy nearer to the optimum harvesting time for farm sizes of



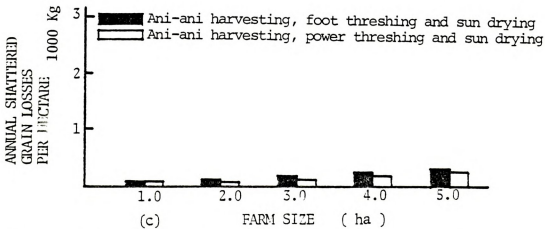
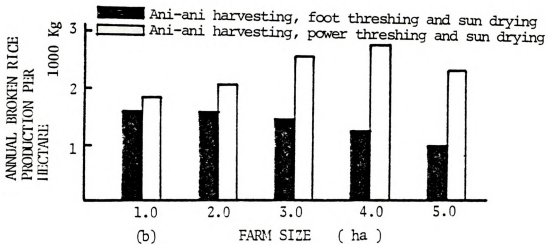
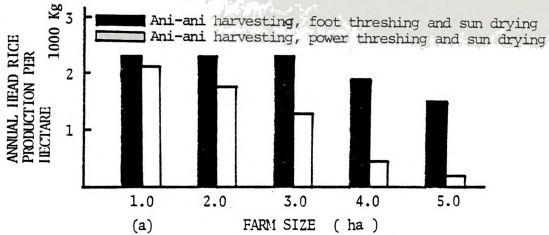


Figure 6.3.--Comparison of (a) Head Rice Production, (b) Broken Rice Production and (c) Shattered Grain Losses on an Alternative with Foot Threshing and an Alternative with Power Threshing.



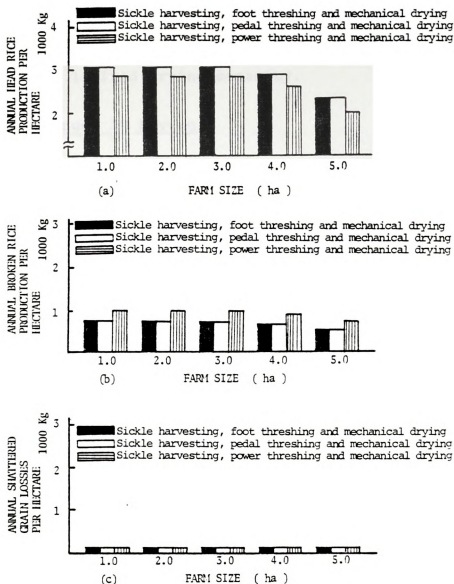


Figure 6.4.--Comparison of (a) Head Rice Production, (b) Broken Rice Production and (c) Shattered Grain Losses on Three Different Threshing Practices



1.0 hectare, 2.0 hectares and 3.0 hectares and thus maintain the broken rice production at a constant level. The decrease in head rice production and broken rice production for 4.0 hectare and 5.0 hectare farm sizes was due to the limited drying capacity.

#### 6.1.4 Changes in Drying Methods

Figures 6.5 and 6.6 show the changes in drying operations. Figure 6.5 compares the head rice production with different dryer capacities. The head rice productions for 5.0 hectare, 7.5 hectare and 10.0 hectare farm sizes increased when the dryer capacity was increased from 0.125 ton per hour to 0.150 ton per hour and 0.175 ton per hour. The results indicated that the maximum head rice production for 5.0 hectare, 7.5 hectare and 10.0 hectare farm sizes were determined by the dryer capacity.

The use of a mechanical dryer produces higher head rice and lower broken rice production than sun drying, particularly when the paddy is harvested nearer to the optimum harvesting time (Bhole, et al., 1970). The results of the simulation model showed an increase in head rice in all cases when mechanical drying was compared to sun drying in combination with ani-ani harvesting and foot threshing (Figure 6.6). The standard deviation of head rice production from twenty simulation runs for the





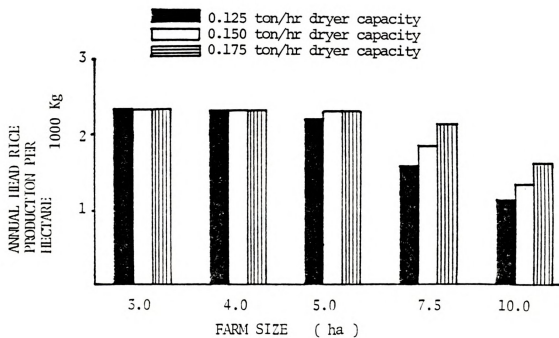


Figure 6.5.--Comparison of Annual Head Rice Production per Hectare of Three Different Dryer Capacities



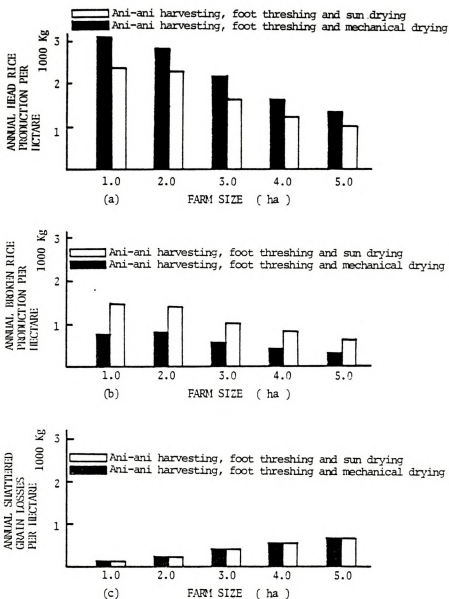


Figure 6.6.--Comparison of (a) Head Rice Production, (b) Broken Rice Production and (c) Shattered Grain Losses on an Alternative with Sun Drying and an Alternative with Mechanical Drying



mechanical dryer was smaller than the standard deviation from the sun drying. This result indicated a stable head rice production when a mechanical dryer was used and the independence of a mechanical drying operation from the weather condition.

#### 6.1.5 Harvesting with a Combine-Harvester

A combine-harvester cuts and threshes the paddy simultaneously in the field. Thus, in nonrain days and at a soil moisture content where a combine can work at highest efficiency, a combine can work for at least eight hours. The use of a walking rice combine-harvester at assumed capacity of 0.040 hectare per hour and sun dryer achieved maximum annual total head rice and broken rice production of 3845 kilograms on a 1.0 hectare farm. This amount was similar to the maximum annual total head rice and broken rice production (3839 kilograms) from traditional methods with 25 persons. The annual head rice production from using a walking rice combine-harvester for a 1.0 hectare farm, however, was only 1944 kilograms, and was lower than traditional method with 25 persons and ani-ani (2348 kilograms). The lower head rice production for the combine-harvester than ani-ani harvesting with a 25 person crew size was due to the interacting effects of delay in harvesting and the impact of the power thresher drum teeth of the combine.



The working capacity and efficiency of a combine-harvester is strongly influenced by the environmental conditions such as, rainfall and soil moisture content. The standard deviation of head rice production (8 1/2 percent) from twenty simulation runs for the combine-harvester was larger than the standard deviation from the traditional method with 25 persons using ani-ani (1/3 percent). This result showed a stronger influence of the weather variability on the rice production of the combine-harvester than that of the manual or traditional method. Thus, the combine-harvester operation is strongly dependent on environmental conditions.

#### 6.2 Twelve Crops per Five Years Schedule

A traditional method and a combination of sickle harvesting, bamboo rack handling, foot threshing and mechanical drying were chosen to make a comparison of the two different harvesting schedules.

Comparisons of head rice production, broken rice production and shattered grain losses of the traditional method with two crops per year and twelve crops per five years with yield factors, are illustrated in 6.7. The number of crops per year affected the total rice production. Higher numbers of crops per year increased the head rice and broken rice productions.





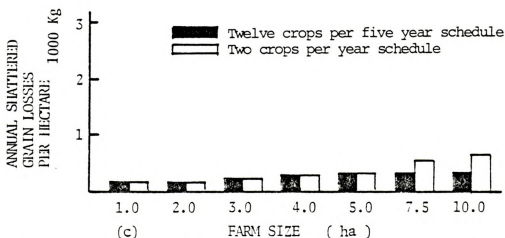
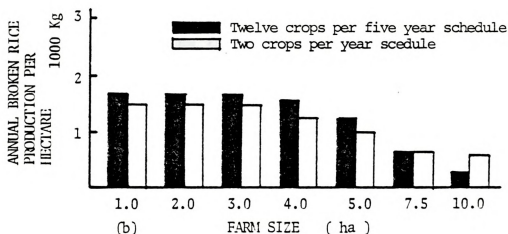
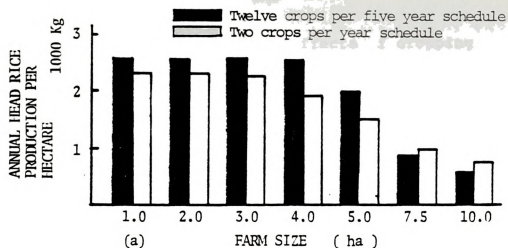


Figure 6.7.--Comparison of (a) Head Rice Production, (b) Broken Rice Production and (c) Shattered Grain Losses on Different Cropping Schedules



Figure 6.8 depicts the effects of cropping schedules and the yield factors on alternative farms with sickle harvesting, bamboo rack handling, foot threshing and mechanical drying. The use of the yield factor in the model, as might be expected, affected the increment in head rice production.

### 6.3 Annual Net Income Per Hectare

Figure 6.9 illustrated the difference in annual net income from using 25 person and 50 person crew sizes in harvesting with ani-ani. The annual net income was defined as the amount of money received by the producers after subtracting the annual post production cost from the annual gross return of selling the head rice and broken rice. The high head rice production of 2329 kilograms per hectare for 3.0 hectare farm size and 50 persons working in harvesting, affected the high annual net income per hectare of 196,674 rupiah for the same farm size. The maximum annual net income, both for 50 person harvesting and 25 person harvesting teams were for the 2.0 hectare farm size.

The annual net income per hectare was affected by the threshing method used. The lower net income per hectare of using a power thresher at any size of farm between 1.0 to 5.0 hectare may be caused by the high expense of owning and operating the power thresher. The



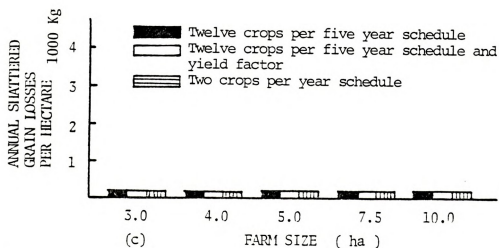
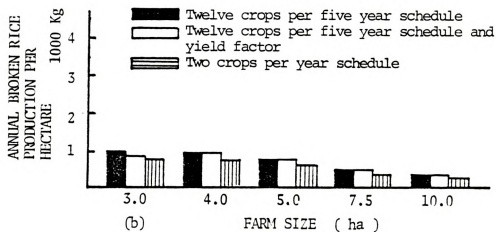
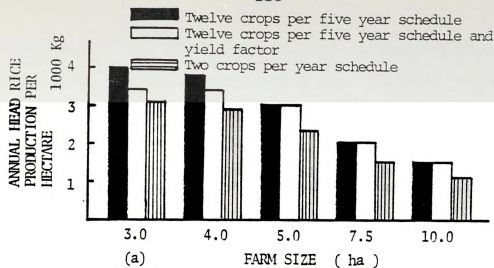


Figure 6.8.--Comparison of (a) Head Rice Production, (b) Broken Rice Production and (c) Shattered Grain Losses on Different Cropping Schedules and Yield Factors



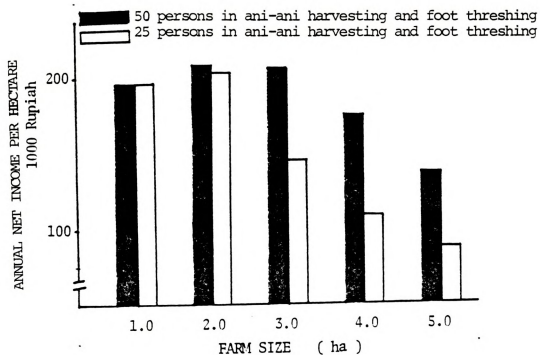


Figure 6.9.--Comparison of Annual Net Income per Hectare on Two Different Ani-ani Harvesting, Foot Threshing and Sun Drying Alternatives





lower head rice production from power threshing when compared to the pedal thresher or foot thresher also resulted in a low annual net income per hectare. Figure 6.10 illustrates the effect of using the power thresher on the annual net income per hectare.

The use of a mechanical dryer affected the annual net income as illustrated in Figure 6.11. The reason for a low annual net income per hectare for the post rice production operation with a mechanical dryer was probably due to higher mechanical dryer operation costs than sun drying.

The use of a walking rice combine-harvester resulted in similar total head rice and broken rice production to the traditional harvesting method with 25 person crew size, but less head rice production due to the use of a mechanical thresher while threshing the stalk paddy. Moreover, the given high initial price of a combine-harvester (5,000,000 rupiah) caused an expensive combine operation expense and thus, resulted in negative annual net income per hectare. Until a low cost combine-harvester or custom combining is available such that low combine operation costs and positive annual net income can be achieved, technology in combination with the use of a combine-harvester is not considered practical.

Increasing 20 percent of drying capacity resulted in 6 percent higher annual net income per hectare for a



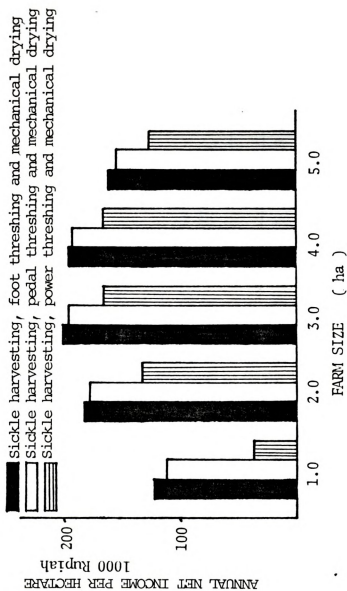


Figure 6.10.---Comparison of Annual Net Income Per Hectare on Three Different Threshing Practices



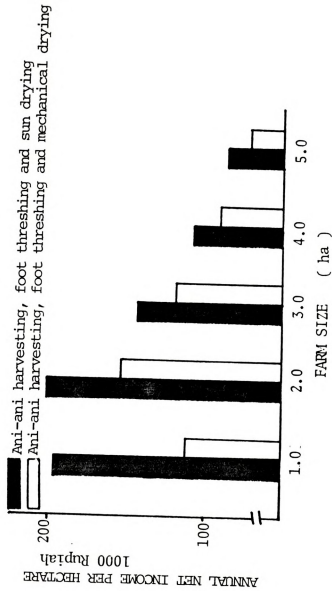


Figure 6.11.--Comparison of Annual Net Income per Hectare on an Alternative with Sun Drying and an Alternative with Mechanical Drying



5.0 hectare farm size if the same dryer price was used. A 5 percent increase in annual net income per hectare could be expected by increasing both the dryer capacity and the dryer price by 20 percent and operating on a farm size of 5.0 hectares. The change of annual net income per hectare due to the increasing capacity and price of the dryer is summarized in Figure 6.12.

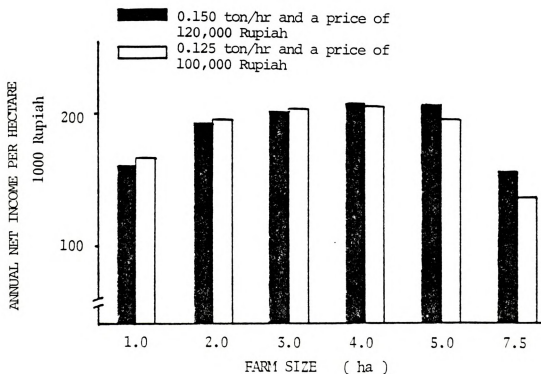


Figure 6.12.--Comparison of Annual Income per Hectare with Two Different Dryer Capacities and Different Dryer Price



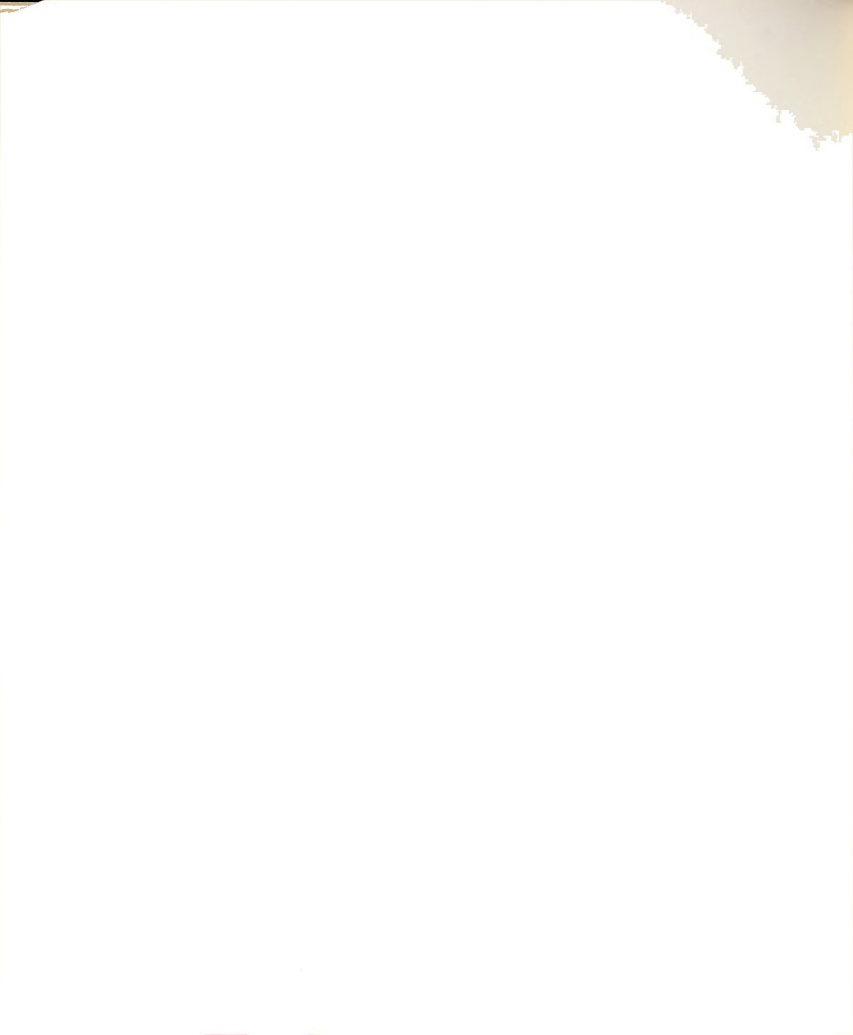


Figure 6.13 illustrates the effects of different cropping schedules and the yield factor. A higher number of crops per year increased the head rice and broken rice production; however, the two crops per year schedule was seen to give the highest annual net income per hectare.

#### 6.4 Comparison of Alternatives

The simulated head rice production for nine selected technology combinations on a two crops per year schedule are compared in Figure 6.14 for a 1.0 hectare farm size and in Figure 6.15 for a 3.0 hectare farm size.

As it has been discussed in previous sections separately, the simulation results showed an increase in head rice productions in all cases when a mechanical dryer was compared to sun drying.

The use of power threshing in a technology combination resulted in lower head rice production than using the foot threshing method. Harvesting by a rice combine-harvester, in which a mechanical thresher is used while threshing the stalk paddy, also caused a decrease in head rice production. The change from foot threshing to pedal threshing in combination with sickle harvesting and mechanical drying slightly reduced (1/2 percent) the head rice production.

The head rice production of all combinations with ani-ani harvesting did not differ from the head rice



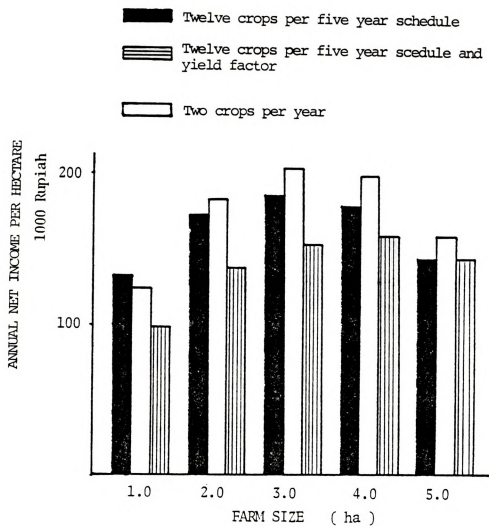
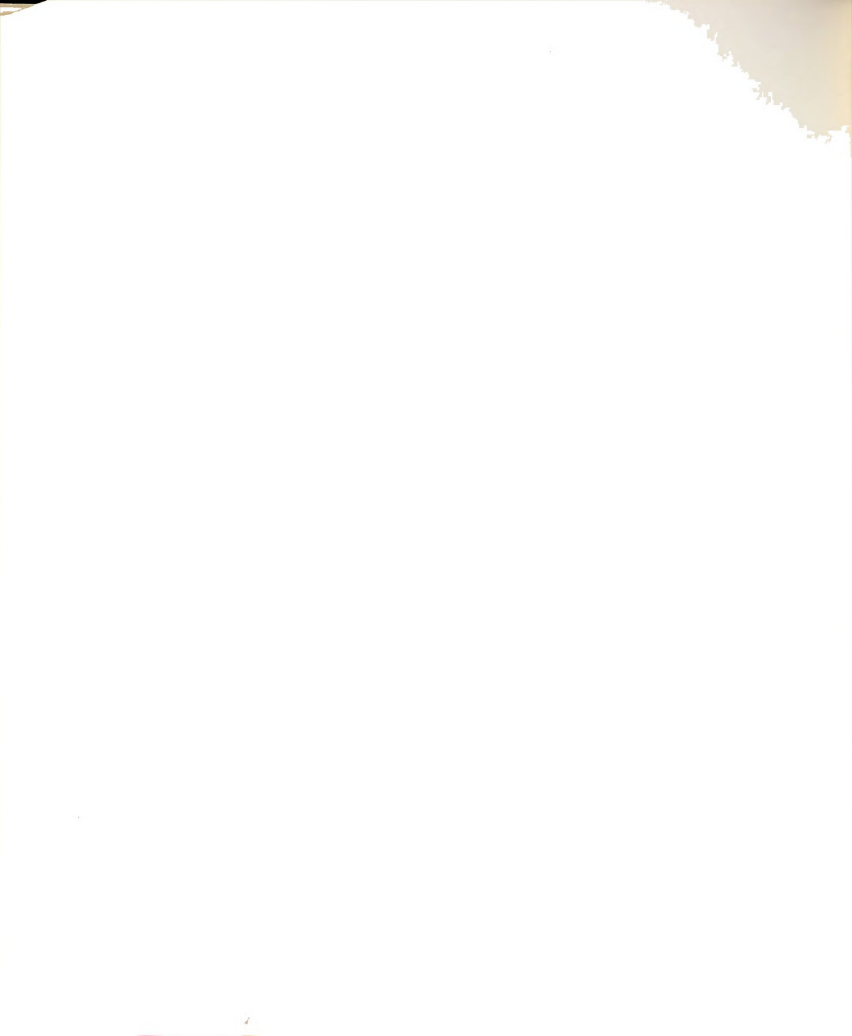


Figure 6.13.--Comparison of Annual Net Income per Hectare for Three Different Cropping Schedules



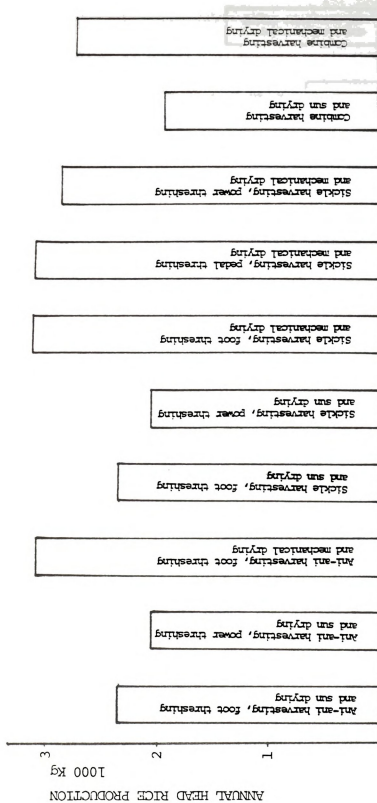


Figure 6.14.--Comparison of Annual Head Rice Production from Nine Alternatives and a Traditional Method for 1.0 Hectare Farm Size



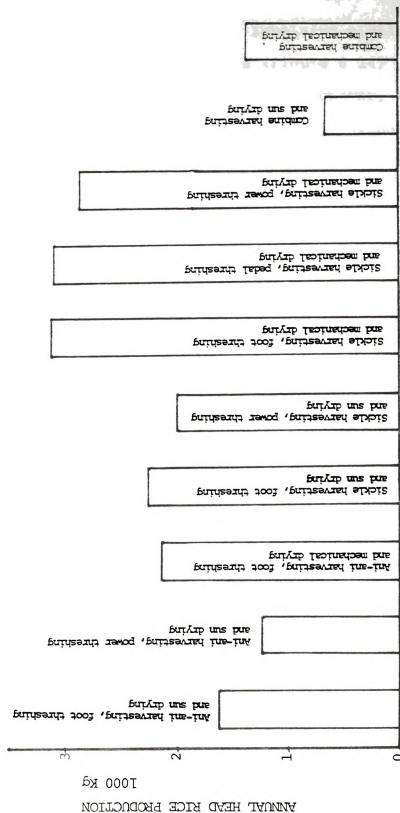


Figure 6.15.---Comparison of Annual Head Rice Production from Nine Alternatives and a Traditional Method for 3.0 Hectare Farm Size





production of all combinations involving sickle harvesting for a 1.0 hectare farm size (Figure 6.14). When the farm size increases to 3.0 hectares, however, the technology combinations with the use of ani-ani harvesting resulted in incomplete harvesting and delays in harvesting; thus, the head rice productions were lower than all combinations with sickle harvesting (Figure 6.15).

Comparison of simulated head rice production of various technology combinations in post rice production indicated that the use of sickle harvesting with 25 persons, foot threshing and sun drying was the most appropriate technology combination for the farm size up to 3.0 hectares.

The change from sun drying to a mechanical dryer within the technological combination of sickle harvesting and foot threshing increased the head rice production by 38 percent for the 3.0 hectare farm size. The owning and operating expenses of a mechanical dryer, however, would also increase, and thus the annual net income per hectare decreased. For the 3.0 hectare farm size, the use of a mechanical dryer in combination with sickle harvesting and foot threshing resulted in a 6 percent lower annual net income per hectare than if sun drying was used. An effort to reduce mechanical drying expenses through custom drying, cooperative drying practices, subsidy or credit by a



government program could increase the head rice production for the country and offset the decrease in the annual net income.

Simulation output shows only a slight decrease in head rice (1/2 percent), therefore there is some basis for recommendation to improve the working conditions in threshing practices. The use of the pedal thresher instead of manual treading method will make the threshing job more convenient and attractive.



## CHAPTER VII

### CONCLUSIONS

The conclusions of this research study are:

1. The field measurements on post rice production operations and losses indicated:

- a. Any delay in the harvesting operation increased shattered grain losses. Shattered grain losses for sickle harvesting of the IR-36 rice variety was about 50 kilograms per hectare when harvested at optimum maturity, and increased to 68 kilograms per hectare when harvesting was delayed nine days.

- b. Bamboo rack handling losses increased when stalk paddy was harvested after optimum maturity. For IR-36, the transportation loss was 11.5 kilograms per hectare when harvested six days after the optimum harvesting date. The handling losses were about 8 kilograms when the harvesting was at the optimum maturity.

- c. Improper temporary storage losses for wet rough rice and wet stalk paddy of the IR-36 rice variety was 25 percent and 42 percent respectively by the fifth day.



2. The system simulation of post rice production operations illustrated the influence of environment on the system as well as interactions within the system. As verified by post rice production data, the system simulation provided an evaluation of the post rice production system for the selection of post rice production technology alternatives.

The simulation indicated:

a. The low traditional harvesting capacity of 0.050 hectare per hour with 25 person crew in ani-ani as the bottleneck of the overall system for farms over 1.0 hectare in size. The final rice production was determined by the harvesting capacity as affected by delays and incomplete harvesting while the sun dryer capacity of 0.125 ton per hour was never fully utilized. If harvesting labor were abundant, the simulation with an assumed 100 harvesters indicated that the sun drying capacity of 0.125 ton per hour was the limiting factor in the post production operation for a 3.0 hectare farm size.

b. The interacting effects between the impact of the power threshing drum teeth and the delay in harvesting caused more broken rice kernels. The use of power drum thresher in combination with 25 persons in ani-ani harvesting, therefore increased the broken rice production for farm sizes over 1.0 hectare because of the delay in harvest.





c. The change from sun drying to a mechanical dryer within the technological combination of sickle harvesting and foot threshing increased the head rice production by 38 percent for 3.0 hectare farm size. The owning and operating expenses of a mechanical dryer; however, would increase and thus lower the annual net income per hectare by 6 percent.

The direct application of the simulation model was in the selection of technology alternatives for the post rice production operations. The simulation indicated that 25 persons for sickle harvesting, bamboo rack handling, foot threshing and sun drying was the most appropriate technology combination based upon head rice production and income for farm sizes up to 3.0 hectares.

Further information that can be drawn from this simulation study are:

a. The overall post production model illustrates the influence of the weather on the system, the interactions of the rice paddy plants with the operations, the interactions between the post rice production operations (i.e., the effect of harvesting delay on the threshing and drying operations), and finally, the overall effect on rice production, grain losses and income. The comprehensive illustration of the system can contribute substantially to a better understanding of the behavior of the post rice production system.



b. The post rice production model with twenty simulations for each technology alternative provided preliminary results when dealing with weather variability and associated risk. The simulation showed a larger variation of rice production and a stronger dependency of harvesting operations on environmental condition when a combine-harvester was used compared to manual (ani-ani or sickle) harvesting. The simulation also indicated more independence of mechanical drying operations from the weather variability than sun drying.



## CHAPTER VIII

### SUGGESTIONS FOR FURTHER RESEARCH

#### 1. Model modification needs further research.

Particularly, the field moisture model and the working hour model need further development and verification. Whether the field moisture model adequately and realistically represents the real soil moisture status needs further verification. The working hours model also needs further testing. The two basically preliminary models reveal important functions in determining the comparative performance of technology alternatives, but need further work.

2. A greater data base on post rice production is necessary to increase the reliability of the simulation results. Data which are necessary to improve the model performance are:

a. Data related to lodging. Maturity level of the paddy was the only parameter used to predict the losses in the present model. Interacting effects of weather and varietal characteristics, such as, lodging may become a sensitive loss factor.



b. Weather variables other than rainfall and the effect on drying operations. The present model indicated the variations in risk and performance of sun drying and mechanical drying systems by using rainfall as the main parameter. Further study may indicate an importance for other weather variables (e.g., ambient temperature or humidity).

3. Further application of the present model is needed. Suggestions for application are:

- a. Other locations or regions.
- b. Identify the optimum size of machines or tools in one technology package.
- c. More rice varieties.
- d. Develop more sensitivity tests to:
  - indicate logical or theoretical inconsistencies in the model,
  - add to user's understanding of and insights into the model and corresponding real system,
  - provide a direct way to test alternatives,
  - suggest data collection priorities by indicating those parameters which are most sensitive to the performance of the model.





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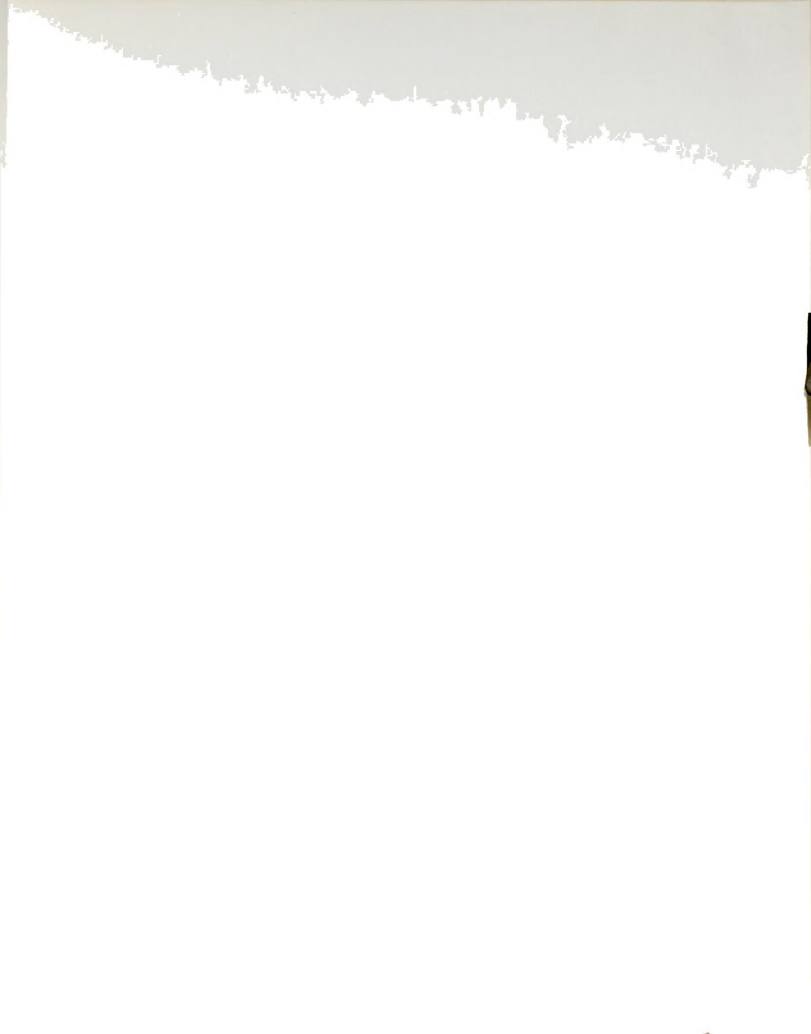


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