THE EFFECTS OF SELECTED LEVELS OF MECHANIZATION ON SMALL-SCALE RICE PRODUCTION SYSTEMS: A CASE STUDY OF CENTRAL LUZON IN THE PHILIPPINES.

by

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Declaration

I, JULIUS MALIMI KIGALU, hereby do declare, to the Senate of Sokoine University of agriculture, that this dissertation is my original work and that it has not been submitted for a similar degree or any other degree to any other University.

(signed)

27/6/1986

(date signed)

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ABSTRACT

This study was tailored to assess the impact of selected levels of mechanization on crop yields, cropping intensity, labor use and energy utilization in rice production in Central Luzon, Philippines. Labor use was partitioned into labor for land preparation, weeding, other preharvest tasks and total post production operations.

Farm households representing three levels of mechanization, namely fully mechanized (using four wheel tractors), partially mechanized (using two wheel tractors or power tillers), and unmechanized (using human and animal power), were selected at random from eight villages. Three cropping seasons (with number of households planting rice in parentheses): 1979/80 wet season (318), 1980 dry season (211), and 1980 wet season (302) were investigated. The study uses data obtained from the Consequences of the Small Rice Farm Mechanization (CSRFM) project conducted by the International Rice Research Institute (IRRI). Four of the eight villages contained rainfed farms while the remaining four were irrigated.

Patterns between farm mechanization and other variables were documented using three approaches: analysis of variance (ANOVA), analysis of covariance (ANACOVA) and production function analysis models. ANOVA was used to compare variances among different mechanized farms while the ANACOVA models were employed to study variations within different mechanized farms. The production function model was used to investigate the combined effects of several explanatory variables on farm productivity: level of fertilizer used, total labor used, other

cash expenses, farm size, and dummy variables representing levels of mechanization and irrigation.

The results revealed a statistical association of high levels of farm mechanization with high yields per hectare, high cropping intensity, low labor used, high level of fertilizer used, high hired labor expenses and high cash expenses. Irrigation, however, showed a more significant effect on cropping intensity than mechanization.

The effect of level of mechanization on energy utilization in rice production was also investigated. Results showed that partially mechanized farms had higher output to input energy ratios than fully mechanized farms during the 1979/80 wet and 1980 dry seasons. The reverse was observed during the 1980 wet season. Fully mechanized farms produced both high rice yields (output) and energy output equivalent of paddy and rice to labor hours. The study also revealed that seed, chemicals and irrigation accounted for high energy input in rice production. It was thus concluded that farm mechanization is profitable despite the present high prices of commercial fuel energy.

CHAPTER I

INTRODUCTION

1.1 Problem

Farm mechanization technology is but one among many confounding inputs which can affect crop output (or yields), cropping intensity, employment and energy utilization efficiency derived from small rice farms (Duff, 1975; 1978; 1979). However, there is a controversial dichotomy centered on farm mechanization. Proponents of mechanization believe that use of farm machinery increases labor absorption in crop production through higher cropping intensity and inducing increased use of modern inputs. They also argue that mechanization makes possible a faster turnaround time from harvesting to land preparation by augmenting effective supplies of land and labor thereby facilitating some farm operations and shortening the production cycle (Binswanger, 1978; Bockhop, 1980; Duff, 1976; 1978; Tan, 1981; Thapa, 1979). Opponents of mechanization believe that introduction and use of capital intensive technology in a relatively labor abundant and capital scarce economy compounds unemployment and underemployment problems.

The debate about the benefits of farm machinery has essentially been between two apparently contradicting domains of thought namely the net contributor view and the substitution theory. Binswanger (1977) summarizes the debate briefly as follows:

The net contributor view maintains that power is a primary constraint to agricultural production regardless of factor prices. Tractors, for example, allow more thorough and deeper tillage leading to higher yields. Tractor drawn implements like seed drills and levellers also add to better performance of farm operations. The higher power and speed of tractors contribute to higher yields by allowing more timely operations and a greater possibility of double cropping. This leads to increased production which requires more labor in operations not performed by the tractor. This view is mainly shared by engineers and implies that mechanization conforms with employment objectives even in low wage countries.

In contrast, the substitution theory assumes that machines and animals are two different sources of power which technically are perfectly substitutable. This implies that any farm operation which is performed by a tractor and its implements can be accomplished by a combination of animal drawn implements and human labor. Hence, the switch from animal power to tractor power primarily depends on factor prices or factor scarcities.

Under the substitution theory, farmers would shift from animal power to tractors only when the opportunity cost of labor and cost of maintaining bullocks become sufficiently high.

Binswanger (1977) reviewed the results of a large number of surveys conducted in India. He concluded, "--- these surveys failed to provide convincing evidence that tractors were responsible for substantial increases in cropping intensity, yields, timeliness, and gross returns. This fairly consistent picture which emerged from the surveys largely supports the substitution view and thus implies that, at existing and constant wages and bullock costs, tractors fail to be a strong engine of growth. They would gain such a role only under rapidly rising prices of factors of production under which they have the potential to replace."

A controversy prevails about the appropriate strategy for mechanizing agriculture. Orcino and Duff (1973) report that one recurring issue is the optimal means of achieving widespread availability and efficient use of farm machinery in situations characterized by small holdings and farm size. In such situations some argue that small machines like power tillers (two wheel tractors) should be introduced and ownership be vested in the hands of small scale farmers. Others suggest that the economies obtainable from the use of large scale machines can be realized if there is an appropriate institutional framework within which use of these machines can be spread over large areas. All in all, the machines to perform land preparation, transplanting, harvesting, and threshing operations should be appropriate in size and complexity to the task at hand and in consonance with the farmer's ability in terms of education, experience and ability to invest (IRRI, 1977).

The level and pattern of a country's use of energy from different sources often serves as an index of its agro-industrial development and standard of living (Kiamco and McMennamy, 1979; Fluck, 1981; Chern, 1984). However, as food production systems modernize, they become less energy efficient and more dependent on commercial energy (Kuether and Duff, 1979; Pimentel et al, 1980; Chern, 1984). Slight increases in the energy inflow into agriculture often cause significant responses in food production (Kiamco and McMennamy, 1979). Boughton (1981) reports measurements of the use and productivity of resources used on rainfed and irrigated farms in the Philippines in energy as well as financial terms. He found fertilizer use on all farms and water supply on pump irrigated farms accounted for the largest shares of fossil energy use and cash expenditure.

These issues are empirical rather than theoretical. In a decade of rising input prices and growing demand for rice, mechanical innovations are needed to increase yields, cropping intensity, and labor employment, and concurrently improve the productivity of scarce resources. There is a need to test the validity of these controversial issues by assessing possible effects of selected levels of mechanization on rice yields, employment and cropping intensity, and energy utilization efficiency. It is also important to identify the factors explaining the differences among farms with respect to the degree of mechanization employed. This requires statistical models to test the significance of differences under conditions of uncertainty.

1.2 Objectives

The objectives of the study are:

1. To investigate whether various levels of mechanization raise total land productivity and how this is accomplished;

2. To investigate whether mechanization lowers production costs such as labor cost;

3. To investigate if mechanization raises cropping intensity;

4. To study energy utilization efficiency in agriculture and determine if it is profitable to mechanize given the present high costs of commercial fuel energy; and

5. To design statistical models to predict the effects of mechanization on yields, employment and cropping intensity.

1.3 Hypothesis

The major issue to be resolved in this study is whether different levels of mechanization cause significant changes in crop output, employment, cropping intensity, and energy utilization efficiency. The study is therefore designed to test the following hypothesis:

1. Mechanization raises total land productivity;

2. Mechanization raises cropping intensity;

3. Machines are associated with output differences between mechanized and nonmechanized farms;

4. There is a reallocation and lowering of selected input costs (such as labor) in the production system as a result of mechanization; and

5. Mechanization raises energy utilization efficiency in small rice farm production.

CHAPTER II

REVIEW OF LITERATURE

2.1 Mechanization and Crop Output

The main advantage the mechanized farmer has over those depending on manual labor alone is the timely performance of operations to obtain maximum benefits of other technologies (i.e. inputs) such as improved varieties, fertilizers, chemicals for weed and pest control (Bockhop, 1980; Igbeka, 1983; Coats and Porterfield, 1975). Land preparation, transplanting, harvesting, and threshing are the critical farm operations in rice production (Bockhop, 1980; Orcino and Duff, 1974). Machines to perform these operations should be appropriate in size and complexity in conformity with the farmer's ability to invest and operate them (IRRI, 1977; 1982; Bockhop, 1980).

Whether mechanization per se increases crop output is an unresolved issue. There is a growing body of evidence that most important effects of mechanization are not direct or immediate (Duff, 1976). For example, timeliness of operations leading to increased cropping intensity and higher yields is complemented by labor and power augmenting technology (Tan, 1981; Binswanger, 1978; Duff, 1976). Duff (1978) gives a general consensus that mechanization has the potential for increasing farm output, for example, by increasing cropping intensity, expanding area under cultivation, diversifying and improving cropping patterns. Moya (1981) found that irrigation pumps can increase yield from an average of 1.5 to 3.4 tons per hectare compared to rainfed rice fields. In the Philippines, yields during the 1970/80 decade increased from 2.6 t/ha to 3.4 t/ha due to dramatic change in rice production technology (Cordova et al., 1981). Most of this increase in productivity is, however, ascribed to HYVs, fertilizers and expanded use of irrigation.

Portable threshers can increase yield by approximately 292 kilograms per hectare, an incremental yield due to change in technique from the manual method to machine threshing. Khan (1971), Juarez and Pathnopas (1981), Habito (1977), and Toquero (1983) all examined the effects of mechanizing rice harvesting and threshing. Their findings showed that mechanization significantly improves rice recovery and grade.

The effects of farm mechanization on output have been examined by Thapa (1979) and Lingard (1981) using a production function framework based on covariance analysis and by Tan and Wicks (1981) using a decomposition analysis model in which an arithmetic decomposition technique was used to disaggregate output differences between mechanized and nonmechanized farms. The production function framework was used to investigate further the yield effect of mechanization. Total yield differences were decomposed into the effects of neutral technological change (using animal and / or human labor only) and change in the use of input components. Lingard (1981), and Tan and Wicks (1981) report that yield was significantly related to mechanization. Thapa (1979) reported that mechanization was positively associated with an increase of yield per hectare. Similar results from data for two crop seasons have been reported by Wicks (1979), Ahammed and Herdt (1981), IRRI (1980), and Shields (1983). Their conclusions agree with those of Lingard (1981), Tan and Wicks (1981), and Thapa (1979).

2.2 Mechanization and Cropping Intensity

Thapa (1979) defines cropping intensity as the ratio of the area under different crops in a given crop year to the total cultivated physical area in that year, expressed in percentage. Cropping intensity is a unitless quantity and, therefore, can serve as a good index for investigating the effect of mechanization on crop yields. Shields (1983) defined cropping intensity as the sum of areas cultivated during two consecutive crop seasons (e.g. wet and dry seasons) to the maximum area cultivated during the two seasons expressed in percentage.

Lingard (1981), and Tan and Wicks (1981) report that mechanization showed a positive significant relationship with cropping intensity. They, however, found that irrigation and credit availability modified cropping intensity more significantly than mechanization alone. Similar results were obtained by Shields (1983), Wicks (1979), IRRI (1980), Ahammed and Herdt (1981), Sison et al (1981; 1983), and Williams and Chancellor (1975). Thapa (1979) concluded that mechanization increased cropping intensity significantly.

2.3 Mechanization and Labor Employment

Some research findings have shown that mechanization of certain farm operations results in labor replacement and displacement (Shields, 1983; Sison et al., 1983; Duff, 1978; Barker and Cordova, 1978). This is an undesirable effect in countries where labor is abundant and farming operations are labor intensive. Gonzales et al. (1981; 1983) evaluated the impact of mechanization on employment (and crop output) in the Philippines using a simulation analysis. They found that power tillers and tractors displaced about 25 and 28 mandays of family labor per hectare respectively, for each cropping season. In the same study, they report that portable rice transplanters and threshers displaced hired labor by about 26 and 6 mandays per hectare respectively. Irrigation pumps, however, showed no known direct effect on employment. Sinaga (1978) reports that mechanization reduces seasonal labor requirements in crop production.

Thapa (1979) in his study on the economics of tractor ownership and use in selected districts of the Nepal Terai, concludes that a high level of mechanization is associated with the following effects: high labor input level (except in land preparation), high percentage of hired labor, and low labor input for land preparation. His results agree with those of researchers already cited in this section. However, Thapa (1979) cautions that rather than mechanization causing these effects, the association is between endogenous (or confounding) variables, mechanization itself being endogenous to the system. Better quality land, for instance, leads to a higher percentage of hired labor, higher cropping intensity and more intensive cultivation of a crop. This means that even in the absence of mechanization, high cropping intensity, high yields per hectare, high labor and high percentage of hired labor in farms with good quality land would be expected.

Labor employment for hand weeding declined substantially over the 1970/80 decade due to an increase in the use of chemicals for weed control (Cordova et al., 1981).

2.4 Mechanization and Energy Utilization Efficiency

Land preparation demands much energy, time and labor. However, energy efficiency during tillage is often very low (Lee, 1979). Kuether and Duff (1979) found that land preparation was one of the most energy demanding operations in the mechanical system of rice production. Other energy intensive operations were crop husbandry, and threshing and drying. For both traditional and transitional rice production systems, land preparation ranked second to crop husbandry operations in terms of energy inputs. Planting and harvesting required relatively low energy inputs in all three rice production systems. Their results agree with those reported by Chancellor (1977), Heichei (1973), and Duff (1978). Stout et al (1979) and Fluck (1981) report energy constants for performing various farm operations.

Williams and Chancellor (1975) produced computer simulations of crop production models. They found that crop yield was sensitive to energy, fertilizer and water input. Similar results are reported by Rutger and Grant (1980) in their study on energy use in rice production. From their results, it is interesting to note that as the rice production system improves technologically it becomes less energy efficient. For example, whereas the ratio of energy output to energy input in the USA rice producing areas is only slightly larger than 1, the ratios in the Philippines for 1972-73 wet and dry seasons were 3.4. Kuether and Duff (1979) report a similar result after comparing three rice production systems in the Philippines.

Kiamco and McMennamy (1979), Pimentel (1980), and Kuether and Duff (1979) found that energy input for fertilizer, especially nitrogen fertilizer, was the highest in crop husbandry operations. In fact, fertilizer N was second to gasoline in terms of energy input expenses in the Philippines during 1972-73 wet and dry seasons as reported by Rutger and Grant (1980) and Smil et al, (1983). In the latter's report, rice yield was 3232 and 4175 kg per hectare for the wet and dry season respectively. In terms of energy equivalents these yields represented about 39800 and 51500 megajoules per hectare. Also the ratios of energy output per hour of labor (MJ/labor hour) in the USA were lower than those in the Philippines.

Other inputs like machinery, herbicides, insecticides and seeds have been measured in terms of weight (kilograms) and energy in joules (Pimentel, 1980; Kuether and Duff, 1979; Smil et al, 1983). In general, they found that chemicals used for weed and pest control had high energy equivalents.

Boughton (1981) investigated the implications of rising fossil fuel energy prices on the development of rice production technology, particularly in the field of mechanization. The use and productivity of resources employed on rainfed and irrigated rice farms in the Philippines were measured in energy as well as financial terms. He found that fertilizer use on all farms and water supply on pump irrigated farms accounted for the largest shares of fossil fuel energy use and cash expenditure. He further concluded that there should be mechanical innovations for increasing yields and improving the productivity of resources which are scarce relative to demand, and so as to meet the rising input prices and growing demand for rice.

Roy (1966) reports on energy-saving in rice and wheat production in India. He found that total energy requirements, for all field operations, in the whole country, using improved bullock-drawn implements and machines already developed was about 199.4 MJ/ha compared to 1263.6 MJ/ha by conventional methods. Energy-saving impact of mechanization has also been reported by McColly (1971) in terms of man-hours per hectare. Results at that time showed that on average 1000 man-hours per hectare were expended in paddy production with the use of animal power. In Japan and Taiwan this figure was 1300 while in other countries where broadcasting, less inter-cultivation and less tillage were practised, the figure was 700 man-hours per hectare. He further reports that sources of energy were normally purchased.

Srivastava (1982) compared conventional to mechanized farming in relation to energy use and cost. He found that energy and cost inputs were higher for mechanized than for conventional farm operations, yet the increase in crop yield and timeliness of farm operations encourages the use of farm machinery. Furthermore, his results showed that crop yield was directly proportional to energy input. His results were similar to those reported earlier by Pimentel (1980), Kuether and Duff (1979), Kiamco and McMennamy (1979), Chancellor (1977), Heichel (1973), Duff (1978), Sanvictores (1977), and Igbeka (1983).

Energy for irrigation has been reported by Batty et al., (1974), Rutger and Grant (1980) and Knutson et al., (1977). This study uses the results of these studies in estimating energy for irrigation in Central Luzon.

CHAPTER III

RESEARCH METHODOLOGY

3.1 Source and Scope of Data

Data from the Consequences of Small Rice Farm Mechanization (CSRFM) Project were used for the present study. The CSRFM project involved three countries in Asia namely the Philippines (in the province of Nueva Ecija, Central Luzon), Indonesia (South Sulawesi and West Java), and Thailand (Supanburi). In the Philippines field surveys were funded by the United States Agency for International Development (USAID), the International Rice Research Institute (IRRI) and the Republic of the Philippines (RP). The project was implemented by IRRI and ADC (the Agricultural Development Council, Inc.) in the Philippines from 1978 to 1984.

Central Luzon was selected for the project because it is one of the main rice producing regions in the Philippines. Also irrigation and modern agricultural technology such as mechanization and improved rice varieties (HYVs) are relatively widely used. Small tractors are also used in the region due to their versatility in a wide range of field operations such as land preparation, water pumping, and threshing. Central Luzon, therefore, provides a suitable environment within which to study the effects of mechanization on farm crop output, cropping intensity, labor employment and energy utilization efficiency.

3.2 The Sampling Procedure

In the CSRFM survey, a total of 318 rice farm households (which planted rice) from eight villages were involved for the 1979/80 wet season. There were 211 and 302 sample households for the 1980 dry and wet season respectively. The villages were randomly sampled according to irrigated and rainfed farms. Irrigation is based on the type of water control. Four villages located in the municipality of Cabanatuan City and another four from Guimba municipality composed the study area. These villages were classified according to the type of water availability as follows:

Cabanatuan City:

San Isidro -------------- irrigated farms

Lagare -------------- irrigated farms

Caalibangbangan --------- irrigated farms

Kalikid Sur ------------- irrigated farms;

Guimba:

Galvan ----------------- rainfed farms

San Andres -------------- rainfed farms

Bunol ------------------- rainfed farms

Narvacan I -------------- rainfed farms.

Figure 1a is a map of the Philippines showing the Province of Nueva Ecija in Central Luzon. The relative locations of the villages are also detailed in figures 1b, 1c and 1d.

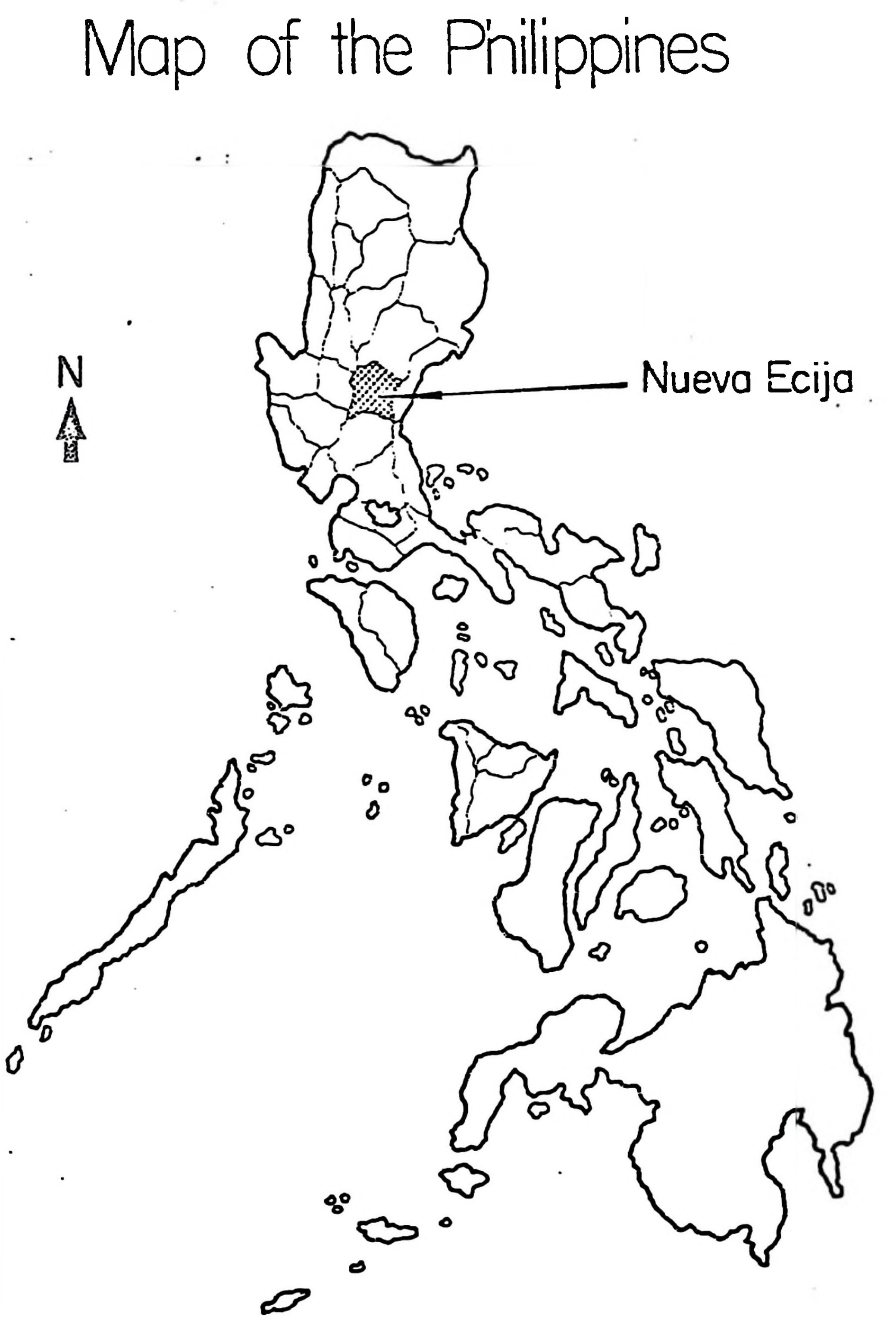

Figure 1a. Map of the Philippines showing the province of Nueva Ecija, Central Luzon .

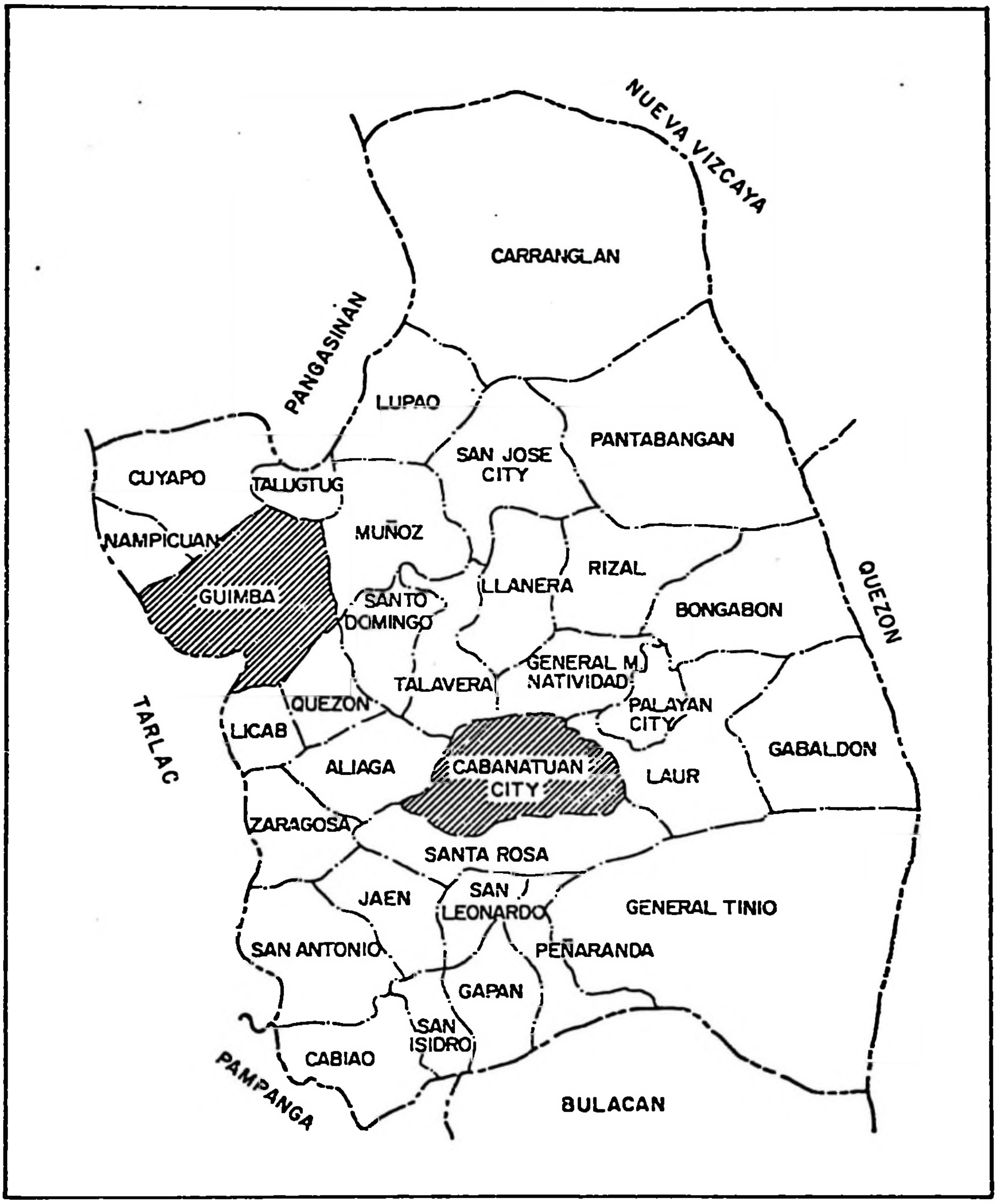

Fig. 1b. Map of Nueva Ecija province showing the sample areas.

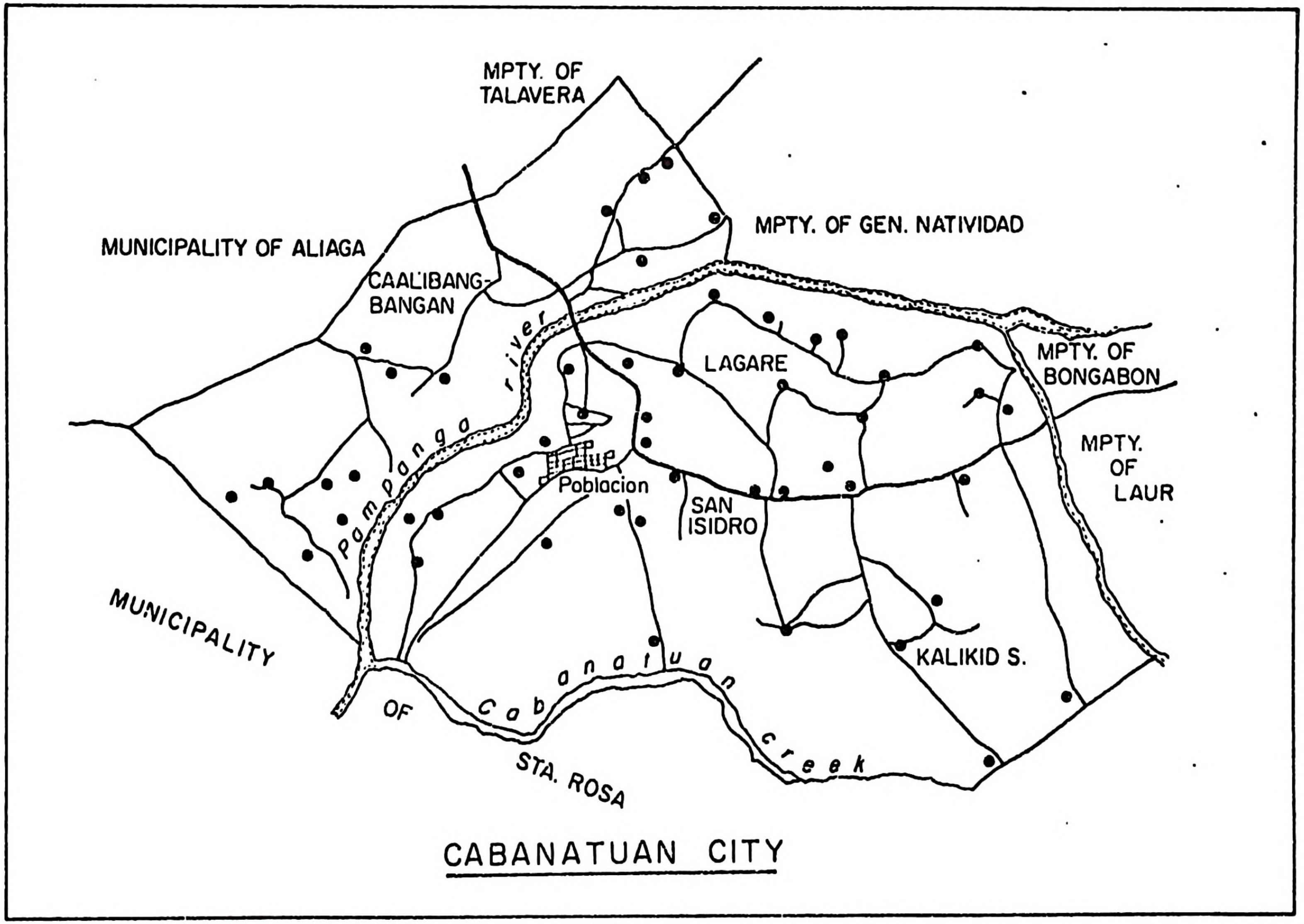

Fig. 1c. A map of Cabanatuan City showing relative locations of the sample villages.

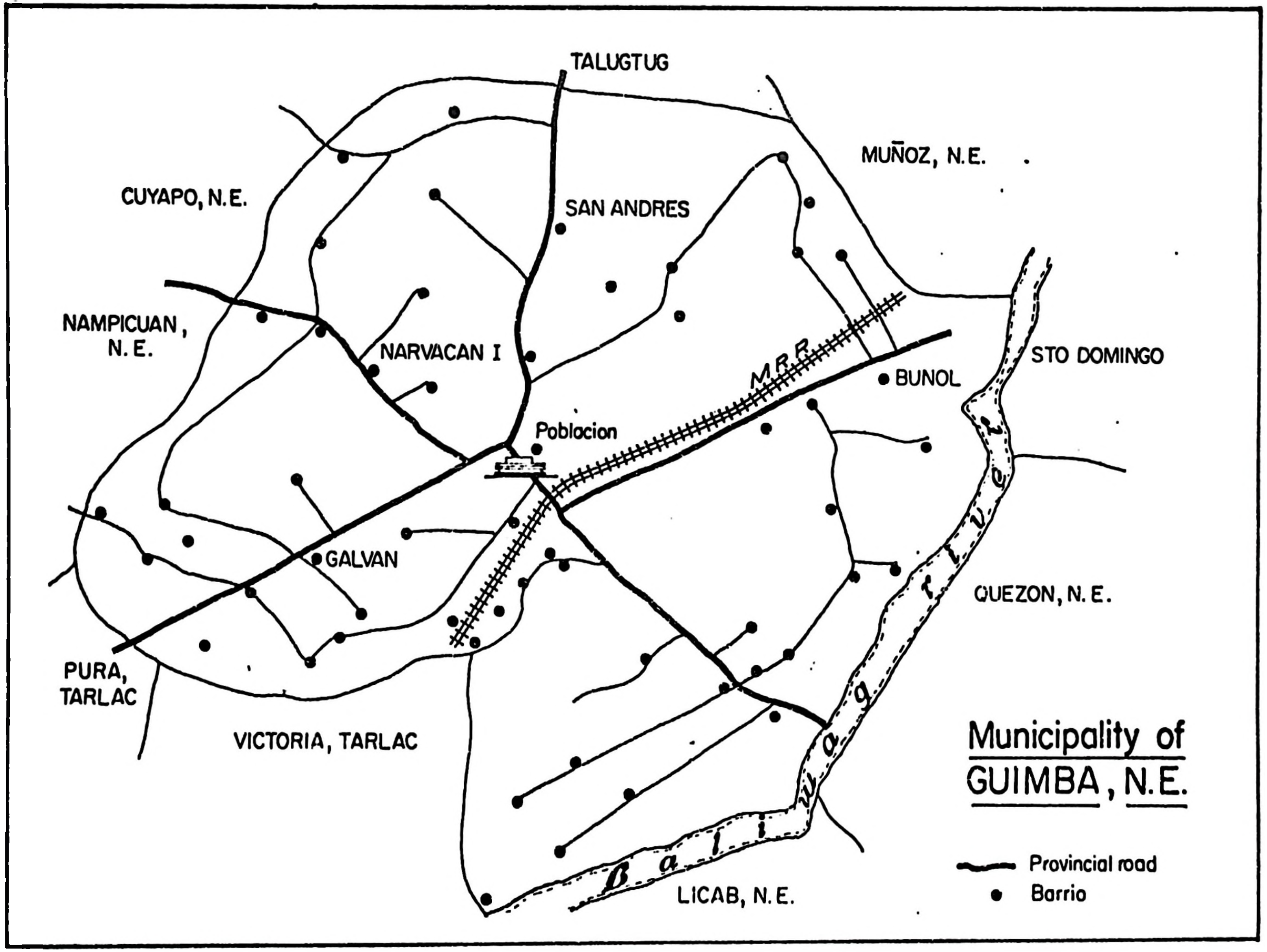

Fig. Id. A map of Guimba showing relative locations of the sample villages.

Irrigated farms were further classified into pumpset irrigated and gravity irrigated farms. Altogether, therefore, there were three levels of villages by water availability namely; pumpset irrigated, gravity irrigated, and rainfed farms. The latter will be the control or reference group of farms for changes due to water availability.

For each of the three classes of villages by water availability there were three types or levels of mechanization which are defined below. This farm classification by water availability and level of mechanization gives us nine farm types (Table 1) for each cropping season:

rainfed-nonmechanized farms;

rainfed-partially mechanized farms;

rainfed-fully mechanized farms;

pump irrigated-nonmechanized farms;

pump irrigated-partially mechanized farms;

pump irrigated-fully mechanized farms;

gravity irrigated-nonmechanized farms;

gravity irrigated-partially mechanized farms; and

gravity irrigated-fully mechanized farms.

In the present study, rainfed and nonmechanized farms are considered to be the reference farms for comparisons of farm differences and productivity due to mechanization of farm operations. Finally farms were sorted into three main groups (or types) according to source of power for land preparation:

(i) Fully mechanized farms (M_1) - farms using four wheel tractors for land preparation. Such farms are either rainfed, gravity

Table 1. Frequency counts of rice farms by type and season.

Farm type	Central Luzon Wet Season 1979/80	 Dry Season 1980	 Wet Season 1980
		Number of farms	
Rainfed - Nonmech	77	19	90
Rainfed - Partmech	46	15	4
Rainfed - Fullmech	1	1	28
Pump-Irrig - Nonmech	39	25	29
Pump-Irrig - Partmech	15	12	7
Pump-Irrig - Fullmech	-[a]	-[a]	9
Grav-Irrig - Nonmech	7	7	17
Grav-Irrig - Partmech	79	78	23
Grav-Irrig - Fullmech	54	54	95
Total	318	211	302

[a]Observations with missing values.

irrigated or pump irrigated as mentioned above and use machines such as four wheel tractors, reapers and threshers for harvesting and threshing paddy.

(ii) Partially mechanized farms (M_2) - farms using power tillers for land preparation and which are rainfed, gravity irrigated or pump irrigated. Postproduction activities such as harvesting and threshing are also mechanized as in (i) above.

(iii) Nonmechanized farms (M_3) - farms using animal or human power for land preparation in rainfed, gravity irrigated or pump irrigated areas. All other farm activities are not mechanized.

These farm groups will henceforth be called levels (or degrees) of mechanization in the present study.

Seed variety was specified in the research proposal to be one of the explanatory variables. Since it is very rare to find farmers growing traditional rice varieties, it is assumed in the present study that all rice farms planted improved high yielding varieties (HYVs). Dramatic changes in rice production technology over the last 15 years have been reported by Cordova et al (1981). They report that as early as 1970 almost 80% of the total rice area was planted to HYVs and that this figure had risen to 95% by 1980.

Variations between farm groups by mechanization caused by seasonal effects are assumed to be taken care of since the present study attempts to analyze data by season. In this way changes in the observations caused by by seasonality can be compared.

Data were collected by the survey method using the FAO Farm Management Data Collection and Analysis System (FMDCAS) package (Friedrich, 1977), Operations Handbook No. 1 (IRRI, 1978d; 1980) and

Operations Handbook No.4 (IRRI, 1984) which specify the instruments used for interview.

3.3 Limitations of Data

During the implementation of the CSRFM survey, all information or data, both farm level primary data and secondary or complementary daily records, were collected based on the farmer's memory. Farmers do not usually keep farm records. Farmers also have a difficulty in recalling information. Moreover, there is a tendency for farmers to overestimate costs and underestimate their farm returns (or production) in order to avoid higher government taxation.

The CSRFM was a cross-sectional survey study. Cross-sectional studies have the disadvantage of having mechanized and unmechanized farms which differ in many other respects from each other than only with respect to their power source. For example, mechanized farms using four wheel tractors usually are larger than unmechanized ones. Furthermore, mechanized farms are generally expected to be better endowed with productive capital and to have a better access to credit markets. This is likely to enhance greater use per hectare of irrigation and purchased inputs, and hence to higher observed yields and cropping intensities. All these factors and other confounding factors may lead to higher yields, higher intensities and higher labor use even in the absence of tractors. The studies, however, provide a comprehensive context for identifying relevant issues for further research.

3.4 Analytical Methods

Based on the objectives of the present study and the hypotheses formulated, this section deals with specifications of the variables and statistical analysis techniques. Data were analysed using various techniques such as analysis of variance (ANOVA), analysis of covariance (ANACOVA), and a production function analysis model. The techniques and their use in this study are discussed in turn.

3.4.1 Comparison of Some Weighted Average Statistics of Sample Farms

Analysis of variance (ANOVA) was used to compare yields (kg/ha), labor use (mandays/ha), cropping intensity (percentage), and other variables among different mechanized farm groups. Regression analysis of variance was chosen because the data from the CSRFM survey was unbalanced and thus could not be analysed using one way analysis of variance. The latter is used to analyse balanced data (i.e., data having equal numbers of observations for each treatment variable). In this case there were different numbers of observations for each farm group. Farm size was used as a continuous explanatory variable. There were also three dummy variables representing levels of mechanization (M_1, M_2, M_3). These dummies represented different numbers of farms as shown in Tables 2 to 4 in Chapter IV. The following were the dependent or response variables: land preparation labor (mandays per hectare), weeding labor (mandays per hectare), post production labor (mandays per hectare), other preharvest labor (mandays per hectare), total labor use (mandays per hectare), hired labor expenses (pesos per hectare), level of fertilizer use (kilograms per hectare), other cash expenses (pesos per hectare), yields (kilograms per hectare), and cropping intensity (percentage). These variables are clearly defined on the next page.

ANOVA was chosen because it shows differences among farm groups with varying degrees of mechanization and enables us to test whether observed farm group differences are significant or not. However, ANOVA cannot be used for comparisons of differences within treatment groups. For this reason, we use a different technique of data analysis to study the within farm group variations on the dependent variables.

3.4.2 Mechanization and Differences in Input Intensity Use

Analysis of covariance (ANACOVA) was used to study the patterns in input use intensity because ANACOVA embodies corrections for differences in other independent variables such as dummy irrigation and farm size (a continuous variable) when comparing labor input and cropping intensity, for instance, by mechanization class. The dependent variables will be total labor use, labor use (in specific farm operations such as land preparation, weeding, etc), cropping intensity, hired labor expenses, level of fertilizer use, and other cash expenses for each of the different mechanized classes. We now define the measures of labor use and other variables which will be compared among and within mechanization levels:

(i) Land preparation labor (mandays per hectare) --- includes labor used for clearing, seedbed preparation, plowing, harrowing, repairing irrigation facilities, etc;

(ii) Post production labor (mandays per hectare) ---- includes labor for harvesting, threshing, drying the produce, sorting, and other activities;

(iii) Total labor use (mandays per hectare) --- includes labor inputs in land preparation, transplanting, weeding, and other crop care practices, and post production labor or the sum of (i) and (ii) above.

(iv) Hired labor expenses (pesos per hectare) --- is the product of the wage rate (pesos/ha) and total hired labor (mandays/ha);

(v) Level of fertilizer use (kgN/ha) --- is the weight of nitrogen fertilizer used;

(vi) Other cash expenses (pesos per hectare) --- includes expenditures on seeds, insecticides, herbicides, and fungicides. These variables are quantified in terms of energy in the section on mechanization and energy utilization in rice production.

(vii) Cropping intensity (percent) --- is the ratio of area under different crops in a given crop year to the maximum physical cultivated area in that crop year.

The covariance analysis model is fitted in an unconstrained as well as a constrained form. The unconstrained model contains interactive terms and is of the following form:

$$L_t = \alpha_o + \sum_{i=1}^{2} \alpha_{it} M_{it} + \sum_{j=1}^{2} \alpha_{j+2} I_{jt} + \alpha_{5t} A_t + \sum_{i=1}^{2} \sum_{j=1}^{2} \alpha_{ij} M_{it} I_{jt} + \mu_t \quad (1)$$

where

L_t = land preparation labor (mandays per hectare) in the t^{th} observation;

A_t = farm size (hectares) of the t^{th} observation;

M_{it} = dummy for level of mechanization, i = 1, 2, 3 for observation t;

M_{1t} = fully mechanized farm dummy for observation t;

M_{2t} = partially mechanized farm dummy for observation t;

M_{3t} = nonmechanized farm dummy for observation t;

I_{jt} = dummy for level of irrigation, j = 1, 2, 3 for observation t;

I_{1t} = pump set irrigation dummy for observation t;

I_{2t} = gravity irrigation dummy for observation t;

I_{3t} = rainfed dummy for observation t;

μ_t = disturbance or residual term for observation t in the unconstrained model;

t = 1, 2, 3, ---, N number of observations;

α_o = intercept term; α_{it} and α_{ijt} are the regressors.

It was assumed that this model allows for non-additive effects which measure the interactive effects of irrigation and mechanization on land preparation labor use and other characteristics.

The significance of the interaction effects was tested directly by fitting a constrained version of model (1) specified as follows:

$$L_t = \alpha_o + \sum_{i=1}^{2} \alpha_i M_{it} + \sum_{j=1}^{2} \alpha_{j+2} I_{jt} + \alpha_{5t} A_t + \mu'_t \qquad (2)$$

where, μ'_t = disturbance term of the constrained model.

The set of restrictions α_t = 0 will be tested with F-statistics based on the residuals of the estimating equations for (1) and (2). The F-statistics will be computed as follows:.

$$F_{[r,\ N-K],\alpha} = \frac{\left[\sum_{t=1}^{N} \mu'^{2}_{t} - \sum_{t=1}^{N} \mu_{t}^{2}\right]/r}{\left(\sum_{t=1}^{N} \mu_{t}^{2}\right)/[N-K]} \tag{3}$$

where

$\sum_{t=1}^{N} \mu'^{2}_{t}$ = sum of squares of the residuals in the constrained model;

$\sum_{t=1}^{N} \mu_{t}^{2}$ = sum of squares of the residuals of the unconstrained model;

r = number of restrictions;

N = number of observations;

K = number of regressors or independent variables;

(r, N-K) = degrees of freedom of the F-statistics at a given α level of significance.

If the computed F-ratio is greater than the tabulated value at the given level of significance and degrees of freedom, then reject the null hypothesis (H_o) and conclude that the interaction effects are significant. Otherwise, fail to reject H_o and conclude that the interaction terms are nonsignificant.

A model similar to the one specified in equations (1) to (3) was developed to compare the level of fertilizer use, cropping intensity, hired labor expenses, and level of other cash input expenses among different levels of mechanization.

The analysis of covariance model cannot be used to sort out the influence of mechanization on post production labor, for example, which arises independently of the effects of other specified inputs such as level of fertilizer use. This is a shortcoming of the covariance model. For this reason, we developed a production function analysis model to evaluate for the effects of input variables arising independently of one another and which will sort out the influence of mechanization on them.

3.4.3 Mechanization and Productivity

In this section, a generalized production function was developed to compare productivity among different mechanization classes. The function has the following unconstrained form:

$$\ln Y_t = \ln\alpha_o + \sum_{i=1}^{2} \alpha_{it} I_{it} + \sum_{j=1}^{2} \alpha_{(j+2)t} M_{jt} + \alpha_{5t} \ln F_t$$

$$+ \alpha_{6t} \text{lbL}_t + \sum_{i=1}^{2} \sum_{j=1}^{2} \alpha_{ijt} I_{it} M_{jt} + \alpha_{11t} \ln C_t + \alpha_{12t} \ln A_t + \varepsilon_t \quad (4)$$

where

$\ln Y_t$ = natural logarithm of yield (kg/ha) in observation t;

$t = 1, 2, 3, ---, N$.

$\ln\alpha_o$ = natural logarithm of the intercept term;

I_{it} = irrigation dummy as defined earlier;

M_{jt} = mechanization dummy as defined earlier;

$\ln F_t$ = natural logarithm of the level of fertilizer used (kgN/ha);

$\ln L_t$ = natural logarithm of total labor used (mandays/ha);

$\ln C_t$ = natural logarithm of other cash expenses (pesos/ha);

$\ln A_t$ = natural logarithm of farm size (ha);

α_i & α_{ij} = regressors or parameter estimators; i=1, 2, 3, ---, 12.

ε_t = the residual terms of the unconstrained model;

The significance of the effects of the interaction terms was tested directly by fitting a constrained model version of equation (4) as follows:

$$\ln Y_t = \ln\alpha_o + \sum_{i=1}^{2} \alpha_{it} I_{it} + \sum_{j=1}^{2} \alpha_{(2+j)t} M_{jt} + \alpha_{5t}\ln F_t + \alpha_{6t}\ln L_t$$

$$+ \alpha_{7t}\ln C_t + \alpha_{8t}\ln A_t + \varepsilon'_t \qquad (5)$$

where

ε'_t = disturbance or residual term of the constrained model;

The set of restrictions $\alpha_{ij} = 0$ were tested with F-statistics based on the residuals of the estimating equations (4) and (5) using the following equation:

$$F_{r,N-K} = \frac{\left[\sum_{t=1}^{N} \varepsilon'^{2}_t - \sum_{t=1}^{N} \varepsilon_t^2\right] / r}{\left[\sum_{t=1}^{N} \varepsilon_t^2\right] / N-K} \qquad (6)$$

where

$\sum_{t=1}^{N} \varepsilon'^{2}_t$ = sum of the squares of the residuals in the constrained model;

$\sum_{t=1}^{N} \varepsilon^{2}_t$ = sum of the squares of the residuals in the unconstrained model;

r = number of restrictions;

N = number of observations;

K = number of regressors or independent variables;

(r., N-K) = degrees of freedom of the F-statistics at a given level of significance.

If the observed (or computed) F-ratio in equation (6) is greater than the tabulated value at the given level of significance, reject the null hypothesis (H_o) and conclude that the interaction effects are significant. Otherwise, fail to reject H_o and conclude that the interaction terms are not significant.

The results of the analysis of variance (ANOVA), analysis of covariance (ANACOVA) and production function models are presented in Chapter IV.

3.4.4. Mechanization and Energy Utilization in Rice Production

Energy flow in agriculture has been measured in terms of the Gross National Product (GNP) of a country (Fluck, 1981; 1985; Chern, 1984). Stout et al (1979) presented energy expenditure rates for various agricultural tasks and working conditions. In this study, net energy expenditures for various selected inputs and farm operations in paddy fields are investigated and analyzed by level of mechanization per season.

The present study considers the following inputs, and energy constants given in Appendix A, for rice production:

seeds (kg/ha);

machinery (for the estimation of embodied and manufacturing energy, and repair and maintenance energy);

fossil fuel (gasoline or diesel) and oil (in liters/ha);

source of power for performing various selected farm operations:
human, animal and tractor;

fertilizers: Nitrogen (N), Phosphate (P_2O_5), Potash (K_2O), Calcium (CaO) all measured in kg/ha);

chemicals: insecticides (carbofuran) and herbicides (2,4-D) measured in kilograms of active ingredient per hectare (kg a.i./ha).

pump irrigation: measured in terms of the net depth (m) of water applied per hectare by pump irrigation.

Farm operations are classified into four main groups namely, land preparation, weeding, and other preharvest tasks (including seedbed preparation, land clearing, digging, plowing, cultivating, hoeing, planting, fertilizer application, pesticide application, and irrigating; all measured in man hours per hectare). Land preparation and weeding are considered separately from other preharvest operations because of their importance in crop establishment. The fourth farm operation group consists of total post production operations (including harvesting, cutting, threshing, sorting, and other activities) measured in man hours per hectare.

Farm operations performed using animal or tractor power included soil preparation, cultivating, harvesting (especially in transporting the harvested paddy stacks), and other activities. These operations were measured in animal or tractor hours per hectare depending on whether they were performed by animal or tractor power.

Energy requirements for these operations were also investigated by level of mechanization. The values of energy requirements were obtained by multiplying the measured values of inputs or operations by corresponding energy constants derived from a specific source or reference which are found in the resulting tables and appendices attached to this report.

As defined earlier, the three types of farms to be investigated in relation to energy utilization, by level of mechanization, are fully mechanized farms (M_1 - using four wheel tractors for land preparation operations in rainfed or gravity or pumpset irrigated farms), partially mechanized farms (M_2 - using two wheel tractors or power tillers for land preparation in rainfed or gravity or pumpset irrigated farms), and nonmechanized farms (M_3 - using animal or carabao and human power for land preparation in rainfed or gravity or pumpset irrigated farms). It was assumed that fully mechanized farms used four wheel, 60 horsepower tractors, similar to Massey Ferguson MF165 tractors, weighing 2360 kg (Massey Ferguson Agricultural Machinery, 1973). It was further assumed that partially mechanized farms used PT3 - 6 horsepower IRRI diesel engine power tillers weighing 200 kg (or 441 lbs) (IRRI, 1977). These assumptions were adapted in order to facilitate computation of the energy requirements more consistently and reliably.

Embodied energy requirements for farm machinery were calculated using Smil et al (1983) coefficients. For the four wheel tractor, the coefficient for machinery embodied energy was 85 megajoules per kilogram (MJ/kg) which is higher than the value (49.5 MJ/kg) reported by Doering III (1980). Therefore, a four wheel tractor weighing 2360 kg contains an embodied energy equivalent to 200600 MJ (or 2360 kg x 85 MJ/kg). The embodied energy and energy used in manufacturing was then determined and divided by the total area cultivated in a given season using the tractor.

Repair parts, materials replacement and maintenance was assumed to be about eight percent of the embodied and manufacture energy (Smil et al, 1983).

The above procedure was also used to determine the total embodied and manufacturing energy content of the power tiller and also the required repair and maintenance energy.

The energy content of fossil fuel (gasoline or diesel) and oil, and seeds are used as direct inputs whereas the energy value of fertilizer, insecticide, herbicide, and farm machinery are aggregates of all energy used to produce the materials, including the energy expended directly in producing them and the energy required to build and maintain the production facilities and provide for the worker's food, transport, and distribution.

Some of the human energy expenditure constants used in the study were obtained experimentally (Duff, 1978). Energy consumption values varied by operation. However, an average of expenditures for all operations approximate those generally cited in the literature (Chancellor, 1977; Pimentel, 1980). Human energy in those operations not measured directly was estimated using values from similar or related tasks or by averaging the energy for similar tasks. Appendix A presents the energy constants used in this study.

Energy required for pumping irrigation was calculated using a formula developed by Batty, et al (1974). The formula is of the following form:

$$PE = k \times A \times D \times H/(E_i \times E_p) \quad (7)$$

where

PE = pumping energy

A = area irrigated (ha)

D = net depth of irrigation (cm)

H = pumping head or the sum of elevation differences, operating pressure, and friction and minor losses (m)

E_i = irrigation efficiency or the percentage of the water applied that is stored in the root zone (percentage)

E_p = pumping efficiency (percentage)

In using the above formula, it was assumed that pump irrigation was used and that the net depth of irrigation was 0.15 m (15 cm) for the wet seasons (Knutson et al, 1977). Irrigation and pumping efficiencies were considered to be 40% and 60% respectively (Batty et al, 1974). It was difficult to calculate the energy used in providing water to farms by gravity irrigation and in rainfed farms because these sources of water were not easily quantifiable.

For the 1980 dry season, the above assumptions were adapted except that total farm area was pumped to a net depth of 0.30 m (30 cm) of water (Knutson et al, 1977).

Upon substitution of the values given above into the formula, the energy for irrigation for the dry season was 26907.403 MJ/ha.

Throughout the present study, it is assumed that 1 kcal is equivalent to 4.186 kJ of energy (Hoare, 1976).

Total energy input (E_i) in the present study is the sum of all energy equivalents (both commercial and noncommercial) for each input and farm operation by level of mechanization.

The total labor energy requirement is assumed to be the sum of all the energy equivalents for performing each specified farm operation using human power. This includes all tasks from land preparation to total post production human energy requirements by season and level of mechanization. Total labor hours was determined for each season and level of mechanization in order to compute energy utilization efficiency in terms of energy output (MJ) per hour labor input.

Rice production (or yield) is investigated in terms of paddy and milled paddy (heretofore, called rice). It was assumed that 69% by weight of paddy was approximately equivalent to rice (IRRI, 1978c). Furthermore, rice was assumed to have an energy equivalent of 15.07 MJ/kg (or 3600 kcal/kg) while paddy gives an energy equivalent of 12.36 MJ/kg (or 2952 kcal/kg), which is about 82% of the energy equivalent of rice (Rutger and Grant, 1980; Faidley, 1977; Leach, 1976).

In the present study, energy utilization efficiency in rice production is measured in two ways. First, assume that E_o and E_m represent the total energy output in paddy and rice produced per season respectively. Then, if E_{ro} and E_{rm} are the energy utilization efficiencies for producing paddy and rice respectively, then:

$$E_{ro} = E_o / E_i, \text{ and}$$

$$E_{rm} = E_m / E_i,$$

where, E_i is the total energy input in rice production by mechanization class.

This method gives dimensionless energy utilization efficiencies.

Energy utilization efficiencies were also computed in megajoules per hour of labor as follows:

Assume l_h is the amount of hours of labor spent in rice production per mechanization class, and E_o and E_m as already defined above. Therefore, we have:

$E_{lo} = E_o / l_h$, and

$E_{lm} = E_m / l_h$

where

E_{lo} and E_{lm} are the energy utilization efficiencies for paddy and rice respectively measured in megajoules per hour of labor by level of mechanization.

Energy expenditure in rice production was also compared on a perr season basis by summing all input energy equivalents, output energy equivalents, and total hours of labor and computing the ratios as defined above.

Energy equivalent estimates by level of mechanization are calculated in terms of both paddy and rice and presented in kilograms per hectare as shown in Chapter IV.

Based on the estimated energy values, the relative costs (in US dollars) of commercial and noncommercial (or on farm) energy for the three levels of mechanization were calculated by season. The results are shown in the next chapter.

Input costs, in US dollars per hectare, at market prices for the three seasons under study are presented and compared with those for the 1984/85 wet season.

The distribution of labor (man hours per hectare) by major farm operations and energy inputs (megajoules per hectare) by source will be illustrated in tables and charts by level of mechanization.

CHAPTER IV

RESULTS AND DISCUSSION

4.1. Comparison of Weighted Average Statistics for Sample Farms by Level of Mechanization

Analysis of variance (ANOVA) enables the comparison of dependent variables such as yields, cropping intensity, labor use, and other variables among different mechanized farm groups. ANOVA enables the summary differences among the farm groups with different levels of mechanization to be shown. It is also used to test whether or not the observed farm group differences are significant. The weighted average statistics of the sample farms by degree of mechanization per season are shown in Tables 2 to 4.

Differences in farm groups were tested using F-statistics computed as the ratio of the mean square variations between farm groups to the mean square variations within the groups. Significant F-statistics imply significant differences in farm group means for the variable under test.

Since the observed F-statistics were higher than the tabulated F-ratios for all dependent variables, the null hypothesis of no differences in yields, cropping intensity, labor use, and other variables among the farm groups is rejected.

The statistics in Tables 2 to 4 indicate significant differences among farms. Such differences will be tested latter using the ANACOVA

Table 2. Comparison of selected weighted average statistics per hectare from sample farms by mechanization type, 1979/80 Wet Season.*

Operation	Type of farm: Fully mechanized N=55	Partially mechanized N=140	Nonmechanized N = 123
Land preparation labor (mandays)	6.1737	9.9934	18.2512
Weeding labor (mandays)	0.2621	1.4363	2.2068
Other preharvest labor (mandays)	32.8088	31.9516	40.4164
Post harvesting labor (mandays)	28.2250	33.1059	35.9482
Total labor (mandays)	67.4697	76.4872	96.8226
Hired labor expenses (pesos)[a]	824.4472	667.1965	402.2007
Level of fertilizer (KgN)	51.3764	43.8072	30.8798
Other cash expenses (pesos)	470.4425	320.0570	237.7459
Yields (kg) (ton, t)	3897.6887 (3.9 t)	3166.2595 (3.2 t)	2175.7425 (2.2 t)
Cropping intensity (percentage)[b]	N.A.	N.A.	N.A.

* These results and those of subsequent tables may be rounded to the nearest decimal digit for easy interpretation.

[a] The 1979 exchange rate was 1 US$ = 7.5 pesos (Philippine pesos).

[b] $\text{Cropping intensity} = \frac{\text{Area under different crops in a given crop year}}{\text{Maximum cultivated physical area in that year}} \times 100$

N.A. = not applicable this season alone.

to investigate whether they are solely due to mechanization or caused by other confounding variables in addition to mechanization.

Yields were higher on mechanized farms by 990 to 1722 kilograms per hectare (or 45% to 79% higher) than on nonmechanized farms which recorded an average of 2176 kilograms per hectare of paddy in the 1979/80 wet season (Table 2). The 1980 dry season (Table 3) paddy yields were higher than those in the 1979/80 and 1980 wet seasons (Tables 2 and 4). During this season, mechanized farms reported higher yields by 749 to 1439 kilograms per hectare (or 22% to 42% higher) than those of the nonmechanized farms which produced 3.4 tons per hectare (Table 3). Mechanized farms also produced higher yields in the 1980 wet season (Table 4) by 668 to 747 kilograms per hectare (or 28% to 31% higher) compared to nonmechanized farms which reported 2.4 tons per hectare. In all the three seasons, yields were highest on fully mechanized farms (Tables 2 to 4). Thus, the level of mechanization may be associated with increasing yield differences between mechanized and nonmechanized farms.

Cropping intensity was higher on mechanized farms than on nonmechanized farms by 32 to 45 percent. Nonmechanized farms had a cropping intensity of 148 percent (Table 3). Fully mechanized farms recorded the highest cropping intensity (193%) followed by partially mechanized farms (180%). This suggests that mechanization increeases cropping intensity.

Hired labor expenses and other cash expenses were uniformly higher on mechanized farms on nonmechanized farms. Fully mechanized farms reported the highest weighted averages of these variables in the 1979/80 and 1980 wet seasons (Tables 2 and 4). In Table 3, hired·labor expenses

Table 3. Comparison of selected weighted average statistics per hectare from sample farms by mechanization type, 1980 Dry Season.

Operation	Type of farm: Fully mechanized N=55	Partially mechanized N=105	Nonmechanized N = 51
Land preparation labor (mandays)	6.6079	10.6384	27.0395
Weeding labor (mandays)	0.1248	0.1381	0.6487
Other preharvest labor (mandays)	28.8873	35.1816	59.4944
Post harvesting labor (mandays)	24.8397	31.4909	40.6707
Total labor (mandays)	60.4597	77.4491	127.8532
Hired labor expenses (pesos)[a]	802.9453	822.8798	569.5414
Level of fertilizer (KgN)	64.2531	75.2960	84.6088
Other cash expenses (pesos)	549.4240	473.1514	431.6448
Yields (kg) (ton, t)	4876.8776 (4.9 t)	4187.4716 (4.2 t)	3438.3122 (3.4 t)
Cropping intensity (percentage)[b]	192.7718	180.1936	147.5723

[a] The 1980 exchange rate was 1 US$ = 7.60 pesos (Philippine pesos).

[b] $$\text{Cropping intensity} = \frac{\text{Area under different crops in a given crop year}}{\text{Maximum cultivated physical area in that year}} \times 100$$

were highest on partially mechanized farms. The level of fertilizer use was lowest on fully mechanized farms whereas other cash expenses were the highest. This is possible because in the dry season fewer households cultivated their farms. As a result labor was more abundant for the fewer cultivated farms. Partially mechanized farms used more hired labor expenses than other farm groups.

Nonmechanized farms used the highest level of labor inputs in rice production except post production labor which was highest on partially mechanized farms in the 1980 wet season. Reviewing Tables 2 to 4, we observe that as the level of mechanization increases labor input decreases. Thus, there is reallocation and a lowering of labor costs in production systems as a result of mechanization.

During the 1980 dry season, total labor use in rice production operations was lower on mechanized farms by 51 to 68 mandays per hectare compared with nonmechanized farms which used a weighted average of 128 mandays per hectare (Table 3). On fully mechanized farms, other preharvest operations recorded the highest labor input of 29 mandays per hectare followed by post production labor (25 mandays per hectare). Land preparation required between 6 and 11 mandays per hectare of labor (Tables 2 to 4) on mechanized farms. The lowest labor use was reported for hand weeding activities on all farm types in the three seasons. A similar trend of labor replacement and displacement by farm operation was reported for fully mechanized and partially mechanized farms during all three seasons. During the 1980 wet season (Table 4), however, partially mechanized farms reported slightly higher weighted average of post production labor use (38 mandays per hectare) than nonmechanized farms. This suggests that postproduction operations more human labor

Table 4. Comparison of selected weighted average statistics per hectare from sample farms by mechanization type, 1980 Wet Season.

Operation	Type of farm: Fully mechanized N=132	Partially mechanized N=34	Nonmechanized N = 136
Land preparation labor (mandays)	9.5099	13.6145	18.4781
Weeding labor (mandays)	0.8118	0.8365	2.0309
Other preharvest labor (mandays)	31.1123	35.7694	39.6564
Post harvesting labor (mandays)	34.8218	38.1678	35.3593
Total labor (mandays)	76.2558	88.3882	95.5247
Hired labor expenses (pesos)[a]	771.0891	732.1933	441.16876
Level of fertilizer (KgN)	86.8578	87.7019	61.2822
Other cash expenses (pesos)	487.6296	427.1315	287.3771
Yields (kg) (ton, t)	3127.9188 (3.1 t)	3048.7299 (3.0 t)	2380.6715 (2.4 t)
Cropping intensity (percentage)[b]	N.A.	N.A.	N.A.

[a] The 1980 exchange rate was 1 US$ = 7.60 pesos (Philippine pesos).

[b] $$\text{Cropping intensity} = \frac{\text{Area under different crops in a given crop year}}{\text{Maximum cultivated physical area in that year}} \times 100$$

N.A. = not applicable this season alone.

and therefore partially mechanized farms were less mechanized in this season.

Results of the ANOVA presented in Tables 2 to 4 only allow us to perform comparative analyses of the farm groups with varying levels of mechanization. The weighted means presented in these tables do not segregate the effects of other factors such as irrigation and farm size from the effect of mechanization. For example, labor use differences and other differences among the farm classes may be associated with variations in irrigation or other independent variables although using the ANOVA model such differences may be attributed only to mechanization. Therefore, further analysis was required.

4.2.0. Mechanization and Differences in Input Intensity Use

This section presents and documents the results of input use patterns between mechanization classes presented in the foregoing section. A covariance analysis (ANACOVA) model was used to study patterns of input use intensity. The ANACOVA compares differences in total labor use, labor use in certain selected farm operations, level of fertilizer use, other cash expenses, and cropping intensity among differently mechanized farms. Analysis of covariance incorporates corrections for differences in other factors such as irrigation and farm size when comparing the weighted means of the dependent variables by level of mechanization. The results of the ANACOVA model are presented in Tables A1 to A10. Model 1, in these tables, is the unconstrained model which contains interactive effects between mechanization (M) and irrigation (I) levels whereas model 2 is the constrained model without these interaction effects.

Results of the ANACOVA showed that during the 1979/80 wet season and 1980 dry seasons (Tables A1 to A7), the fully mechanized pump irrigated farm interaction effect was zero. This is possible probably because pump irrigated, fully mechanized farms had missing values as shown in Table 1. The table shows, however, that such a combination was quite rare during the two seasons. The same interactive term, however, was nonzero and showed significant effects in the 1980 wet season. Probably, some households were by then able to fully mechanize rice production operations in conjunction with use of pumpset irrigation facilities.

4.2.1. Differences in Input Intensity Use, 1979/80 Wet Season

F-statistics showed that the interactive effects between mechanization and irrigation were statistically insignificant (Table A1) for the model explaining variations in land preparation labor. The fully mechanized pump irrigated farm interactive effect (M_1*I_1) was zero as explained above. However, all other interactive effects were significant in the model explaining variations in post production labor. Farm size was statistically significant at the 1 percent level for the models explaining variations in both land preparation labor (negative effect) and post production labor (positive effect). The constrained model explaining changes in land preparation labor showed 7 and 5 mandays less labor per hectare was required for fully mechanized and partially mechanized farms respectively than nonmechanized farms. The unconstrained model reported land preparation labor significantly lower (7 mandays per hectare) on partially mechanized farms than nonmechanized farms.

Post production labor was higher by 9 mandays per hectare for partially mechanized compared with nonmechanized farms. Gravity irrigated farms had higher post production labor requirements (26 mandays per hectare) but used 13 mandays per hectare lower than pump irrigated farms compared with nonmechanized rainfed farms.

The interactive effects between mechanized and irrigated farms in the model explaining variations in total labor use and hired labor expenses were also examined using the F-test (Table A2). Partially mechanized farms showed lower total labor use by 16 mandays per hectare than nonmechanized farms. Hired labor expenses were higher by 134 and 187 pesos per hectare in the fully mechanized farms and partially mechanized farms respectively than their nonmechanized counterparts. The partially mechanized pump irrigated interaction term was significant and reported hired labor expenses of about 246.50 pesos per hectare higher than the nonmechanized farms.

The effect of farm size on total labor use was negatively significant while it was positive and significant on hired labor expenses.

The results of the ANACOVA models used to explain variations in the level of fertilizer used and other cash expenses are shown in Table A3. F-tests showed that interactive effects were significant in both the partially mechanized and pump irrigated farm models. These effects reported lower levels of fertilizer use (29 kgN/ha) and higher cash other expenses (157.00 pesos/ha) than nonmechanized farms. Partially mechanized farms reported increased fertilizer rates of 10.9 kg N/ha over unmechanized farms. The constrained model revealed an increase of 99 and 65 pesos per hectare in other cash expenses for fully mechanized and partially mechanized farms respectively compared with the nonmechanized farms.

Pump irrigated and gravity irrigated farms applied higher levels of fertilizer by 12.9 and 36.8 kgN per hectare respectively than nomechanized farms. These farms also reported higher other cash expenses of 109 and 238 pesos per hectare respectively above compared with nonmechanized farms.

4.2.2. Differences in Input Use Intensity, 1980 Dry Season

F-tests showed mechanization and irrigation interactive effects were insignificant in the model explaining variations in land preparation labor but significant in explaining variations in post production labor. The fully mechanized and gravity irrrigated farm interaction effects significantly estimated post production labor requirements to be 47 mandays per hectare lower than on unmechanized farms (Table A4). In the two models explaining variations in labor requirements for land preparation, mechanized farms reported significant lower labor use by 10.7 to 11.6 mandays per hectare relative to nonmechanized farms. In post production labor changes, fully mechanized farms showed a significant increase of 33 mandays per hectare over nonmechanized farms. Gravity irrigated farms reported significantly lower post production labor requirements of 13.6 mandays per hectare in the constrained covariance analysis model compared with the nonmechanized farms.

Farm size in Table A4 showed a significant negative relationship with land preparation labor and post production labor.

F-tests on the interaction terms in Table A5 showed that the fully mechanized and gravity irrigated farm interactive effects were significant and reported significant lower variation (60 mandays per hectare) in total labor use and significantly higher variation (528 pesos per hectare) in hired labor expenses than nonmechanized farms. Fully and partially mechanized farms reported lower land preparation labor inputs by 42 and 39 mandays per hectare respectively contrasted with the nonmechanized farms. These farm groups also showed lower hired labor expenses by 172.75 and 78.90 pesos per hectare respectively. However, gravity irrigated farms reported significantly higher hired labor expenses of 436.80 pesos per hectare and lower total labor use by 33 mandays per hectare than nonmechanized farms. Pump irrigated farms also reported significant lower total labor use by 22 mandays per hectare compared with nonmechanized farms.

Farm size showed statistically significant lower effect on total labor use by about 7 mandays per hectare than nonmechanized farms. The effect of farm size on hired labor expense was insignificant (Table A5). This is probably because farms were small and manageable by family labor.

Partially mechanized pump irrigated farm interactive effects were shown by F-tests to be significant in the model explaining variations in the level of fertilizer use (Table A6). Partially mechanized farms reported lower application levels of fertilizer (58.7 kgN/ha) and lower cash expenses (166.85 pesos per hectare). The effect of fully mechanized farms on the level of fertilizer use was negative and significant (58.90 kgN/ha lower) than nonmechanized farms. Fully mechanized farms also reported lower but insignificant effects on the level of other cash expenses. Farm size was significant and demonstrated increased levels of fertilizer use and other cash expenses in all the models explaining variations in these variables.

Results of the covariance (ANACOVA) models explaining variations in cropping intensity are shown in Table A7. Gravity irrigated farms reported significant gains in cropping intensity of 52.5 to 60.8 percent higher relative to nonmechanized farms. Although the analysis of variance (ANOVA) showed higher cropping intensity for fully mechanized farms, ANACOVA models reveal no significant increases in cropping intensity due to mechanization. Pump irrigated farms showed negative but insignificant effects on cropping. The coefficient of determination, R^2 of the models explaining cropping intensity was about 80%. The adjusted R-square was about 79%. This means the explanatory power of the cropping intensity models was significant and high. From these results, we can say that cropping intensity is not constrained by mechanization. However, omission of explanatory variables such as farm management and aspects of land quality like topography, natural soil fertility, farm location, and a dummy representing crop season differences, etc., may have affected the model results explaining differences in cropping intensity as well as other dependent variables discussed previously. Earlier studies by Uy (1979) indicated that good quality land with good natural fertility increases cropping intensity.

4.2.3. Differences in Input Use Intensity, 1980 Wet Season

Fully mechanized and partially mechanized farms reported lower variation in labor utilization for land preparation by 3.5 to 8.8 and 2.9 to 9.2 mandays per hectare respectively compared with nonmechanized farms (Table A8). Fully mechanized farms also reported a gain of 5.0 to 8.3 mandays per hectare in post production labor compared with nonmechanized farms. Partially mechanized farms showed no significant variations in post production labor. F-tests in the model explaining land preparation showed that all mechanization and irrigation interactive effects were significant with the except of partially mechanized pump irrigated and gravity irrigated farms. All interactive effects in the model were insignificant in explaining variations in post production labor. Both pump and gravity irrigated farms reported significant changes in both land preparation and post production labor. Farm size was also significant with decreasing changes in land preparation labor and post production labor (Table A8) with increasing size.

In Table A9, results of variations in total labor use and hired labor expenses are compared. For fully mechanized and pump irrigated farms, the interactive effects were significant in the model explaining variations in total labor use. Partially mechanized pump irrigated farm interactions were significant in the model explaining variations in hired labor expenses. F-tests showed that all other interactve effects were insignificant.

In all models explaining variations in both total labor use and hired labor expenses, the results were significant for fully mechanized farms. These were estimated to be lower by 8.6 to 14.1 mandays per hectare and higher by 191.55 to 201.60 pesos per hectare than nonmechanized farms. Partially mechanized farms reported negative but insignificant changes in total labor use but a highly significant effect on hired labor expenses (188.55 pesos per hectare above nonmechanized farms). Pump irrigated farms reported significantly lower total labor use (by 12 mandays per hectare) and lower hired labor expenses (by 184.00 to 190.00 pesos per hectare) than nonmechanized rainfed farms. Gravity irrigated farms also reported significant lower (14.5 mandays per hectare) total labor use and an average of 237.00 pesos higher per hectare more in hired labor expenses than nonmechanized rainfed farms.

Farm size was significant and showed lower total labor use (6 mandays per hectare on average) and higher hired labor expenses (23.00 pesos per hectare) than nonmechanzed farms.

The F-tests in Table A10 show the fully mechanized pump irrigated farm and fully mechanized gravity irrigated farm interactive effects were significant in both models in explaining variations in the level of fertilizer use and other cash expenses. Pump irrigated and gravity irrigated farm models reported significant effects in explaining variations in both level of fertilizer use and other cash expenses (Table A10).

Fully mechanized farms reported significant effects on the level of fertilizer use and other cash expenses, estimating them on average higher by 42.1 kgN/ha and 176.80 pesos per hectare than nonmechanized farms. Partially mechanized farms showed no significant effects in the models explaining level of fertilizer use and other cash expenses.

Farm size showed a significant relationship with level of fertilizer use and other cash expenses per hectare.

4.3. Mechanization and Productivity

In this section, a generalized production function is used to compare productivity among different classes of mechanized farms. The covariance analysis models developed in the previous section cannot be used to disaggregate, for example, the influence of mechanization on yields and post production labor which arise independently of other specified inputs such as level of fertilizer use, other cash expenses and farm size.

Table A11 contains the results of the generalized production function model used to sort out the influence of mechanization on crop yields in the 1979/80 wet season. All explanatory terms in the constrained model (i.e., the model without the interactive effects) were significant. In contrast, F-tests on the unconstrained model showed that the partially mechanized pump irrigated farm interactions had significant effects on rice crop yields. Fully mechanized pump irrigated (M_1*I_1) farms had zero coefficients implying they had no effect on yields. This is in general agreement with the explanation already provided in section 4.2 and the results in Table 1.

Gravity irrigation, level of fertilizer use, total labor use, other cash expenses and farm size all showed significant relationships with crop yields. The coefficient for gravity irrigated farms in the unconstrained model was positive and insignificant. It was, however, positive and significant in the constrained model implying that yields on gravity irrigated farms were significantly higher.

From these results it can be inferred that mechanized and irrigated farms obtained higher yields than nonmechanized and rainfed farms. In the present study, it is assumed that improved rice varieties (HYVs) were grown in all farms. Only 293 of the 318 sample farms were used for this analysis. The remaining 25 sample farms had missing values probably because they did not cultivate this season.

The results of the production function model for the 1980 dry season are presented in Table A12. F-tests show mechanized and irrigated farm interactive effects were insignificant except for the fully mechanized gravity irrigated farm interactions which were highly significant. Fully mechanized farms reported significant increases in yields. Irrigation, however, accounted for significant effects on yields. Total labor use had positive and significant effects on yields. Pump irrigation contributed positively and significantly to yields probably due to assured water availability through irrigation. During the 1980 dry season, only 204 farms were used for the analysis in the study because the remainder were not cultivated. The main reason was a shortage of water during the dry season.

In Table A13, we present the results of the production function analysis for the 1980 wet season. F-tests showed not all interactive terms contributed to variations in rice production during this season. Pump and gravity irrigated farms showed no significant variations in yields. This may suggest that rainfall was adequate. The level of fertilizer use and other cash expenses showed positive and significant relationship with yields. This means farms which used these inputs obtained higher yields than those not applying them.

Both fully mechanized and partially mechanized farms had significantly higher yields than nonmechanized farms. During this season, only 287 observations were used for the analysis. The remaining 15 farms had missing values.

In general, the production function models showed that mechanization was associated with increases in yields, although there is no evidence to indicate that mechanization alone increases yields per hectare. However, significant gains in yields per hectare were obtained when mechanized farms were also irrigated (i.e., showed mechanized/irrigation interactions). Furthermore, the coefficients of determination, R^2 were high for the equations explaining variations in yields per hectare (Tables A11 to A12) and R^2 was low in Table A13. If other confounding explanatory factors such as farm management, soil fertility, land quality, etc., were included in the models the coefficient of determination may have been higher. For example, 'timeliness' of performing farm operations has been reported to lead to increasing yields (FAO, 1975). The present study, however, does not investigate the effects of these endogenous explanatory variables on crop yields.

Results from the covariance analysis (ANACOVA) models generally showed farm size was negatively related with the dependent variables. This supports the earlier results showing an inverse relationship between farm size and yields per hectare, total labor use per hectare, hired labor and other cash expenses per hectare (Thapa, 1979; Roumasset, 1973). This inverse relationship was also to be partially explained by land quality (Roumasset, 1973).

4.4. Mechanization and Energy Utilization in Rice Production

Energy requirements for rice production by season and level of mechanization are presented in Tables 5 to 7. Reviewing particular inputs within each farm type, we find that nitrogen fertilizer was the most energy intensive input followed by farm machinery and seed energy equivalents. In the 1979/80 wet season (Table 5), the energy embodied in the nitrogen fertilizer used in rice production was 3134, 2672, and 1884 megajoules per hectare for fully mechanized, partially mechanized, and nonmechanized farms respectively. Calcium fertilizer showed zero results in any of the three seasons. This suggests that it was not applied during these seasons. Fully mechanized farms had machine energy requirements of 1613 megajoules per hectare (MJ/ha) while partially mechanized farms expended 64 MJ for machine based energy per hectare. Energy embodied in seed was 1378, 1302, 1110 MJ/ha for fully, partially, and nonmechanized farms respectively. Energy in lubricating oil was 9 MJ/ha and 63 MJ/ha for fully mechanized and partially mechanized farms respectively. This low energy in the former farm class suggests that four wheel tractors were less used than the two wheel tractors.

On fully mechanized farms, land preparation and crop husbandry operations (including weeding and all other preharvest tasks) used more labor (314 hours per hectare) than all post production operations combined (226 hours per hectare). Based on the energy ratings adopted in the present study, post production tasks used more energy (375 MJ/ha)

Table 5. Energy requirement for rice production by level of mechanization in Central Luzon, Philippines, 1979/80 Wet Season.

Inputs	Fully mechanized farms Energy* (MJ/ha)	Partially mechanized farms Energy* (MJ/ha)	Nonmechanized farms Energy* (MJ/ha)
Seeds	1378.034	1301.613	1110.456
Machinery:			
embodied and manufacture	1493.115	59.432	0.000
repair and maintenance	119.449	4.755	0.000
gasoline fuel	0.000	0.000	0.000
diesel fuel	203.593	71.867	0.000
oil	9.085	48.833	0.000
Land preparation	52.096	84.329	201.843
Weeding	2.793	15.305	23.515
Total other preharvest tasks	279.647	284.459	363.989
Seedbed preparation	2.790	6.280	10.833
Clearing	0.338	3.704	2.630
Digging	0.000	0.024	0.000
Plowing	41.266	63.629	133.140
Cultivating	3.057	16.753	24.411
Hoeing	0.000	0.000	0.000
Planting	191.448	159.961	163.891
Fertilizer application	14.729	13.384	10.728
Pesticides application	25.846	19.520	17.173
Irrigating	0.173	1.206	3.865
Total post production tasks:	374.609	437.799	482.967
Harvesting	356.708	411.842	327.775
Cutting	0.000	7.304	11.729
Threshing	8.663	5.838	11.377
Sorting	0.000	0.000	0.000

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Table 5 continued.

Inputs	Fully mechanized farms Energy* (MJ/ha)	Partially mech farms Energy* (MJ/ha)	Nonmechanized farms Energy* (MJ/ha)
Other activities	9.238	12.815	8.800
Nitrogen fertilizer	3133.961	2672.237	1883.666
Phosphate fertilizer	205.111	233.844	161.696
Potassium fertilizer	97.897	54.427	42.131
Calcium fertilizer	0.000	0.000	0.000
Chemicals:			
Insecticides (carbofuran)	304.125	304.125	304.125
Herbicides (2,4-D)	77.000	77.000	77.000
Total animal hours:	0.060	59.234	162.928
Animal hrs soil preparation	0.000	57.320	160.265
Animal hrs cultivating	0.000	0.000	0.000
Animal hrs harvesting	0.000	0.148	0.420
Animal hrs other activities	0.060	1.765	2.243
Total tractor hours:	35.201	14.065	0.000
Tractor hrs soil preparation	34.864	14.002	0.000
Tractor hrs cultivating	0.000	0.030	0.000
Tractor hrs harvesting	0.082	0.000	0.000
Tractor hrs other activities	0.255	0.033	0.000
Irrigation	13615.124	11371.912	9702.028
Total energy input (Ei)	21380.901	17093.238	14316.344
Total labor hours	709.145	821.892	1.72.314
Paddy yield (Eo)	48164.020	9125.692	26885.807
Rice (Em)	40528.260	2922.839	22623.423
Ratio Eo/Ei (No.)	2.253	2.289	1.852
Ratio Em/Ei (No.)	1.896	1.926	1.558
Ratio Eo/labor hour	89.233	63.942	34.710
Em/Total labor hours	75.086	53.804	29.207

* Energy values calculated using constants given in Appendix A and Table A14.

than land preparation and crop husbandry operations together (335 MJ/ha) for the same farm type. Energy expenditures for these operations were higher on partially mechanized farms in which total post production tasks and land preparation plus crop husbandry operations expended 438 and 384 MJ/ha respectively. For nonmechanized farms 589 MJ/ha were expended in land preparation and crop husbandry operations while 483 MJ/ha were required in all post production operations. These results are to be expected because land preparation and crop husbandry activities performed using human labor are more laborious, with a very high energy expenditure per hectare. In contrast, mechanized farms tend to produce higher yields than nonmechanized farms. As a result, more labor and hence greater energy is required in post production activities which include harvesting, cutting and stacking, threshing, sorting, and drying.

Digging (except on partially mechanized farms), hoeing and sorting of paddy (mandays/ha) presented no energy expenditure indicating that these operations were not performed during the three seasons covered by the study. In fact, these operations showed zero (mandays/ha) values on the observed data (Tables 5 to 7). About 7 to 12 MJ/ha of energy were expended on partially and nonmechanized farms for cutting and stacking of paddy manually.

All farms were assumed to have used identical insecticide and herbicide application rates (carbofuran at 0.75 kilogram of active ingredient per hectare and 2,4-D at the rate of 0.7 kilogram of active ingredient per hectare) which are the recommended rates for the Philippines (IRRI, 1978a). Thus all farm types are assumed to have the

Table 6. Energy requirement for rice production by level of mechanization in Central Luzon, 1980 Dry Season.

Inputs	Fully mechanized farms Energy* (MJ/ha)	Partially mechanized farms Energy* (MJ/ha)	Nonmechanized farms Energy* (MJ/ha)
Seeds	1479.126	1516.705	1004.632
Machinery:			
embodied and manufacture	1509.178	95.073	0.000
repair and maintenance	120.734	7.606	0.000
gasoline fuel	0.000	0.000	0.000
diesel fuel	68.306	68.435	0.000
oil	78.438	62.785	0.000
Land preparation	55.760	89.771	299.035
Weeding	1.330	1.475	6.912
Total other preharvest tasks	251.529	307.181	528.680
Seedbed preparation	2.525	7.843	15.729
Clearing	0.000	1.765	1.433
Digging	0.000	0.000	0.000
Plowing	35.509	65.708	303.480
Cultivating	1.512	1.639	7.174
Hoeing	0.000	0.000	0.000
Planting	162.723	178.379	231.294
Fertilizer application	20.525	18.304	19.493
Pesticides application	28.682	26.325	31.483
Irrigating	0.054	6.820	19.811
Total post production tasks:	328.450	416.227	551.525
Harvesting	309.725	395.075	537.818
Cutting	0.662	2.990	0.000
Threshing	5.302	5.239	6.122
Sorting	0.000	0.000	0.000

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Table 6 continued.

Inputs	Fully mechanized farms Energy/ha* (MJ)	Partially mechanized farms Energy/ha* (MJ)	Nonmechanized farms Energy/ha* (MJ)
Other activities	12.761	12.923	7.586
Nitrogen fertilizer	5298.329	5349.813	3779.416
Phosphate fertilizer	289.880	250.722	245.675
Potassium fertilizer	69.742	47.657	51.273
Calcium fertilizer	0.000	0.000	0.000
Chemicals:			
Insecticides (carbofuran)	304.125	304.125	304.125
Herbicides (2,4-D)	77.000	77.000	77.000
Total animal hours:	0.406	65.797	247.145
Animal hrs soil preparation	0.000	63.500	242.390
Animal hrs cultivating	0.000	0.000	0.000
Animal hrs harvesting	0.000	0.171	0.926
Animal hrs other activities	0.406	2.126	3.828
Total tractor hours:	36.154	16.495	0.124
Tractor hrs soil preparation	35.986	16.344	0.124
Tractor hrs cultivating	0.000	0.000	0.000
Tractor hrs harvesting	0.022	0.000	0.000
Tractor hrs other activities	0.146	0.151	0.000
Irrigation	26907.403	18958.754	11321.816
Total energy input (Ei)	36875.892	27635.622	18417.357
Total labor hours	637.070	814.654	1022.826
Paddy yield (Eo)	60263.928	51744.889	2487.472
Rice (Em)	50709.891	43541.431	35751.653
Ratio Eo/Ei (No.)	1.634	1.872	2.307
Ratio Em/Ei (No.)	1.375	1.576	1.941
Ratio Eo/Labor hours	124.595	83.514	41.539
Ratio Em/labor hours	104.842	70.274	34.954

* Energy values calculated from energy constants in Appendix A and Table A15.

same energy expenditure equivalent to 304 and 77 MJ/ha for insecticides (carbofuran) and herbicides (2,4-D) respectively.

As expected, nonmechanized farms used more animal power than either fully or partially mechanized farms. Animal energy expenditure in nonmechanized, partially, and fully mechanized farms was 163, 59, and 0.06 MJ/ha respectively (Table 5). Also, in consonance with general expectactions, fully mechanized farms used more tractor hours (33.3 tractor hours per hectare) for performing operations than either partially mechanized farms (13.3 tractor hours per hectare) or nonmechanized farms which recorded little use of tractors for field operations.

Total energy input requirements for rice production operations were about 21381, 17095, and 14516 MJ/ha for fully mechanized, partially mechanized and nonmechanized farms respectively. The correponding energy equivalents (E_o) of crop output (or yield) of paddy were 48164, 39126, and 26886 MJ/ha. Rice, which is about 69% (IRRI, 1978c) the weight of paddy had energy equivalent (E_m) of 40528, 32923, and 22623 MJ/ha for fully, partially, and nonmechanized farms respectively. From these results, energy utilization efficiencies were computed as the ratios of output energy equivalent to input energy equivalent for paddy and rice in turn. The results were 2.25, 2.29, and 1.85 for paddy on fully, partially, and nonmechanized farms respectively. The corresponding ratios for rice were 1.90, 1.93, and 1.56.

In Tables 5 and 6 partially mechanized farms presented higher energy utilization efficiencies than either fully or nonmechanized farms. However, in Table 7 fully mechanized farms presented a higher energy output to input ratio than either of the two farm groups.

Table 7. Energy requirement for rice production by level of mechanization in Central Luzon, 1980 Wet Season.

Inputs	Fully mechanized farms Energy* (MJ/ha)	Partially mechanized farms Energy* (MJ/ha)	Nonmechanized farms Energy* (MJ/ha)
Seeds	1559.259	1654.460	1451.082
Machinery:			
embodied and manufacture	703.120	228.925	0.000
repair and maintenance	56.250	18.314	0.000
gasoline fuel	0.000	0.000	0.000
diesel fuel	49.090	198.305	0.000
oil	1.805	226.169	0.000
Land preparation	80.248	114.884	204.353
Weeding	8.650	6.6929	21.641
Total other preharvest tasks	273.141	324.883	359.771
Seedbed preparation	5.674	11.887	11.744
Clearing	1.726	0.839	3.168
Digging	0.000	0.000	0.000
Plowing	43.742	88.452	128.188
Cultivating	9.895	89.757	22.491
Hoeing	0.000	0.000	0.000
Planting	165.816	169.703	162.009
Fertilizer application	15.887	16.882	12.082
Pesticides application	30.109	29.939	22.316
Irrigating	0.292	1.551	0.683
Total post production tasks:	462.930	512.646	479.633
Harvesting	383.374	439.832	427.377
Cutting	64.874	58.865	41.554
Threshing	0.984	0.061	1.669
Sorting	0.000	0.000	0.000

---/continued.

Table 7 continued.

Inputs	Fully mechanized farms Energy* (MJ/ha)	Partially mechanized farms Energy* (MJ/ha)	Nonmechanized farms Energy* (MJ/ha)
Other activities	113.698	13.888	9.033
Nitrogen fertilizer	3919.441	4593.054	5259.287
Phosphate fertilizer	243.027	376.788	473.806
Potassium fertilizer	102.673	92.941	108.128
Calcium fertilizer	0.000	0.000	0.000
Chemicals:			
Insecticides (carbofuran)	304.125	304.125	304.125
Herbicides (2,4-D)	77.000	77.000	77.000
Total animal hours:	27.825	83.118	168.306
Animal hrs soil preparation	26.532	81.924	162.179
Animal hrs cultivating	0.000	0.000	0.000
Animal hrs harvesting	0.203	0.085	2.686
Animal hrs other activities	1.091	1.110	3.440
Total tractor hours:	25.496	14.358	1.338
Tractor hrs soil preparation	25.090	14.159	1.328
Tractor hrs cultivating	0.000	0.000	0.000
Tractor hrs harvesting	0.037	0.099	0.000
Tractor hrs other activities	0.048	0.000	0.010
Irrigation	12028.734	12156.758	10531.404
Total energy input (Ei)	19922.814	20985.643	19439.874
Total labor hours	824.970	961.327	1065.399
Paddy yield (Eo)	38651.918	37673.375	29418.129
Rice (Em)	32524.175	31700.767	24754.280
Ratio (Eo/Ei) (No.)	1.940	1.795	1.513
Ratio (Em/Ei) (No.)	1.633	1.511	1.273
Ratio Eo/Labor hours	63.359	44.832	38.495
Ratio Em/labor hours	53.314	34.890	32.393

* – All input quantities except machinery and irrigation are from the CSRFM project. Machinery embodied and manufacture, and repair and maintenance energy values are adapted from Stout, et al (1979).
Energy values calculated from constants in Appendix A and Table A16.

Partially mechanized farms produced high yields for relatively lower energy inputs. An increase in the yields without an increase in the energy inputs for any level of mechanization would modify the ratio rankings presented in Tables 5 to 7. Alternatively, a decrease in energy input without a decrease in yields would also change the ratios. Hence, judged purely on the energy obtained from rice yields, partially mechanized farms were superior. According to the literature, energy utilization efficiencies decrease as the total energy used in the production system increases (Heichel, 1973). Often times, this results because production systems with low energy inputs tend to involve high levels of human decision making per unit of energy input, with the result that output is more a product of these, or their non-energy inputs (Kuether and Duff, 1979). With the energy prices prevailing in the 1979-1980 period and using these levels of mechanization, energy efficiency ratios compare favorably with those presented in the literature (Kuether and Duff, 1979; Rutger and Grant, 1980; Kiamco and McMennamy, 1979).

Total human energy utilization in major farm operations was also computed and presented in Tables 5 to 7. Throughout these tables it is shown that as the level of mechanization increases, the ratio of total energy output to labor hours increases. This observation is in agreement with results presented in the literature (Kiamco and McMennamy, 1979; Rutger and Grant, 1980; Kuether and Duff, 1979). Calculating the ratios of paddy energy equivalents to total labor hours gives 89, 64, and 35 MJ/labor hour corresponding to fully, partially, and nonmechanized farms respectively (Table 5). The ratios for rice energy equivalents to total labor hours were 75, 54, and 29 MJ/labor hour labor for fully, partially, and nonmechanized farms respectively (Table 5).

The energy input calculations presented in Tables 6 and 7 are similar to those in Table 5. However, the energy for irrigation during the dry season was 26907.4 MJ/ha for all farm types (Table 6). This result is slightly more than double the corresponding results in Tables 5 and 7. In the dry season (Table 6) it was assumed that 0.30 m was the net depth of irrigation instead of 0.15 m (Tables 5 and 7) to meet the increased demand for irrigation water during the dry season (Rutger and Grant, 1980; Knutson et al, 1977).

Reviewing Table 6 it can be noted that yields for both paddy and milled paddy were correspondingly higher than those in Tables 5 and 7) to meet the increased demand for irrigation water during the dry season (Rutger and Grant, 1980; Knutson et al., 1977).

Reviewing Table 6, it is noted that yields for both paddy and rice were correspondingly higher than those in Tables 5 and 7. This is in agreement with results already presented in the literature (Rutger and Grant, 1980). As a result, the energy equivalents for both paddy and rice were higher during the dry season (Table 6) than those in either the 1979/80 or 1980 wet seasons. Total labor use during the dry season was 484, 620, and 1023 hours per hectare on the fully, partially, and nonmechanized farms respectively. The respective total input energy equivalents were 36876, 27634, and 18417 MJ/ha while yield (or output) energy equivalents of paddy and rice (figures in parentheses) were 60264 (50710), 51745 (43541), and 42487 (35752) MJ/ha. Energy utilization efficiencies were 1.63 (1.38), 1.87 (1.58), and 2.31 (1.94). The ratios of output energy equivalent to labor hours were 125 (105), 84 (70), and 42 (35).

Table 7 presents input-output energy equivalents for the 1980 wet season. Energy utilization efficiencies were computed and presented for paddy and rice (figures in parentheses) and the results were 1.94 (1.63), 1.80 (1.51), and 1.51 (1.27) for fully, partially, and nonmechanized farms respectively. The ratios of output energy equivalent to total labor hours ratios were 63 (53), 53 (45), and 39 (32).

Tables 8 to 10 present labor distribution in labor days and labor hours per hectare by major farm operations and by level of mechanization. One manday of labor was assumed to be equivalent to eight man labor hours. Approximately 50% of the total labor requirements (about 67.5 labor days or 540 labor hours per hectare) on the fully mechanized farms was utilized for crop husbandry operations (of which 38% was used for planting, 0.4% in weeding, and 10% in other preharvest operations), 42% in post production tasks and only 9% in land preparation (Table 8 and Fig. 2). Nonmechanized farms utilized 95.8 labor days or 767 labor hours per hectare out of which about 19% was used in land preparation, 23% in planting, about 2% in weeding, 18% in other preharvest operations, and 38% in post production operations. Crop husbandry operations used up to 43% of the total hours. Partially mechanized farms required about 76.5 labor days or 612 labor hours per hectare to perform major farm operations. About 13% of total labor requirements was used for land preparation, 28% in planting, 1.9% in weeding, 13.6% in other preharvest activities, and 43% in post

Table 8. Labor (days and hours/ha) distribution by major farm operations in Central Luzon, 1979/80 Wet Season.

Farm Type and Operation	Labor[a] (days/ha)	Labor (hours/ha)	Fraction Labor (percent)
M1 -- Fully Mechanized Farms:			
Land preparation	6.174	49.390	9.150
Planting	25.765	206.123	38.188
Weeding	0.262	2.097	0.388
Other preharvest tasks	7.044	56.352	10.440
Post-production tasks	28.225	225.800	41.833
Total	67.470	539.762	100.000
M2 -- Partially Mechanized Farms:			
Land preparation	9.934	79.948	13.065
Planting	21.528	172.223	28.146
Weeding	1.436	11.490	1.878
Other preharvest tasks	10.424	83.392	13.628
Post-production tasks	33.106	264.847	43.283
Total	76.487	611.900	100.000
M3 -- Nonmechanized Farms:			
Land preparation	18.251	146.009	19.047
Planting	22.057	176.455	23.019
Weeding	2.207	17.654	2.303
Other preharvest tasks	17.359	138.872	18.116
Post-production tasks	35.948	287.586	37.516
Total	95.822	766.576	100.000

[a] One manday of labor = eight man-hours.

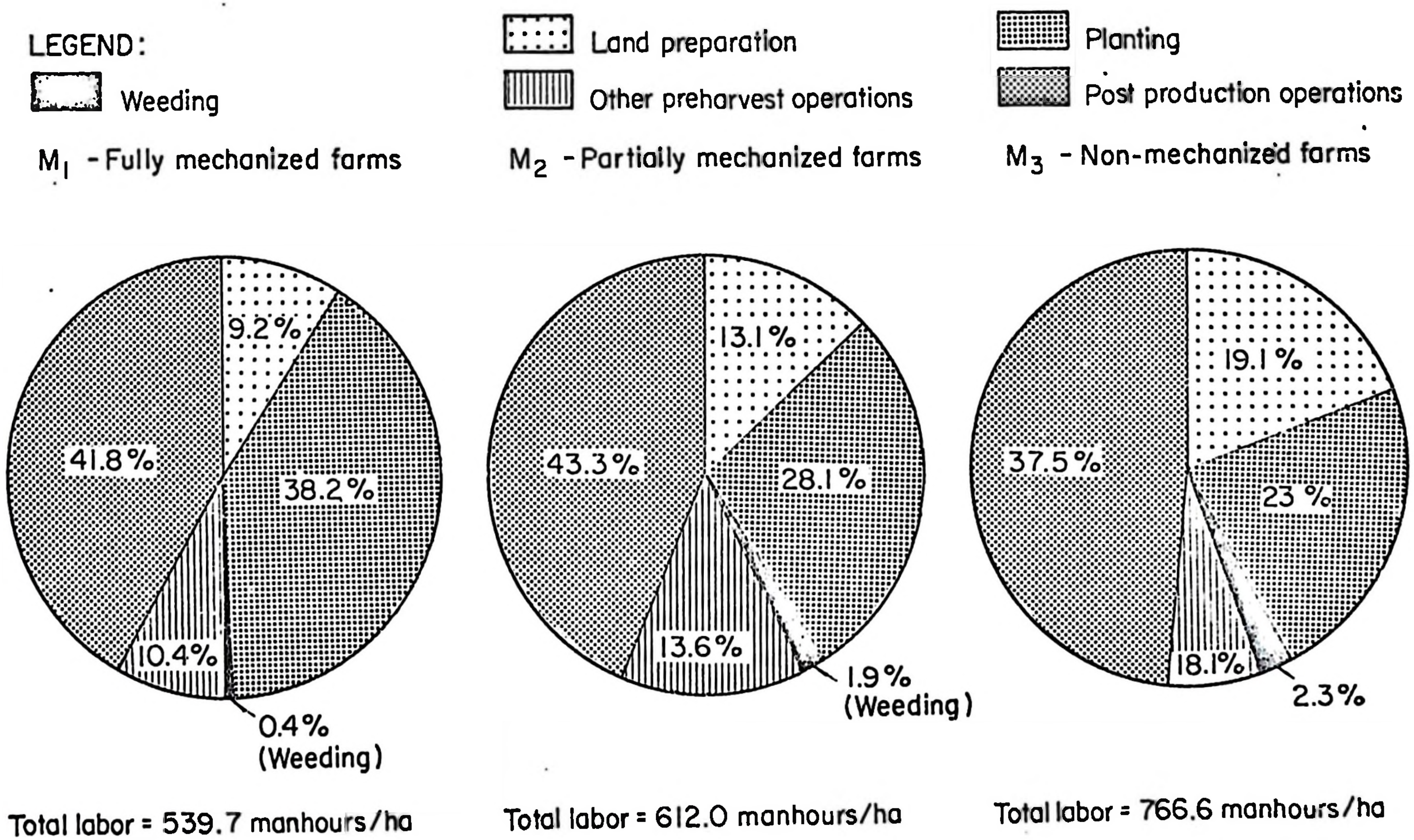

Fig. 2. Labor (manhours/hectare) distribution by major farm operations, wet season, 1979-'80.

Table 9. Labor (days and hours/ha) distribution by major farm operations in Central Luzon, 1980 Dry Season.

Farm Type and Operation	Labor[a] (days/ha)	Labor (hours/ha)	Fraction Labor (percent)
M1 -- Fully Mechanized Farms:			
Land preparation	6.608	52.863	10.930
Planting	21.900	175.197	36.222
Weeding	0.125	0.998	0.206
Other preharvest tasks	6.987	55.896	11.557
Post-production tasks	24.840	198.717	41.085
Total	60.459	483.672	100.000
M2 -- Partially Mechanized Farms:			
Land preparation	10.638	85.107	13.736
Planting	24.007	192.053	30.997
Weeding	0.138	1.105	0.178
Other preharvest tasks	11.175	89.400	14.429
Post-production tasks	31.491	251.927	40.660
Total	7.449	619.592	100.000
M3 - Nonmechanized Farms:			
Land preparation	27.039	216.316	21.149
Planting	31.128	249.025	24.347
Weeding	0.649	5.190	0.507
Other preharvest tasks	28.365	226.928	22.186
Post-production tasks	40.671	325.365	31.811
Total	17.853	1022.823	100.000

[a]One manday of labor = eight man-hours.

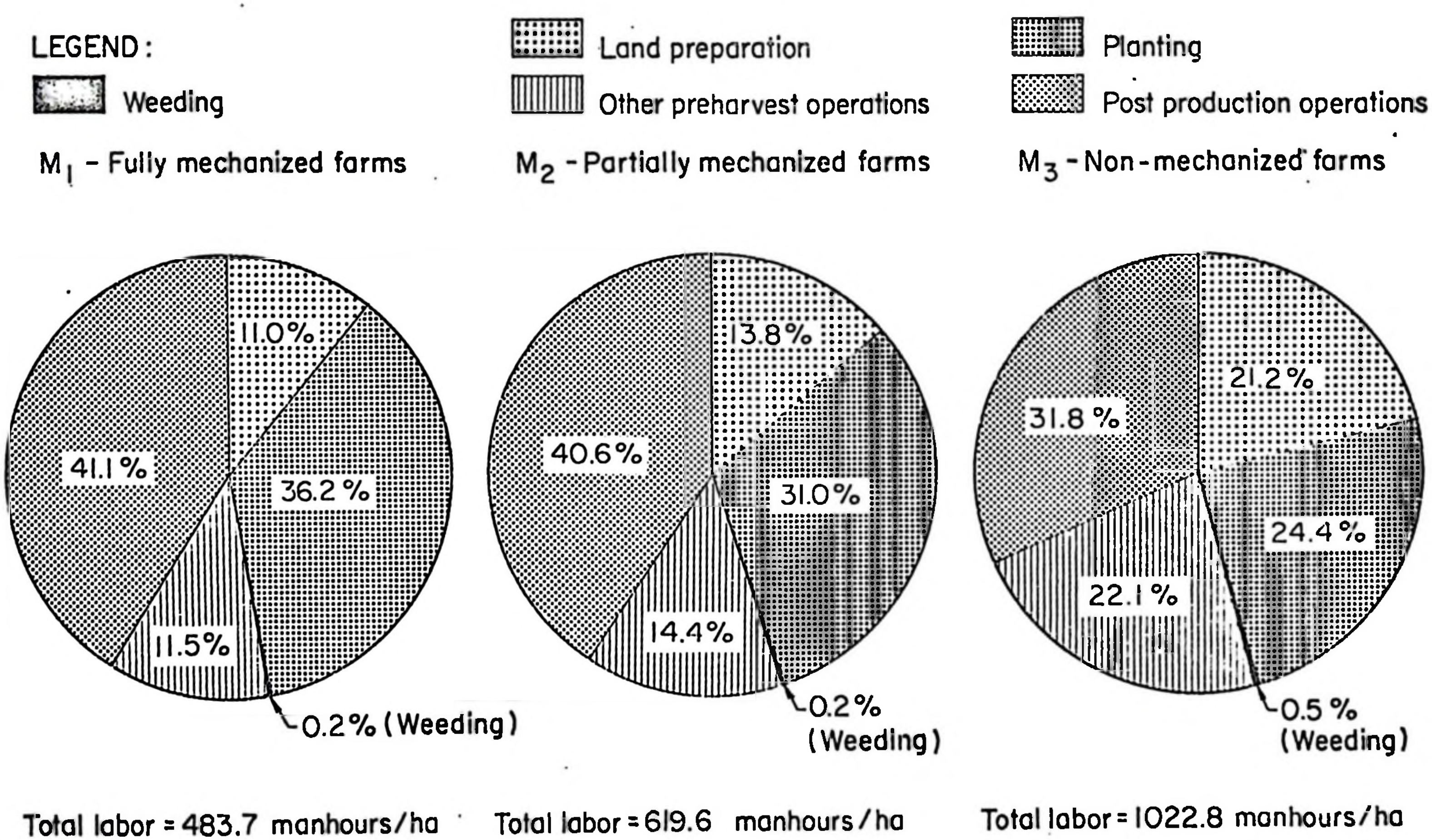

Fig. 3. Labor (manhours/hectare) distribution by major farm operations, dry season, 1980.

Table 10. Labor (days and hours/ha) distribution by major farm operations in Central Luzon, 1980 Wet Season.

Farm Type and Operation	Labor[a] (days/ha)	Labor (hours/ha)	Fraction Labor (percent)
M1 -- Fully Mechanized Farms:			
Land preparation	9.510	76.079	12.471
Planting	22.316	178.527	29.265
Weeding	0.812	6.494	1.063
Other preharvest tasks	8.796	70.368	11.535
Post-production tasks	34.820	278.575	45.665
Total	76.255	610.043	100.000
M2 -- Partially Mechanized Farms:			
Land preparation	13.614	108.916	15.403
Planting	22.839	182.712	25.840
Weeding	0.836	6.692	0.946
Other preharvest tasks	12.930	103.440	14.629
Post-production tasks	38.168	305.343	43.182
Total	88.38	707.102	100.000
M3 - Nonmechanized Farms:			
Land preparation	18.478	147.825	19.344
Planting	21.804	174.428	22.825
Weeding	2.031	16.247	2.126
Other preharvest tasks	17.852	142.816	18.689
Post-production tasks	35.359	282.874	37.016
Total	95.524	764.190	100.000

[a]One manday of labor = eight man-hours.

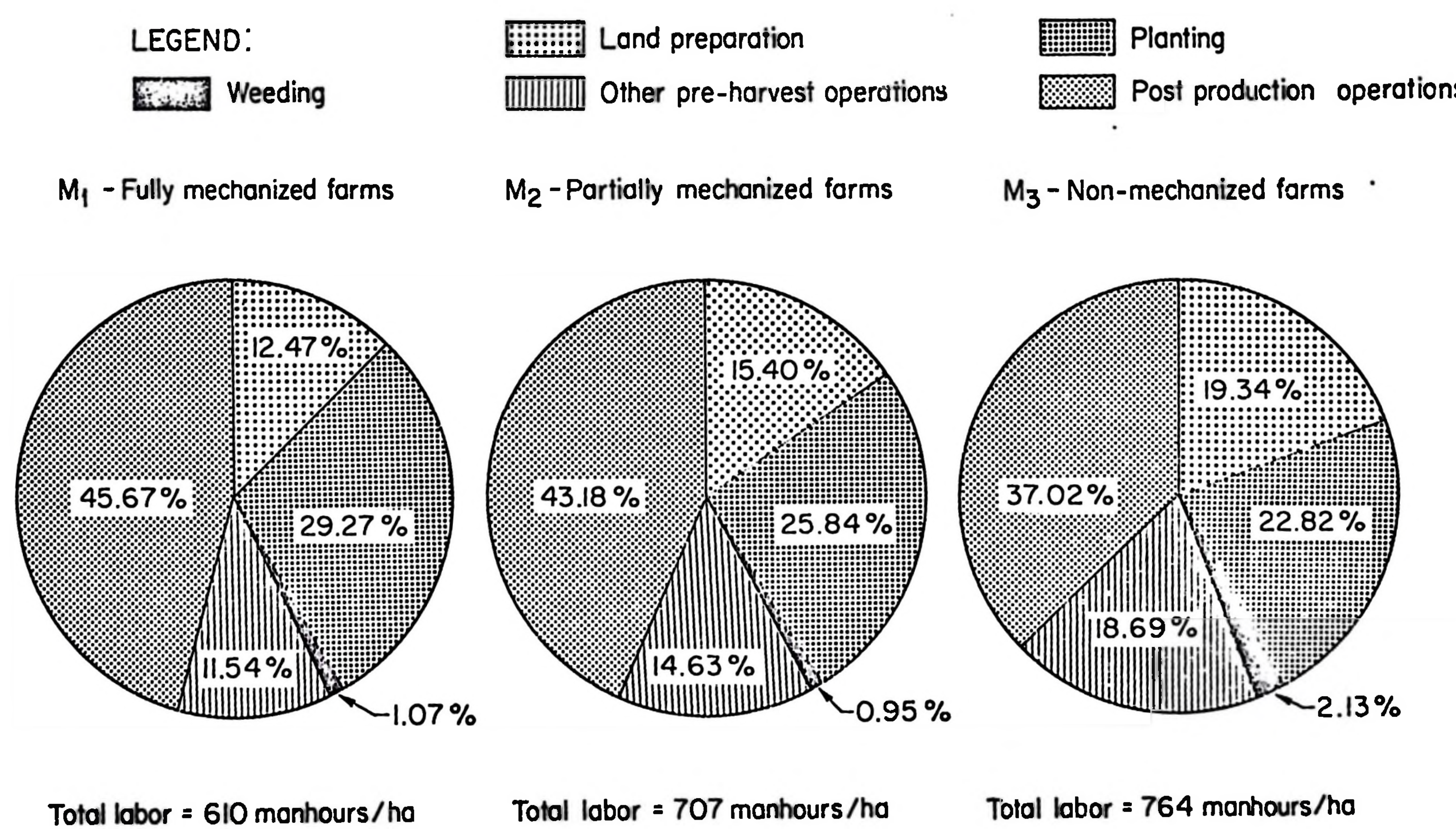

Fig. 4. Labor (manhours per hectare) distribution by major farm operations, wet season, 1980.

production tasks. Thus, about 44% of the total labor requirements was utilized in crop husbandry operations.

The labor utilization (or distribution) pattern presented in Tables 9 and 10 and illustrated in Figures 3 and 4 show the same trend depicted in Table 8 and Fig. 2. These results show that as the level of mechanization rises, total labor requirement for performing farm operations decreases. This agrees with the results presented in the literature (Rutger and Grant, 1980; Sukharomana, 1984; Farrington et al, 1984). For example, nonmechanized farms in Central Luzon used more labor per hectare than fully mechanized farms. Partially mechanized farms used labor per hectare at an intermediate level between that used by fully and nonmechanized farms. Clearly then mechanization results in labor replacement in rice production systems. This is in agreement with recent reports by Sukharomana (1984) and Farrington et al, (1984).

Comparative energy budgets including all energy requirements converted to paddy and rice equivalents and are presented in Tables 11 to 13. The results represent the amount of rice required to generate the energy needed by each level of mechanization. Reviewing each table, we find that fully mechanized farms have the highest estimated energy values followed by partially mechanized farms with nonmechanized farms being the last. However, in Table 13, partially mechanized farms have higher estimated energy values than fully mechanized farms.

Pricing the paddy and rice as shown in Table 14 gives an indication of the relative commercial and noncommercial (or on-farm) energy costs in monetary terms.

Table 15 and Figures 5 to 7 present energy inputs by source and level of mechanization. A review of the table and figures indicates

Table 11. Estimated energy by level of mechanization in kg/ha of paddy and rice in Central Luzon, 1979/80 Wet Season.[a]

Item		Fully mechanized farms	Partially mechanized farms	Nonmechanized farms
		paddy and rice equivalent (kg/ha)		
Seed:		111.491	15.308	89.843
		(91.442)	(86.371)	(73.687)
Fertilizers:	Nitrogen	253.557	216.200	152.400
		(207.960)	(177.322)	(124.994)
	Phosphate	16.595	18.919	13.082
		(13.611)	(15.517)	(10.730)
	Potassium	7.920	4.403	3.409
		(6.496)	(3.612)	(2.796)
Insecticide (carbofuran)		24.606	24.606	24.606
		(20.181)	(20.181)	(20.181)
Herbicide (2, 4-D)		6.230	6.230	6.230
		(5.109)	(5.109)	(5.109)
Fuel and oil		17.207	9.765	0.000
		(14.113)	(8.009)	(0.000)
Machinery		130.466	5.193	0.000
		(107.005)	(4.259)	(0.000)
Animal power		0.005	4.792	13.182
		(0.004)	(3.931)	(10.811)
Human power		57.374	66.496	86.757
		(47.050)	(54.538)	(71.156)
Irrigation		1101.547	920.058	784.954
		(903.459)	(754.606)	(643.797)
Total		1727.069	1381.972	1174.462
		(1416.366)	(1133.455)	(963.261)

[a]Based on 12.36 MJ/kg of paddy and 15.07 MJ/kg of rice.
Figures in parentheses represent rice equivalents.

Table 12. Estimated energy by level of mechanization in kg/ha of paddy and rice in Central Luzon, 1979/80 Dry Season.[a]

Item		Fully mechanized farms	Partially mechanized farms	Nonmechanized farms
		paddy and rice equivalent (kg/ha)		
Seed:		119.670	122.711	81.281
		(98.150)	(100.644)	(66.664)
Fertilizers:	Nitrogen	428.667	432.833	305.778
		(351.581)	(354.998)	(250.791)
	Phosphate	23.453	20.285	19.877
		(19.236)	(16.637)	(16.302)
	Potassium	5.643	3.856	4.148
		(4.628)	(3.162)	(3.402)
Insecticide (carbofuran)		24.606	24.606	24.606
		(20.181)	(20.181)	(20.181)
Herbicide (2, 4-D)		6.230	6.230	6.230
		(5.109)	(5.109)	(5.109)
Fuel and oil		11.872	10.617	0.000
		(9.737)	(8.707)	(0.000)
Machinery		131.870	8.373	0.010
		(108.156)	(6.813)	(0.008)
Animal power		0.003	5.323	19.996
		(0.027)	(4.366)	(16.400)
Human power		51.543	65.911	112.148
		(42.274	(54.058)	(91.981)
Irrigation		2983.486	1533.880	916.005
		(2446.974)	(1258.046)	(751.282)
Total		3787.083	2234.677	1490.078
		(3106.044)	(1832.602)	(1222.120)

[a]Based on 12.36 MJ/kg of paddy and 15.07 MJ/kg of rice. Figures in parentheses represent rice equivalents.

Table 13. Estimated energy by level of mechanization in kg/ha of paddy and rice in Central Luzon, 1980 Wet Season.[a]

Item		Fully mechanized farms	Partially mechanized farms	Nonmechanized farms
		paddy and rice equivalent (kg/ha)		
Seed:		126.154	133.856	117.401
		(103.468)	(109.785)	(96.289)
Fertilizers:	Nitrogen	317.107	371.606	425.509
		(260.082)	(304.781)	(348.991)
	Phosphate	19.662	30.484	38.334
		(16.127)	(25.003)	(31.440)
	Potassium	8.307	7.519	8.748
		(6.813)	(6.167)	(7.175)
Insecticide (carbofuran)		24.606	24.606	24.606
		(20.181)	(20.181)	(20.181)
Herbicide (2, 4-D)		6.230	6.230	6.230
		(5.109)	(5.109)	(5.109)
Fuel and oil		4.118	34.343	0.000
		(3.377)	(28.167)	(0.000)
Machinery		61.438	20.003	0.081
		(50.390)	(16.406)	(0.066)
Animal power		2.251	6.725	13.617
		(1.846)	(5.515)	(11.168)
Human power		66.745	77.777	86.197
		(54.743)	(63.791)	(70.697)
Irrigation		973.199	983.556	852.055
		(798.191)	(806.686)	(698.832)
Total		1609.815	1768.706	1572.699
		(1320.327)	(1319.591)	(1290.029)

[a]Based on 12.36 MJ/kg of paddy and 15.07 MJ/kg of rice. Figures in parentheses represent rice equivalents.

Table 14. Relative costs (US$/ha) of commercial and non-commercial energy by level of mechanization and season.[a]

Season/Source	Fully mechanized farms	Partially mechanized farms	Nonmechanized farms
Wet Season, 1979/80*			
Commercial	264.894	204.914	167.396
	(421.695)	(329.543)	(266.515)
Noncommercial	28.708	30.021	32.263
	(45.706)	(47.797)	(51.361)
Total	293.602	234.935	199.659
	(467.401)	(377.340)	(317.876)
Dry Season, 1980**			
Commercial	687.015	387.739	242.564
	(1008.302	(568.824)	(356.006)
Noncommercial	32.531	36.850	40.551
	(47.753)	(54.261)	(59.515)
Total	719.546	424.589	283.115
	(1056.055)	(623.085)	(415.521)
Wet Season, 1980**			
Commercial	268.786	294.56	257.542
	(394.492)	(387.770)	(378.038)
Noncommercial	37.079	41.488	41.271
	(54.419)	(60.891)	(60.572)
Total	305.865	336.054	298.813
	(448.911)	(448.661)	(438.610)

[a]Based on data in Tables 11-13 and all energy equivalents charged at the cost of energy in paddy and rice.

* paddy and rice priced at US$0.17/kg and US$0.33/kg. respectively. US$1=P7.50

** paddy and rice priced at US$0.19/kg and US$0.3/kg respectively. US$1=P7.60

Table 15. Energy inputs (MJ/ha) by source and level of mechanization in Central Luzon.[a]

Item	Fully mech farms (MJ/ha)	(Percent)	Partially mech farms (MJ/ha)	(percent)	Nonmech farms (MJ/ha)	(percent)
Wet Season, 1979/80						
Human	709.145	9.173	821.892	14.396	1072.340	22.274
Animal	0.060	0.001	59.234	1.038	162.928	3.384
Machine use	1612.564	20.860	64.187	1.124	0.000	0.000
Fuel and oil	212.678	2.751	120.700	2.114	0.000	0.000
Seed and chemicals	5196.128	67.215	4643.246	81.328	3579.074	74.342
Total	7730.575	100.00	5709.259	100.000	4814.342	100.000
Dry Season, 1980						
Human	637.070	6.414	814.654	9.407	1386.152	37.530
Animal	0.460	0.005	65.797	0.760	247.145	6.691
Machine use	1629.912	16.410	102.679	1.186	0.000	0.000
Fuel and oil	146.744	1.477	131.220	1.515	0.000	0.000
Seed and chemicals	7518.202	75.694	7546.022	87.133	2060.121	55.778
Total	9932.388	100.00	8660.372	100.000	3693.418	100.000
Wet Season, 1980						
Human	824.970	10.484	961.327	10.906	1065.399	11.961
Animal	27.825	0.354	83.118	0.943	168.306	1.890
Machine use	759.370	9.651	247.239	2.805	0.000	0.000
Fuel and oil	50.895	0.647	424.474	4.816	0.000	0.000
Seed and chemicals	6205.525	78.865	7098.368	80.530	7673.428	86.149
Total	7868.585	100.00	8814.526	100.000	8907.133	100.000

[a]Based on energy equivalents presented in Tables 5 to 7.

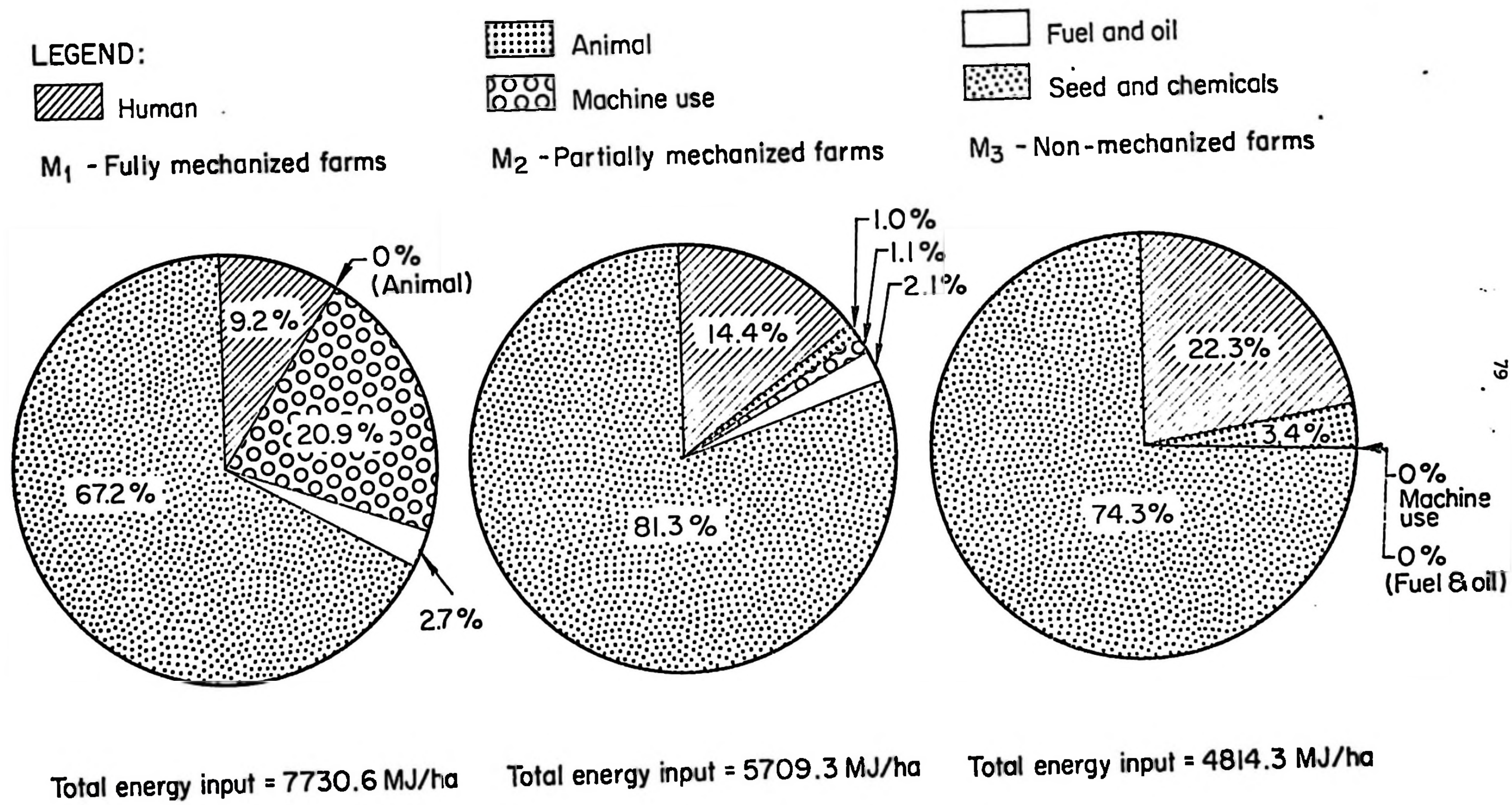

Fig. 5. Energy inputs (MJ/ha) by source and level of mechanization, 1979/80. Wet Season.

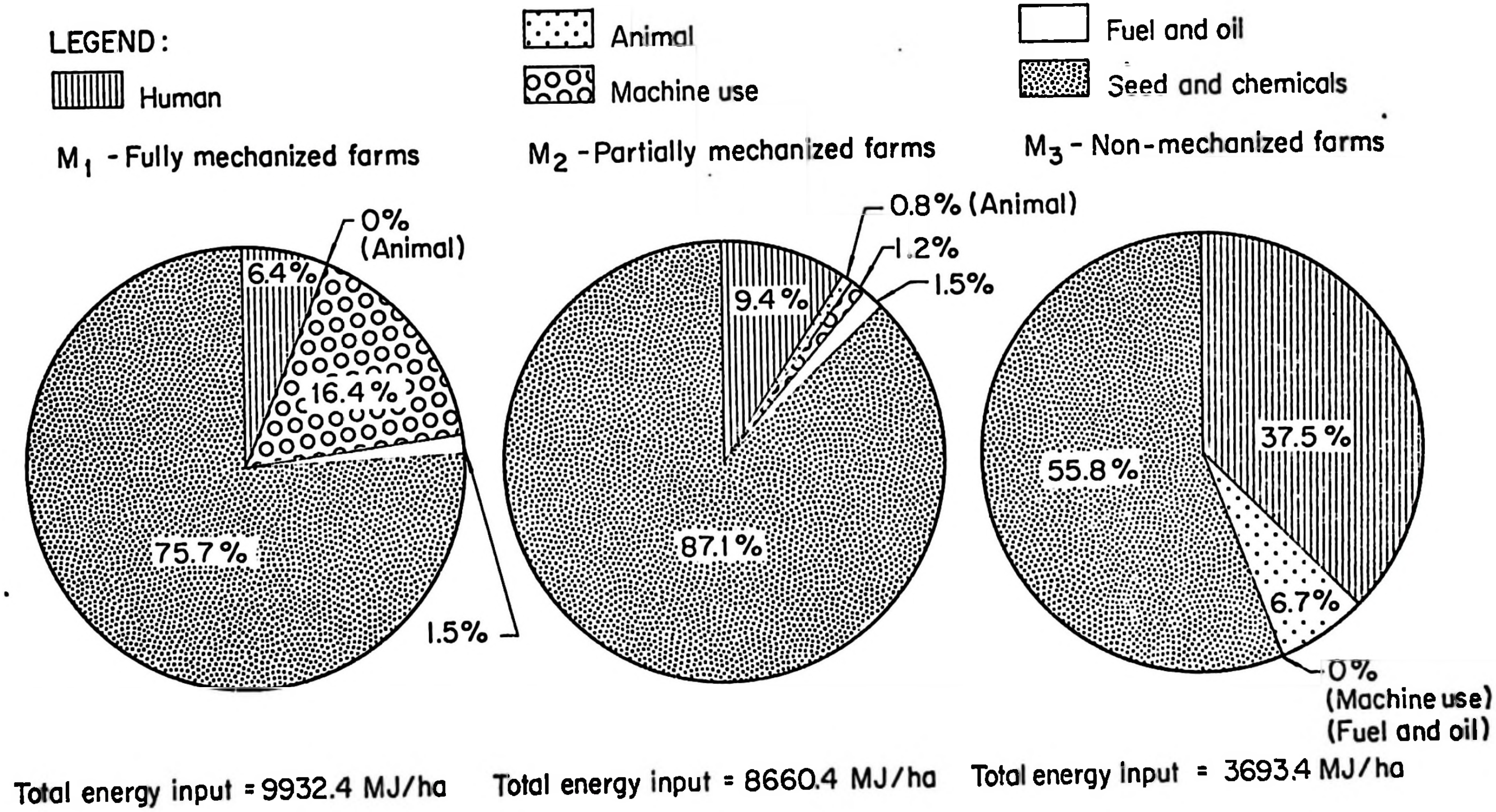

Fig. 6. Energy inputs (megajoules/ha) by source and level of mechanization, dry season, 1980.

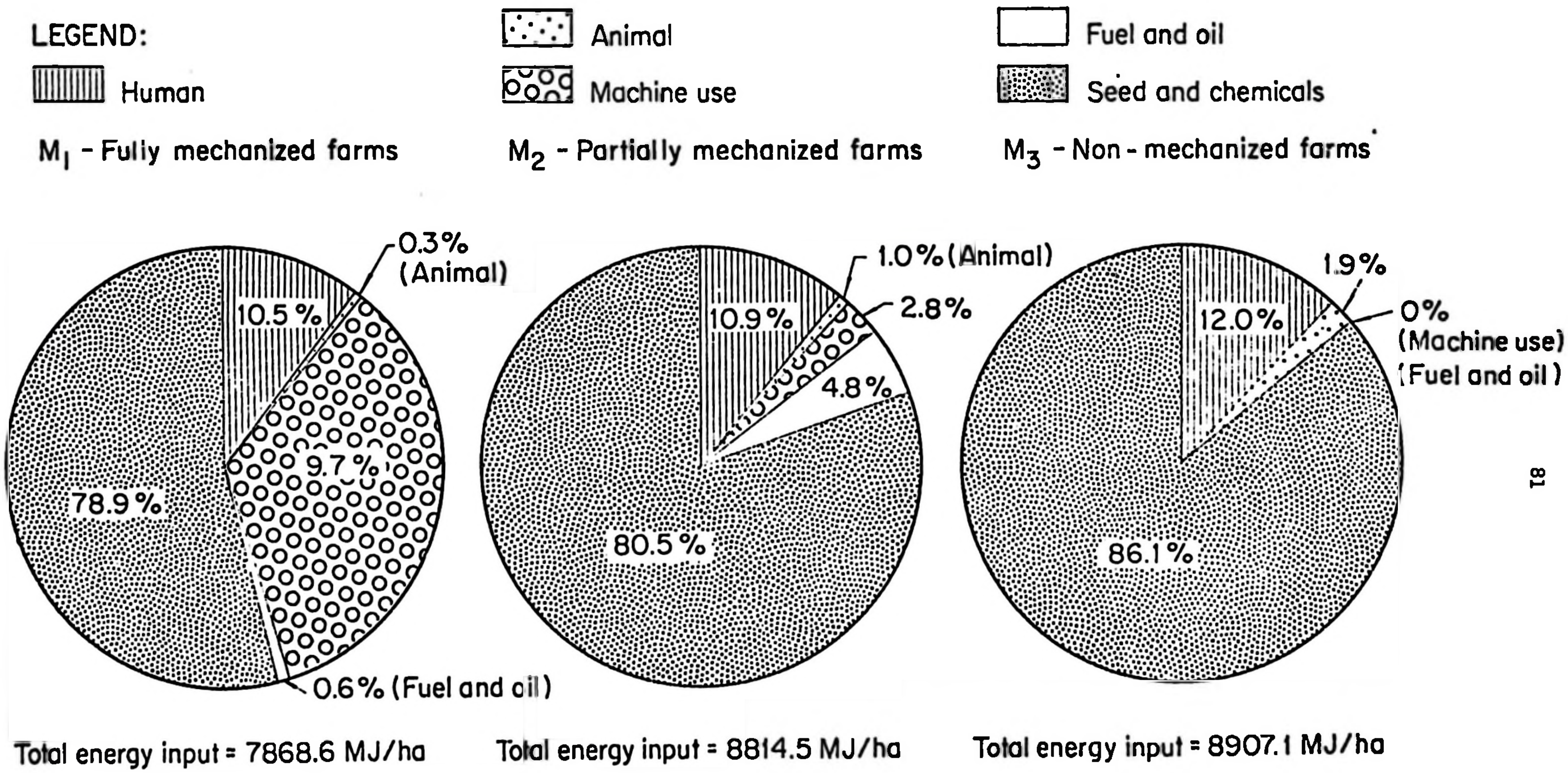

Fig. 7. Energy inputs (megajoules/ha) by source and level of mechanization, wet season, 1980.

that the higher the level of mechanization the higher the energy inputted in rice production.

In Table 16, inputs are valued at market prices. Comparisons of the energy costs in Tables 11 to 14 with the monetary costs in Table 16 can be made. In terms of energy, use of chemicals on mechanized farms increased energy requirements significantly. In monetary terms, however, the lower the level (or degree) of mechanization, the lower the average per hectare costs (Table 16). In the literature, it stated that the use of machines substitutes low cost fossil fuel energy for higher cost animal energy (Kuether and Duff, 1979; Kiamco and McMennamy, 1979). A second advantage of using market prices is that they make it easy to examine the possible impact of changes in energy costs on the choice of the technology for performing farm operations. For example, doubling the price of fossil fuel and oil does not change the comparative advantage of the fully mechanized farms over others. However, indirect effects of fossil fuel and oil price changes such as increases in the cost of machinery would partially reduce the advantages of fully mechanized farms over partially mechanized or traditional farms.

Table 17 presents the costs of inputs (US$/ha) valued at market prices by level of mechanization for the 1984/85 wet season. Reviewing the figures, it is noted that the prices appear to be lower than those of the three 1979-80 seasons. This finding can be attributed to the prevailing low exchange rate between the US dollar and the Philippines peso in 1979-80. As a result, the figures fail to show clearly the trends in energy use in rice production and the present (1984-85) relative costs of energy. However, if the inputs were valued at the

Table 16. Costs of inputs (US$/ha) at market prices by level of mechanization and season in Central Luzon.

Season and Item	Unit cost in US$	per unit	Fully mechanized farms	Partially mech farm	Nonmechanized farms
Wet Season 1979/80[a]					
Seed	0.170	/kg	18.953	17.902	15.273
Fertilizer N	0.580	/kgN	29.798	25.408	17.910
Fertilizer P	0.100	/kgP	1.578	1.799	1.244
Fertilizer K	0.210	/kgK	2.937	1.633	1.264
Insecticide (carbofuran)	36.000	/kgai	27.000	27.000	27.000
Herbicides (2, 4-D)	38.000	/kgai	26.600	26.600	26.600
Fuel	0.193	/l	0.822	0.290	0.000
Machinery[b]	-		38.667	33.333	0.000
Animal power[c]	0.650	/h	0.036	28.103	76.959
Human power	0.170	/h	91.759	104.023	131.679
Total			238.150	266.091	297.929
Dry Season 1980[d]					
Seed	0.190	/kg	22.737	23.315	15.443
Fertilizer N	0.200	/kgN	17.372	17.540	12.392
Fertilizer P	0.100	/kgP	2.230	1.929	1.890
Fertilizer K	0.290	/kgK	2.889	1.974	2.124
Insecticide (carbofuran)	36.000	/kgai	27.000	27.000	27.000
Herbicides (2, 4-D)	38.000	/kgai	26.600	26.600	26.600
Fuel	0.646	/l	0.923	0.477	0.000
Machinery[b]	-		39.474	36.184	0.000
Animal power[c]	0.370	/h	0.139	17.783	66.505
Human power	0.329	/h	159.130	203.847	336.510
Total			298.494	356.649	488.463
Wet Season 1980[e]					
Seed	0.190	/kg	23.969	25.433	22.306
Fertilizer N	0.200	/kgN	12.851	15.059	17.244
Fertilizer P	0.100	/kgP	1.869	2.898	3.645
Fertilizer K	0.290	/kgK	4.254	3.850	4.480
Insecticide (carbofuran)	44.000	/kgai	33.000	33.000	33.000
Herbicides (2, 4-D)	46.000	/kgai	32.200	32.200	32.200
Fuel	0.333	/l	0.342	1.382	0.000
Machinery[b]	-		46.053	42.763	0.000
Animal power[c]	0.370	/h	7.544	22.336	45.506
Human power	0.329	/h	200.705	232.638	251.421
Total			362.787	411.559	409.801

[a] Based on data in Table 5 and US$1=P7.50 in 1979/80 wet season.
[b] Includes only fixed hire cost component.
[c] Based on daily rental rate without operator.
[d] Based on data in Table 6 and US$1=P7.60 in 1980 dry season.
[e] Based on data in Table 7 and US$1=P7.60 in 1980 dry season.

Table 17. Costs of inputs (US$/ha) at market prices by level of mechanization and season in Central Luzon, 1984/85 Wet Season.[a]

Season and Item	Unit cost in US$	per unit	Fully mecha-nized farms	Partially mech farm	Nonmecha-nized farms
Seed	0.150	/kg	19.958	19.938	19.958
Fertilizer N	0.131	/kgN	6.812	6.812	6.812
Fertilizer P	0.200	/kgP	3.600	3.600	3.600
Fertilizer K	0.125	/kgK	1.875	1.875	1.875
Insecticide (carbofuran)	69.000	/kgai	51.750	51.750	51.750
Herbicides (2, 4-D)	70.000	/kgai	49.000	49.000	49.000
Fuel	0.355	/l	1.459	0.586	0.000
Machinery	-		39.084	33.501	0.000
Animal power	0.297	/h	6.357	15.424	35.894
Human power	0.209	/h	114.112	140.913	153.894
Total			294.008	323.420	322.485

level of mechanization the higher the energy inputted in rice production.

In Table 16, inputs are valued at market prices. Comparisons of the energy costs in Tables 11 to 14 with the monetary costs in Table 16 can be made. In terms of energy, use of chemicals on mechanized farms increased energy requirements significantly. In monetary terms, however, the lower the level (or degree) of mechanization, the lower the average per hectare costs (Table 16). In the literature, it stated that the use of machines substitutes low cost fossil fuel energy for higher cost animal energy (Kuether and Duff, 1979; Kiamco and McMennamy, 1979). A second advantage of using market prices is that they make it easy to examine the possible impact of changes in energy costs on the choice of the technology for performing farm operations. For example, doubling the price of fossil fuel and oil does not change the comparative advantage of the fully mechanized farms over others. However, indirect effects of fossil fuel and oil price changes such as increases in the cost of machinery would partially reduce the advantages of fully mechanized farms over partially mechanized or traditional farms.

Table 17 presents the costs of inputs (US$/ha) valued at market prices by level of mechanization for the 1984/85 wet season. Reviewing the figures, it is noted that the prices appear to be lower than those of the three 1979-80 seasons. This finding can be attributed to the prevailing low exchange rate between the US dollar and the Philippines peso in 1979-80. As a result, the figures fail to show clearly the trends in energy use in rice production and the present (1984-85) relative costs of energy. However, if the inputs were valued at the

1980 US dollar - peso exchange rate, there would be a significant increase in their market prices and relative costs of energy.

Reviewing particular operations within each level of mechanization, we find that crop husbandry, particularly the use of fertilizers and chemicals, used the most commercial energy at all levels of mechanization. On fully mechanized farms, energy embodied in fertilizer and chemicals is closely followed by machinery. These inputs are used at a much lower level on both the partially and nonmechanized farms for all the crop seasons except the 1980 wet season in which the energy for fertilizer use was highest on nonmechanized farms. However, we note from the results in Tables 11 to 14 that the total energy requirement rises with rising level of mechanization. These findings reinforce the earlier observations that mechanization is related with increased energy utilization in rice production. As the level of mechanization rises, added energy expenditure is required and the crop production system becomes less efficient in energy utilization.

From the above findings, it is noted that mechanized farms are associated with lower energy utilization efficiency. However, fully mechanized farms have higher yields, lower labor hours in performing selected farm operations, and higher cropping intensities than either partially or nonmechanized farms. This justifies the observation that, although mechanized farms use more fertilizer and higher levels of most purchased inputs, it is profitable to mechanize rice production systems inspite of the present high prices of commercial fuel energy.

CHAPTER V

SUMMARY, CONCLUSIONS, POLICY IMPLICATIONS AND RECOMMENDATIONS

5.1. Summary and Conclusions

The main objectives of the present study were:

(i) to investigate if various levels of mechanization raise total land productivity and how this is accomplished;

(ii) to investigate whether mechanization lowers the production costs of hired labor and other cash expenses;

(iii) to investigate if mechanization increases cropping intensity;

(iv) to develop models to examine the effects of selective mechanization on the intensity of input use and farm productivity;

(v) to study energy utilization patterns in rice production and determine if mechanization is profitable given the present high prices of commercial fuel energy.

The overall objective of the study was to develop a prototype for similar research work to be replicated in Tanzania.

To document the first four objectives, three approaches were used. Analysis of variance (ANOVA) was used to compare differences in yields, labor use, cropping intensity, level of fertilizer use, other cash expenses, and hired labor expenses among farms grouped by level of mechanization and season. Labor use was partitioned into land preparation, weeding, other preharvest labor use, and total post production labor. Analysis of covariance (ANACOVA) models were developed and used to study patterns of input intensity and to permit comparisons within farm groups by level of mechanization. Finally, a generalized production function model was fitted and used to study and document farm productivity among different mechanized classes.

The following were the main conclusions of the study based on the three statistical approaches. High levels of mechanization were associated with:

(i) high yields per hectare;

(ii) high cropping intensity;

(iii) low labor input use per hectare for all farm operations analyzed;

(iv) high hired labor expenses per hectare;

(v) high levels of fertilizer use per hectare for all seasons except the 1980 dry season when fertilizer use was highest on nonmechanized farms;

(vi) high cash (including insecticides, herbicides and fungicides) expenses per hectare.

It was found, however, that mechanization alone was not sufficient to induce these effects. Rather, there was also a strong association between confounding variables such as irrigation in the rice production system, of which mechanization itself was an endogenous variable.

Other researchers have reported that good land quality leads to more intensive crop cultivation, i.e. all operations are performed at a higher level and levels of use of inputs such as fertilizers, insecticides, herbicides, and labor (Roumasset, 1976; Uy, 1979). As a result, higher yields per hectare are obtained.

The use of irrigation water offers significant potential for raising cropping intensity as second and third crops are added to a single crop system. The results of the present study reveal that access to gravity irrigation increases cropping intensity very significantly. Good quality land with high inherent soil fertility also helps achieve higher cropping intensities (Thapa, 1979). The easier the soil to manage, the bigger the advantage in increasing cropping intensity as a result of greater timeliness of operations.

Land preparation labor was significantly lower on fully mechanized farms. However, post production labor was higher. Thus, the labor displaced in land preparation on fully mechanized farms was offset in part in post production operations. Total labor use was less on all mechanized than nonmechanized farms. A review of literature also revealed that land preparation and post production (e.g. threshing) machinery have obvious labor saving properties and are promoted on the basis that they increase yields by increasing cropping intensity by ensuring the crop is planted or harvested at a more optimal time (Herdt, 1981). 'Timeliness' in performing certain operations has a very great effect on area yields and it is in the 'timeliness' of work that the greatest impact of mechanization on increasing yields is found (FAO, 1975).

To evaluate energy use levels and patterns by alternative mechanization and irrigation classes, a series of energy budgets were developed. Energy use levels in rice production were determined by multiplying each input by a corresponding energy constant or coefficient as derived from standard references.

Results showed that energy use in rice production was highest on fully mechanized farms where labor (labor hours per hectare) use was low. Irrigation, machinery use, fertilizer and chemical use contributed a large share to total energy input. In general, it was found that (nitrogenous) fertilizer rates were higher on mechanized than on the nonmechanized farms during the 1979/80 and 1980 wet seasons. The opposite was observed during the 1980 dry season.

The overall paddy (and rice, figures in parentheses) output/input energy ratios during the 1979/80 wet season were 2.25 (1.90), 2.29 (1.93) and 1.85 (1.56). During the 1980 dry season, the ratios were 1.63 (1.38), 1.87 (1.58) and 2.31 (1.94) while they were 1.94 (1.63), 1.80 (1.51) and 1.51 (1.27) during the 1980 wet season. The energy output/input ratio was lowest on fully mechanized farms during the 1980 dry season. Fully mechanized and partially mechanized farms had almost equally high energy utilization efficiencies due to the small size of farms found in the study area. The average area planted to rice was 1.70 to 2.29 hectares (Moran and Casillan, 1981). Such small farm size is more suitable for power tillers than four wheel tractors in performing farm operations. This leads to high yields with relatively low machinery energy input use and a high energy use efficiency. The energy equivalent of crop output per labor hour was highest on fully mechanized farms which used between 484 and 610 labor hours per hectare. Nonmechanized farms had high labor hours per hectare, ranging from 764 to 1023. Therefore, energy output per labor hour was lower on these farms. These results, together with the high yields and cropping intensities on fully mechanized farms make it profitable to mechanize despite the prevailing high price of fossil fuel and oil.

5.2. Policy Implications:

(1) Where land is abundant and labor is limited (for example in Tanzania), mechanization should be introduced to increase crop production per worker and area under cultivation. In countries like the Philippines, where land is scarce and costly and labor abundant and relatively inexpensive, biological and chemical technology should be emphasized to raise land productivity. Mechanization technology is required as a supporting, complementary input to biological and chemical technology (e.g., the use of water pumps, power tillers, etc.).

(2) In Tanzania, human labor and draft animals will continue to be the major power sources for agricultural production in the near and medium term. Therefore, priority should be given to the introduction of more efficient tools and implements suited to these power sources.

(3) The success of increased use of small-farm equipment technology depends on policy decisions to mechanize and the political will to promote local manufacture of equipment. Trade policies and the availability of credit to farmers and manufacturers will also condition the acceptance and rate of adoption of agricultural equipment.

(4) Energy flows in agriculture are an indicator of the degree of agricultural and technological development of a country. Prices of both inputs and commodities should be included in energy evaluation studies to correctly formulate conclusions. Using prices as a decision criteria allows policy-makers to decide and recommend the amount and manner of use for inputs required for agricultural development. For example,

proper fertilizer placement and correct timing must be economical in both monetary and energy terms.

(5) Training of agricultural engineers and technicians in Tanzania should be emphasized as medium and long run projects. Trained manpower is needed in managing agricultural research and development, and to properly essential agro-industries.

5.3. Recommendations for Research and Development

(1) Land preparation methods in most developing countries are nonmechanized. Therefore, agricultural engineers should conduct research on the design, testing, and evaluation and manufature of low cost and energy efficient farm machinery for land preparation operations which require minimum non-renewable energy expenditure.

(2) Research should be initiated to design small energy efficient machines which minimize energy costs in postproduction operations such as harvesting, threshing, drying, and processing. As noted by this study, rice postproduction operations require high energy inputs.

(3) R & D on the use of natural fertilizers (organic matter) such as compost manure and crop residues, Azolla and Sesbania as cheap, readily available renewable sources of energy should be initiated and supported. This will lessen the use of energy intensive chemical fertilizers which are high. It will be interesting to quantify organic fertilizer inputs in terms of energy.

(4) To develop methods and machines to more efficiently use high-energy inputs (such as seeds, fertilizers, chemicals, water and power) to offer the most potential for reducing the total input energy of crop production systems, thereby making them less sensitive to input

price fluctuations. Work to develop suitable equipment to conserve these inputs may take several years. However, such research is a proper task for agricultural engineers and public research institutes.

5.4. Recommendations for Research on Mechanization Strategies

(1) To initiate research on mechanization strategies to minimize the drudgery of man and farm animals in performing farm operations. The main objective of such research would be to increase input and output efficiency, to reduce reliance on non-renewable energy sources, and make efficient use of resources at present, and over time.

(2) To initiate research to investigate the effects of mechanization strategies on crop output, labor utilization, cropping intensity, crop quality, turnaround time from harvesting to planting the next crop and energy expenditure in agriculture. In this way the optimum strategy for mechanizing agriculture would eventually be determined. The aim would be to clearly target the engineering equipment needs of discret geographical and enviromental areas to ensure efficient design, development and promotion of appropriate machinery tailored to these requirements.

(3) To initiate research to determine and clarify the benefits and costs of mechanization at both the private and social levels. For example, what would be the value of increased machine horse-power per crop? Does the farmer benefit from this? This would enable agricultural engineers to determine if there exists a major difference between private and social profitability of mechanization; and identify criteria to be used in identifying the need for agricultural engineering technologies at the farm level with respect to local technical,

economic, cultural and environmental conditions. The anticipated benefits should be of a scale farmers can appreciate.

(4) To identify the immediate and long term employment (and income) effects of agricultural mechanization policies to encourage rural based agro-industrial activities.

LITERATURE CITED

AHAMMED, C. A. and R. W. HERDT. 1981. A general equilibrium analysis of the effects of rice farm mechanization in the Philippines. The International Rice Research Institute, Los Banos, Laguna, Philippines.

BARKER, R., S. S. JOHNSON, N. ALVIAR and N. ORCINO. 1969. Comparative economic analysis of farm data on the use of carabao and tractors in lowland rice farming. Paper presented at the Farm Management Seminar with Focus on Mechanization sponsored by the Institute of Small-scale Industries, Manila, Philippines. February 24 - March 1, 1969.

BARKER, R. and V. G. CORDOVA. 1978. Labor utilization in rice production. In: Economic Consequences of the New Rice Technology. The International Rice Research Institute, Los Banos, Laguna, Philippines, pp. 113-143.

BATTY, J. C., S. H. HAMAD and JACK KELLER. 1974. Energy inputs to irrigation. Journal of Irrigation and Drainage. Division of ASCE 101 (IR4) 293-307.

BAUMEISTER, T. 1958. Marks mechanical engineers handbook. 6th ed. McGraw-Hill Book Company, pp. 7-21 to 7-23.

BENDER, F., L. DOUGHLASS and A. KRAMER. 1981. Statistical Methods for Food and Agriculture. The Saybrook Press, Inc., U.S.A. pp. 147-157.

BINSWANGER, H. P. 1977. The economics of tractors in the Indian subcontinent: An Analytical Review. Economics program, International Crop Research Institute for the Semi-arid Tropics, Hyderabad, India.

BINSWANGER, H. P. 1978. The economics of tractors in South Asia. Agricultural Development Council (ADC), New York and International Crops Research Institute for Semi-arid Tropics (ICRISAT) Hyderabad, India.

BOCKHOP, C. W. 1980. The need for small-scale agricultural machinery in the tropics. Paper presented at 1980 Annual Meeting of the Chinese Society of Agricultural Machinery, Beijing, China. October 15-17.

BORDADO, G. J. 1984. Factors affecting the adoption of mechanical threshers in Laguna, Philippines. Unpublished M.S. thesis. University of the Philippines at Los Banos, Laguna, Philippines.

BOUGHTON, D. 1981. Energy use in alternative rice production systems in Nueva Ecija, Central Luzon, Philippines. The International Rice Research Institute, Los Banos, Laguna, Philippines.

CHANCELLOR, W. J. 1977. The role of fuel and electrical energy in increasing production from traditionally based agriculture. East-West Food Institute, The East-West Center, Honolulu, Hawaii.

CHERN, W. S. 1984. Energy demand and economic growth in developing countries. Paper presented at the Workshop on Energy Economics Techniques sponsored by the Chinese Petroleum Corporation, Taipei, Taiwan, R.O.C. (April 9-11). Leader Energy Research Group, Dept. of Textiles and Consumer Economics, University of Maryland, U.S.A.

CORDOVA, V. G. and C. C. DAVID. 1985. A macro-micro analysis of fertilizer demand in the Asian Rice Economy. International Rice Research Institute, Los Baños, Laguna. Saturday Seminar Paper.

CORDOVA, V. G., R. W. HERDT, F. B. GASCON and L. YAMBAO. 1981. Changes in Rice Production Technology and Their Impact on Rice Farm Earnings in Central Luzon, Philippines, 1966 to 1979. International Rice Research Institute Los Banos, Laguna. Saturday Seminar Paper.

DOERING III, O. C. 1980. Accounting for Energy in Farm Machinery and Buildings. In: Ed. Pimentel (1980). CRC Press, Inc., pp. 9-14.

DUFF, B. 1975. Output, employment and mechanization in Philippine agriculture. The International Rice Research Institute, Los Banos, Laguna, Philippines.

__________. 1978. Augmenting human energy supplies for agricultural development. Paper presented at the Annual Meeting of the Philippine Society of Agricultural Engineers, Manila, Philippines. April 28-29.

__________. 1978. The potential for mechanization in small farm production systems. Paper presented at the meeting "Integrated Crop and Animal Production to Optimize Resource Utilization on Small Farm in Developing Countries," Bellagio, Italy, October 19-23.

__________. 1979. Assessing the impact of agricultural engineering technology. Paper presented at the Philippine Council for Agriculture and Resources Research (PCARR) Headquarter, Los Banos, Laguna, on "Agricultural Engineering Research Planning Workshop" on September 12-14, Philippines.

FAIDLEY, L. 1977. Energy requirement and efficiency for crop production. Paper No. 77-5528, Winter Meeting of American Society of Agricultural Engineers, Chicago.

FAO. 1975. Summary Report on Meeting of Experts on the Effects of Mechanization on Production and Employment. Food and Agriculture Organization (FAO) of the United Nations, Rome.

FARRINGTON, J., F. ABEYRATNE and G. J. GILL, eds. 1984. Farm power and employment in Asia. Agricultural Development Council (ADC), New York and Singapore.

FLUCK, R. C. 1981. Net Energy sequestered in Agricultural Labor. Transactions of the ASAE, 24(6):1449-1455.

FLUCK, R. C. 1985. Energy sequestered in repairs and maintenance of agricultural machinery. Transactions of the ASAE, 22(3):738-743.

FRIEDRICH, K. H. 1977. Farm management data collection and analysis: An electronic data processing, storage and retrieval system. FAO, Rome.

GONZALES, L. A., R. W. HERDT, and J. P. WEBSTER. 1981. Evaluating the sectoral impact of mechanization on employment and rice production in the Philippines: A simulation analysis. Paper presented at the Joint ADC/IRRI Workshop on the Consequences of Small Rice Farm Mechanization in Asia. The International Rice Research Institute, Los Banos, Laguna, Philippines. September 14-18.

______________. 1983. An ex-ante evaluation of national mechanization policies in the Philippines. In Workshop Papers: Consequences of Small Rice Farm Mechanization in the Philippines. Development Academy of the Philippines, Tagaytay City. December 1-2.

GREEN, M. B. 1978. Eating oil --- energy use in food production. Westview Press, Boulder, Colorado, U.S.A.

GUPTA, R. S. R., R. K. MALIK, R. R. GUPTA and A. R. RAO. 1983. Energetics on bullock - and tractor - powered farms in India. Energy in Agriculture, Vol. 2 (1983) pp. 153-160. Elsevier Science Publishers B.V. Amsterdam -- Printed in The Netherlands.

HABITO, C. F. 1977. The choice of technique in rice harvesting systems in the Philippines. A micro-economic analysis. Unpublished M.S. thesis, University of New England. Australia.

HEICHEL, G. H. 1973. Comparative efficiency of energy in crop production. Bulletin 739, Connecticut Agricultural Experiment Station, New Haven.

HOARE, E. R. 1976. Energy use in agriculture with special reference to rice. 1976 Rice Symposium, Griffith, Australia - 29th January 1976.

IGBEKA, J. C. 1983. Selecting and adapting farm machinery to rural conditions. Agricultural Mechanization in Asia, Africa and Latin America (AMA) Journal, Japan. Farm Machinery Industrial Research Corp. Vol. XIV, No. 3, Summer 1983.

INTERNATIONAL RICE RESEARCH INSTITUTE. Annual Report for 1977. pp. 499-500.

INTERNATIONAL RICE RESEARCH INSTITUTE. 1978a. Annual Report for 1977. Los Baños, Laguna, Philippines, 548 p.

INTERNATIONAL RICE RESEARCH INSTITUTE. 1978b. IRRI long range planning committee report. Los Baños, Laguna, Philippines.

INTERNATIONAL RICE RESEARCH INSTITUTE. 1978c. Rice post production systems in the Bicol River Basin. Submitted by the International Rice Research Institute and the University of the Philippines at Los Baños to the Bicol River Basin Development Program, Los Baños, Laguna, Philippines, Revised, November.

INTERNATIONAL RICE RESEARCH INSTITUTE. 1978d. Operations Handbook No. 1, Farm Survey and Recordkeeping Procedures for Consequences of Small Rice -Farm Mechanization Project. Agricultural Engineering Department, IRRI, Los Baños, Laguna. Revised 1980.

INTERNATIONAL RICE RESEARCH INSTITUTE. Annual Report for 1979. p. 482.

INTERNATIONAL RICE RESEARCH INSTITUTE. Annual Report for 1980. pp. 429-432.

INTERNATIONAL RICE RESEARCH INSTITUTE. Annual Report for 1982. pp. 472-473.

INTERNATIONAL RICE RESEARCH INSTITUTE. 1984. Operations Handbook No. 4, Variable Identification and Data Codes for the Philippines. Consequences of Small Rice Farm Mechanization Project. Agricultural Engineering Department, IRRI, Los Baños, Laguna.

JUAREZ, F. and B. DUFF. 1979. The economic and institutional impact of mechanical threshing in Iloilo and Laguna. Working Paper No. 1, Consequences of Small Rice Farm Mechanization Project. The International Rice Research Institute, Los Banos, Laguna, Philippines.

JUAREZ, F. and R. PATHNOPAS. 1981. A comparative analysis of thresher adoption and use in Thailand and the Philippines. Working Paper No. 28, Consequences of Small Rice Farm Mechanization Project. The International Rice Research Institute, Los Banos, Laguna, Philippines.

KHAN, A.U. 1971. Harvesting and threshing of paddy. Paper presented at the International Rice Research Conference. The International Rice Research Institute, Los Banos, Laguna, Philippines.

KIAMCO, L. and J. McMENNAMY. 1979. Reflection of the energy requirements of small rice farmers. Agricultural Mechanization in Asia (AMA), Spring 1979.

KNUTSON, G. D., R. CURLEY, E. B. ROBERTS, R. M. HAGAN and V. CERVINKA. 1977. Pumping energy requirements for irrigation in California, Special Publication 3215, Division of Agricultural Science, University of California (Cited by Rutger and Grant 1980).

KUETHER, D. O. and J. B. DUFF. 1979. Energy requirements for alternative rice production systems in the tropics. IRRI-Agricultural Engineering Department, Paper No. AE 79-04.

LANTIN, R. M. 1983. A review of past, present and proposed mechanization strategies in the Philippines. In Workshop Papers - Consequences of Small Rice Farm Mechanization in the Philippines. Development Academy of the Philippines, Tagaytay City. December 1-2.

LEACH, G. 1976. Energy and food production. International Institute for Environment and

Development, New Hampshire Ave., Washington, D.C.

LEE, K. S. 1979. An evaluation of water use efficiency and energy requirements for wetland tillage. IRRI, Tuesday Seminar Paper. April 10.

LINGARD, J. 1981. Measuring the impact of mechanization on output. In Workshop Papers - Consequences of Small Rice Farm Mechanization in the Philippines. Development Academy of the Philippines, Tagaytay City. December 1-2.

MARANAN, C. L. 1983. Comparative evaluation of tractor and carabao use in rice land preparation, Nueva Ecija, Philippines, 1980. In Workshop Papers - Consequences of Small Rice Farm Mechanization in the Philippines. Development Academy of the Philippines, Tagaytay City. December 1-2.

MASSEY FERGUSON AGRICULTURAL MACHINERY. 1973. Worldwide Catalogue. AD/Coventry, England.

McCOLLY, H. F. 1971. Proposal for agricultural mechanization in developing countries of Southeast Asia. Agricultural Mechanization in Southeast Asia. Spring.

MONGE, V. S. 1983. Analysis of factors affecting demand of tractor and power tiller services in Nueva Ecija, Philippines. M.S. thesis, University of the Philippines at Los Banos, College, Laguna, Philippines.

MOYA, P. 1981. Benefit-cost analysis for different types of irrigation systems in Central Luzon, Philippines. A paper prepared for the ADC Workshop on Investment-Decision to Further Develop and Make Use of Southeast Asia's Irrigation Resources. Bangkok, Thailand. August 16-21.

MORAN, P. B. and E. C. CASILLAN. 1981. Consequences of Farm Mechanization Project Site Description: Philippines. The International Rice Research Institute, Los Baños, Laguna, Philippines.

ORCINO, N. AND B. DUFF. 1974. Experimental results from alternative systems of land preparation. Saturday Seminar Paper. The International Rice Research Institute, Los Banos, Laguna, Philippines. July.

PIMENTEL, D., L. HURD, A.C. BELLOT, M. J. SORSTER, I. N. OKA, O. D. SHOLES and R. J. WHITMAN, 1973. Food production and the energy crisis. Science 182:443-449.

PIMENTEL, D. 1980. Handbook of Energy Utilization in Agriculture. CRC Press, Inc., Boca Raton, Florida.

ROUMASSET, JAMES A. 1973. Risk and choice of technique for peasant agriculture: The case of Philippine rice farmers. Ph.D. thesis, University of Wisconsin.

RUTGER, J. N. and W. R. GRANT. 1980. Energy use in rice production. In: Handbook of Energy Utilization in in Agriculture, Pimentel, D. (E. ed. CRC Handbook), pp. 93-98.

SAITAN, S. 1984. The effect of tractor use on the structure of income and income distribution on small rice farms: a case study of Suphanburi Province, Thailand. Unpublished M.S. thesis, Kasetsart University.

SANVICTORES, H. 1977. Status of agricultural mechanization in the Philippines. A paper presented at the International Agricultural Machinery Workshop. The International Rice Research Institute, Los Banos, Laguna, Philippines. November 2-5.

SHIELDS, D. 1983. The impact of mechanization on agricultural production in selected villages of Nueva Ecija. In Workshop Papers - Consequences of Small Rice Farm Mechanization in the Philippines. Development Academy of the Philippines, Tagaytay City. December 1-2.

SINAGA, R. S. 1978. Implication of agricultural mechanization for employment and income distribution, a case study from Indramayu, West Java. Rural Dynamic Series No. 2. Agro Economic Survey. Bogor, Indonesia.

SISON, J. F., R. W. HERDT, and B. DUFF. 1983. The effects of small farm mechanization on employment and output in selected rice-growing areas in Nueva Ecija, Philippines. In Workshop Papers – Consequences of Small Rice Farm Mechanization in the Philippines. Development Academy of the Philippines, Tagaytay City. December 1-2.

SMIL, V. P. NACHMAN and T. V. LONG II. 1983. Technological changes and the energy cost of U.S. grain corn. Energy in Agriculture, Vol. 2 (1983) 177-192. Elsevier Science Publishers B.V., Amsterdam – Printed in The Netherlands.

SRIVASTAVA, A. C. 1982. A comparative study of conventional and mechanized farming relative to energy use and cost. Journal of Agricultural Mechanization in Asia, Africa and Latin America (AMA), Vol. XIII, No. 2, Spring 1982.

STOUT, B. A., C. A. MYERS, A. HURAND and L. W. FAIDLEY. 1979. Energy for World Agriculture. Food and Agriculture Organization (FAO) of the United Nations. Rome. ISBN 92-5-100465 pp. 214-223.

SUKHAROMANA, S. 1984. The impact of farm power strategy in Thailand. Ed. ADC 1984. Farm power and employment in Asia, p. 18.

TAN, Y. L. 1981. The impact of farm mechanization on small scale rice production. M.S. thesis, University of the Philippines at Los Banos, Laguna, Philippines.

TAN, Y. L. and J. WICKS. 1981. Production effects of mechanization. Working Paper No. 36. Consequences of Small Rice Farm Mechanization Project. The International Rice Research Institute, Los Banos, Laguna, Philippines.

THAPA, G. P. 1979. The economics of tractor ownership and use in selected districts of the Nepal Terai. M.S. thesis, University of the Philippines at Los Baños, Philippines.

TOQUERO, Z. 1983. A critical evaluation of alternative rice post-production technologies in Central Luzon and Bicol Regions, Philippines. Unpublished Ph.D. Dissertation, Kansas State University, U.S.A.

TERHUNE, ELINOR C. 1980. Energy used in the United States for Agricultural Liming Materials. In: Handbook of Energy Utilization in Agriculture, Pimentel, D. (E. Ed. CRC Handbook), pp. 25-26.

UY, M. 1979. Choice of contracts and internal organization in sugar production. M.S. thesis, University of the Philippines, Diliman.

WICKS, J. A. 1979. Modelling the consequences of future mechanization: An outline of possible procedures. The International Rice Research Institute, Los Banos, Laguna, Philippines. October.

WILLIAMS, D. W. and W. J. CHANCELLOR. 1975. Irrigated agricultural production response to constraints in energy-related inputs. Transactions of the ASAE. 18:459-466.

APPENDIX

Table A1. Differences in land preparation and post production labor in Central Luzon, Philippines, 1979/80 Wet Season.

Independent variables	Dependent variables: Land preparation labor (mandays/hectare) Model 1	Land preparation labor (mandays/hectare) Model 2	Post-production labor (mandays/hectare) Model 1	Post-production labor (mandays/hectare) Model 2
Intercept	21.7780** (17.67)	20.9285** (24.52)	21.6547** (4.60)	13.0215** (3.98)
Farm size	-2.3374** (-10.82)	-2.3856** (-11.02)	7.4219** (8.99)	7.0463** (8.26)
M_1 fully mech. farm	-3.6084 (-0.86)	-6.9388** (-4.94)	11.8957 (0.75)	-1.7337 (-0.31)
M_2 partially mech. farm	-6.5805** (-4.64)	-5.2293** (-7.42)	-4.2259 (-0.78)	8.6209** (3.10)
I_1 pump irrigated farm	0.4679 (0.33)	2.0782** (2.85)	-13.4298* (-2.45)	1.4903 (0.52)
I_2 gravity irrigated farm	1.9020 (0.67)	-2.0043* (-2.12)	26.1310* (2.41)	1.3361 (0.36)
M_1I_1 fully mech. pump irrig.	0.0000 (.)	N.A.	0.0000 (.)	N.A.
M_1I_2 fully mech. gravity irrig.	-8.5084 (-1.70)	N.A.	-49.6143** (-2.59)	N.A.
M_2I_1 partially mech. pump irrig.	2.3074 (1.40)	N.A.	20.8317** (3.30)	N.A.
M_2I_2 partially mech. gravity irrig.	-3.7848 (-1.25)	N.A.	-23.6005* (-2.04)	N.A.
R^2	0.449	0.436	0.278	0.215
Adjusted R^2	0.435	0.427	0.259	0.202
F	31.51	48.33	14.86	17.08
N	318	318	318	318

N.A. = not applicable.

Model 1 is the unconstrained model with interaction terms.

Model 2 is the constrained model without interaction terms.

Figures in parentheses are t-statistics to test the significance of individual coefficients.

* significant at 5% level.
** significant at 1% level.

Table A2. Differences in total labor use and hired labor expenses in Central Luzon, Philippines, 1979/80 Wet Season.

Independent variables	Dependent variables			
	Total labor use (mandays/hectare)		Hired labor expenses (pesos/hectare)	
	Model 1	Model 2	Model 1	Model 2
Intercept	98.5081** (14.03)	84.2564** (16.77)	234.4725** (4.02)	92.5798* (2.29)
Farm size	-2.9691* (-2.50)	-3.5140* (-2.46)	83.4249** (8.51)	81.8445** (8.27)
M_1 fully mech. farm	18.3295 (0.80)	-2.7260 (-0.34)	-185.9969 (-0.98)	133.8777* (2.08)
M_2 partially mech. farm	-16.4789* (-2.11)	4.4933 (1.12)	3.8597 (0.06)	187.2950** (5.81)
I_1 pump irrigated farm	-7.3068 (-0.93)	16.4205** (3.96)	-89.0577 (-1.37)	99.1041** (2.97)
I_2 gravity irrigated farm	32.1910* (2.06)	0.4266 (0.08)	241.6508 (1.87)	419.7881** (9.72)
M_1I_1 fully mech. pump irrig.	0.0000 (.)	N.A.	0.0000 (.)	N.A.
M_1I_2 fully mech. gravity irrig.	-70.9953** (-2.58)	N.A.	364.7047 (1.61)	N.A.
M_2I_1 partially mech. pump irrig.	33.0837** (3.64)	N.A.	246.5008** (3.29)	N.A.
M_2I_2 partially mech. gravity irrig.	-29.0739* (-1.75)	N.A.	213.1599 (1.55)	N.A.
R^2	0.168	0.091	0.463	0.442
Adjusted R^2	0.146	0.076	0.449	0.433
F	7.79	6.23	33.25	49.39
N	318	318	318	318

N.A. = not applicable.

Model 1 is the unconstrained model with interaction terms.

Model 2 is the constrained model without interaction terms.

Figures in parentheses are t-statistics to test the significance of individual coefficients.

* significant at 5% level.
** significant at 1% level.

Table A3. Differences in level of fertilizer use and other cash expenses in Central Luzon, Philippines, 1979/80 Wet Season.

Independent variables	Dependent variables: Level of fertilizer use (kilograms/hectare) Model 1	Level of fertilizer use (kilograms/hectare) Model 2	Other cash expenses (pesos/hectare) Model 1	Other cash expenses (pesos/hectare) Model 2
Intercept	27.1319** (5.84)	42.8700** (12.81)	196.6231** (6.18)	111.0591** (4.96)
Farm size	-2.7172** (-3.36)	-2.4824** (-2.99)	10.8320* (2.02)	9.3062 (1.70)
M_1 fully mech. farm	-0.1166 (-0.01)	-11.7533* (-2.18)	-135.2396 (-1.30)	98.83.70** (2.79)
M_2 partially mech. farm	10.8824* (2.05)	-10.3131** (-3.82)	-45.8301 (-1.30)	65.0558 (3.66)**
I_1 pump irrigated farm	12.9567* (2.42)	-8.7212** (-3.12)	-10.8634 (-0.31)	109.2734** (5.94)
I_2 gravity irrigated farm	36.8536** (3.47)	25.6134** (7.08)	197.2015** (2.80)	237.6127** (9.97)
M_1I_1 fully mech. pump irrig.	0.0000 (.)	N.A.	0.0000 (.)	N.A.
M_1I_2 fully mech. gravity irrig.	-6.2394 (-0.33)	N.A.	195.5518 (1.59)	N.A.
M_2I_1 partially mech. pump irrig.	29.1757** (-4.73)	N.A.	156.7557** (3.83)	N.A.
M_2I_2 partially mech. gravity irrig.	-15.9781 (-1.41)	N.A.	52.7768 (0.70)	N.A.
R^2	0.379	0.333	0.382	0.347
Adjusted R^2	0.362	0.322	0.366	0.336
F	23.53	31.14	23.91	33.10
N	318	318	318	318

N.A. = not applicable.

Model 1 is the unconstrained model with interaction terms.

Model 2 is the constrained model without interaction terms.

Figures in parentheses are t-statistics to test the significance of individual coefficients.

* significant at 5% level.
** significant at 1% level.

Table A4. Differences in land preparation and post production labor in Central Luzon, Philippines, 1980 Dry Season.

Independent variables	Land preparation labor (mandays/hectare)		Post-production labor (mandays/hectare)	
	Model 1	Model 2	Model 1	Model 2
Intercept	29.6811**	30.8503**	44.8086**	42.2287**
	(8.60)	(16.25)	(6.43)	(10.75)
Farm size	-1.4467**	-1.5151**	-1.8103*	-2.0395*
	(-3.65)	(-3.83)	(-2.29)	(-2.51)
M_1 fully mech. farm	-2.1175	-11.5734**	32.8896*	1.6069
	(-0.32)	(-5.27)	(2.46)	(0.36)
M_2 partially mech. farm	-10.7381**	-11.2536**	-2.1703	5.1023
	(-2.66)	(-8.05)	(-0.27)	(1.78)
I_1 pump irrigated farm	-4.4456	-5.1313**	-7.3099	-2.2994
	(-1.17)	(-2.87)	(-0.96)	(-0.63)
I_2 gravity irrigated farm	-3.4909	-8.7831**	3.2600	-13.6516**
	(-0.69)	(4.51)	(-0.32)	(-3.41)
M_1I_1 fully mech. pump irrig.	0.0000	N.A.	0.0000	N.A.
	(.)		(.)	
M_1I_2 fully mech. gravity irrig.	-14.3387	N.A.	-47.2341**	N.A.
	(-1.84)		(-3.04)	
M_2I_1 partially mech. pump irrig.	0.0687	N.A.	10.3938	N.A.
	(0.02)		(1.20)	
M_2I_2 partially mech. gravity irrig.	-4.8440	N.A.	-6.0678	N.A.
	(-0.87)		(-0.55)	
R^2	0.442	0.431	0.248	0.190
Adjusted R^2	0.420	0.417	0.218	0.170
F	19.90	30.89	8.29	9.55
N	210	210	210	210

N.A. = not applicable.

Model 1 is the unconstrained model with interaction terms.

Model 2 is the constrained model without interaction terms.

Figures in parentheses are t-statistics to test the significance of individual coefficients.

* significant at 5% level.
** significant at 1% level.

Table A5. Differences in total labor use and hired labor expenses in Central Luzon, Philippines, 1980 Dry Season.

Independent variables	Dependent variables			
	total labor use (mandays/hectare)		Hired labor expenses (pesos/hectare)	
	Model 1	Model 2	Model 1	Model 2
Intercept	140.5725** (10.95)	154.8231** (21.88)	565.7033** (5.23)	554.2150** (9.17)
Farm size	-7.0812** (-4.93)	-7.2170** (-5.02)	-16.4909 (-1.37)	-12.1714 (-1.00)
M_1 fully mech. farm	9.5923 (0.40)	-42.0948** (-5.28)	-369.0733 (-1.82)	-172.7691* (-2.55)
M_2 partially mech. farm	-24.7035 (-1.69)	-38.6875** (-7.62)	-69.0645 (-0.56)	-78.9101* (-1.83)
I_1 pump irrigated farm	-6.2374 (-0.45)	-21.6375** (-3.33)	115.8757 (1.00)	81.3774 (1.47)
I_2 gravity irrigated farm	-13.6655 (-0.74)	-33.1142** (-4.68)	116.9481 (0.76)	436.7924** (7.25)
M_1I_1 fully mech. pump irrig.	0.0000 (.)	N.A.	0.0000 (.)	N.A.
M_1I_2 fully mech. gravity irrig.	-59.8881* (-2.12)	N.A.	528.5369* (2.24)	N.A.
M_2I_1 partially mech. pump irrig.	-15.8532 (-1.01)	N.A.	-68.9256 (-0.52)	N.A.
M_2I_2 partially mech. gravity irrig.	-18.4815 (-0.92)	N.A.	329.3543 (1.95)	N.A.
R^2	0.463	0.450	0.351	0.314
Adjusted R^2	0.442	0.436	0.325	0.297
F	21.69	33.33	13.57	18.66
N	210	210	210	210

N.A. = not applicable.

Model 1 is the unconstrained model with interaction terms.

Model 2 is the constrained model without interaction terms.

Figures in parentheses are t-statistics to test the significance of individual coefficients.

* significant at 5% level.
** significant at 1% level.

Table A6. Differences in level of fertilizer use and other cash expenses in Central Luzon, Philippines, 1980 Dry Season.

Independent variables	Dependent variables			
	Level of fertilizer use (kgs/hectare)		Other cash expenses (pesos/hectare)	
	Model 1	Model 2	Model 1	Model 2
Intercept	81.9087** (4.78)	132.1864** (13.45)	428.1723** (4.77)	487.8999** (9.94)
Farm size	-8.5528** (-4.43)	-8.1180** (-4.06)	-27.9260** (-2.79)	-26.6980** (-2.69)
M_1 fully mech. farm	-30.0664 (-0.92)	-58.8989** (-5.31)	- 93.3316 (-0.55)	-74.4545 (-1.35)
M^2 partially mech. farm	8.5404 (0.44)	-58.6642** (-8.31)	-80.4479 (-0.79)	-166.8420** (-4.76)
I_1 pump irrigated farm	48.5343** (2.62)	-13.6668 (-1.51)	30.1789 (0.31)	-51.1195 (-1.14)
I_2 gravity irrigated farm	27.2241 (1.10)	7.7123 (0.78)	180.7246 (1.41)	205.1370** (4.19)
M_1I_1 fully mech. pump irrig.	0.0000 (.)	N.A.	0.0000 (.)	N.A.
M_1I_2 fully mech. gravity irrig.	4.5393 (0.12)	N.A.	111.6609 (0.57)	N.A.
M_2I_1 partially mech. pump irrig.	-83.6252** (-3.96)	N.A.	115.3908 (-1.06)	N.A.
M_2I_2 partially mech. gravity irrig.	-33.4715 (-1.24)	N.A.	5.1554 (0.04)	N.A.
R^2	0.377	0.314	0.322	0.314
Adjusted R^2	0.352	0.297	0.295	0.297
F	15.18	18.68	11.96	18.68
N	210	210	210	210

N.A. = not applicable.

Model 1 is the unconstrained model with interaction terms.

Model 2 is the constrained model without interaction terms.

Figures in parentheses are t-statistics to test the significance of individual coefficients.

* significant at 5% level.
** significant at 1% level.

Table A7. Differences in cropping intensity in Central Luzon, Philippines, 1979/80 Wet Season to 1980 Dry Season.

Independent variables	Dependent variables: Cropping intensity (percentage)	
	Model 1	Model 2
Intercept	142.2833**	133.5973**
	(19.95)	(34.25)
Farm size	0.3398	0.3375
	(0.43)	(0.43)
M_1 fully mech. dummy	-11.9039	-1.9063
	(-0.89)	(-0.44)
M_2 partially mech. dummy	-11.4655	-0.4797
	(-1.42)	(-0.17)
I_1 pump irrigated farm dummy	-12.1914	-2.2107
	(-1.60)	(-0.62)
I_2 gravity irrigated farm dummy	52.4807**	60.7762**
	(5.16)	(15.67)
M_1I_1 fully mech. pump irrig.	0.0000	N.A.
	(.)	
M_1I_2 fully mech. gravity irrig.	9.6946	N.A.
	(0.62)	
M_2I_1 partially mech. pump irrig.	12.8408	N.A.
	(1.48)	
M_2I_2 partially mech. gravity irrig.	10.5018	N.A.
	(0.95)	
R^2	0.799	0.797
Adjusted R^2	0.791	0.792
F	100.19	160.48
N	210	210

N.A. = not applicable.

Model 1 is the unconstrained model with interaction terms.

Model 2 is the constrained model without interaction terms.

Figures in parentheses are t-statistics to test the significance of individual coefficients.

* significant at 5% level.
** significant at 1% level.

Table A8. Differences in land preparation and post production labor in Central Luzon, Philippines, 1980 Wet Season.

Independent variables	Dependent variables			
	Land preparation labor (mandays/hectare)		Post production labor (mandays/hectare)	
	Model 1	Model 2	Model 1	Model 2
Intercept	21.4386** (23.20)	21.3777** (22.14)	40.0827** (13.49)	41.6224** (14.85)
Farm size	-1.4458** (-4.51)	-2.7952** (-9.44)	-2.0924* (-2.07)	-1.8360* (-2.18)
M_1 fully mech. farm	-8.7570** (-9.01)	-3.5142** (-4.63)	8.3226* (2.72)	4.9587* (2.30)
M_2 partially mech. farm	-9.1913* (-2.56)	-2.9305* (-1.86)	13.0932 (1.16)	7.5807 (1.69)
I_1 pump irrigated farm	-0.1973 (-0.17)	7.2752** (8.61)	-3.2664 (-0.87)	-6.6492* (-2.77)
I_2 gravity irrigated farm	5.3264** (-2.79)	-2.8695** (-3.10)	-0.9772 (-0.16)	-9.8525** (-3.75)
M_1I_1 fully mech. pump irrig.	14.5592** (8.28)	N.A.	-5.6594 (-1.02)	N.A.
M_1I_2 fully mech. gravity irrig.	4.4436* (2.08)	N.A.	-11.5723 (-1.72)	N.A.
M_2I_1 partially mech. pump irrig.	-8.6827* (1.92)	N.A.	-8.8825 (-0.62)	N.A.
M_2I_2 partially mech. gravity irrig.	7.3230 (1.70)	N.A.	-12.2351 (-0.90)	N.A.
R^2	0.612	0.517	0.081	0.070
Adjusted R^2	0.600	0.509	0.053	0.054
F	51.07	63.26	2.86	4.44
N	301	301	301	301

N.A. = not applicable.

Model 1 is the unconstrained model with interaction terms.

Model 2 is the constrained model without interaction terms.

Figures in parentheses are t-statistics to test the significance of individual coefficients.

* significant at 5% level.
** significant at 1% level.

Table A9. Differences in total labor use and hired labor expenses in Central Luzon, Philippines, 1980 Wet Season.

Independent variables	Dependent variables			
	Total labor use (mandays/hectare)		Hired labor expenses (pesos/hectare)	
	Model 1	Model 2	Model 1	Model 2
Intercept	112.9721** (25.81)	114.6311** (27.50)	403.2292** (9.77)	389.0290** (9.96)
Farm size	-5.1815** (-3.54)	-7.3765** (-5.99)	16.4371 (1.20)	23.1277* (2.02)
M_1 fully mech. farm	-14.1445** (-3.19)	-8.5543* (-2.71)	201.5931** (4.85)	191.5396** (6.51)
M_2 partially mech. farm	-15.6197 (-0.95)	-2.3783 (-0.36)	-66.6145 (-0.43)	188.5373** (3.08)
I_1 pump irrigated farm	-12.0560* (-2.22)	-1.4011 (-0.40)	190.2750** (-3.73)	-184.1540** (-5.62)
I_2 gravity irrigated farm	5.9778 (-0.69)	-14.4888** (-3.76)	248.9090** (3.05)	224.8042** (6.27)
M_1I_1 fully mech. pump irrig.	20.9949* (2.62)	N.A.	-23.9195 (-0.32)	N.A.
M_1I_2 fully mech. gravity irrig.	-8.6667 (-0.89)	N.A.	-33.7385 (-0.37)	N.A.
M_2I_1 partially mech. pump irrig.	19.6078 (0.95)	N.A.	461.3475* (2.39)	N.A.
M_2I_2 partially mech. gravity irrig.	4.3706 (0.22)	N.A.	207.2679 (1.13)	N.A.
R^2	0.204	0.177	0.424	0.411
Adjusted R^2	0.179	0.163	0.406	0.401
F	8.29	12.70	23.83	41.20
N	301	301	301	301

N.A. = not applicable.

Model 1 is the unconstrained model with interaction terms.

Model 2 is the constrained model without interaction terms.

Figures in parentheses are t-statistics to test the significance of individual coefficients.

* significant at 5% level.

** significant at 1% level.

Table A10. Differences in level of fertilizer use and other cash expenses in Central Luzon, Philippines, 1980 Wet Season.

Independent variables	Dependent variables			
	Level of fertilizer use (kgs/hectare)		Other cash expenses (pesos/hectare)	
	Model 1	Model 2	Model 1	Model 2
Intercept	56.0247** (5.55)	62.2712** (6.27)	192.8001** (6.89)	207.4460** (7.39)
Farm size	-0.2169 (-0.06)	7.2346* (2.45)	21.5780* (2.31)	48.4462** (5.86)
M_1 fully mech. farm	61.3111** (5.94)	22.8380** (3.01)	241.4312** (8.54)	112.1768** (5.29)
M_2 partially mech. farm	5.6347 (-0.15)	20.8534 (1.32)	37.5322 (0.36)	26.9941 (0.61)
I_1 pump irrigated farm	23.7573 (1.88)	21.2362** (-2.52)	110.6377** (3.19)	-56.9323* (-2.41)
I_2 gravity irrigated farm	51.0936* (2.52)	0.1340 (0.01)	247.0798** (4.45)	129.9540** (5.03)
M_1I_1 fully mech. pump irrig.	-86.0166** (-4.60)	N.A.	-317.5314** (-6.21)	N.A.
M_1I_2 fully mech. gravity irrig.	-77.6712** (-3.43)	N.A.	-192.3481** (-3.10)	N.A.
M_2I_1 partially mech. pump irrig.	-0.6921 (-0.01)	N.A.	-136.9150 (-1.04)	N.A.
M_2I_2 partially mech. gravity irrig.	6.8033 (0.15)	N.A.	-34.5523 (-0.28)	N.A.
R^2	0.174	0.091	0.401	0.313
Adjusted R^2	0.148	0.075	0.382	0.301
F	6.80	5.89	21.64	26.90
N	301	301	301	301

N.A. = not applicable.

Model 1 is the unconstrained model with interaction terms.

Model 2 is the constrained model without interaction terms.

Figures in parentheses are t-statistics to test the significance of individual coefficients.

* significant at 5% level.
** significant at 1% level.

Table A11. Mechanization and land productivity in Central Luzon, Philippines, 1979/80 Wet Season.

Explanatory variables	Yield (kg/ha)	
	Model 1	Model 2
Intercept	4.0096** (13.60)	3.5619** (13.60)
Fully mechanized dummy (M_1)	0.2494 (1.00)	0.2308** (2.63)
Partially mechanized dummy (M_2)	-0.0790 (-0.87)	0.1762** (3.78)
Level of fertilizer use (F_t)	0.2248** (7.44)	0.1924** (6.70)
Total labor use (L_t)	0.3317** (5.23)	0.3764** (6.14)
Other cash expenses (C_t)	0.2529** (5.10)	0.2851** (6.00)
Farm size (A_t)	0.0652* (2.76)	0.0615* (2.59)
Pump irrigation dummy (I_1)	0.0207 (0.23)	0.2555** (4.77)
Gravity irrigation dummy (I_2)	0.1698 (0.93)	0.3804** (5.44)
Fully mechanized pump irrigated (M_1*I_1)	0.0000 (.)	N.A.
Fully mechanized gravity irrigated (M_1*I_2)	-0.0199 (-0.06)	N.A.
Partially mechanized pump irrigated (M_2*I_1)	0.3659** (3.22)	N.A.
Partially mechanized gravity irrigated (M_2*I_2)	0.2847 (1.49)	N.A.
R^2	0.659	0.645
F	49.40	64.56
N	293	293

N.A. = not applicable.

Model 1 is the unconstrained model with interaction terms.
Model 2 is the constrained model without interaction terms.
Figures in parentheses are t-statistics to test the significance of individual coefficients.

* significant at 5% level.
** significant at 1% level.

Table A12. Mechanization and land productivity in Central Luzon, Philippines, 1980 Dry Season.

Explanatory variables	Yield (kg/ha) Model 1	Model 2
Intercept	5.1284**	5.2262**
	(11.54)	(11.81)
Fully mechanized dummy (M_1)	-0.6419*	-0.1226
	(-2.43)	(-1.26)
Partially mechanized dummy (M_2)	0.0587	-0.0095
	(0.36)	(-0.14)
Level of fertilizer use (F_t)	0.2318**	0.2613**
	(4.85)	(5.41)
Total labor use (L_t)	0.2452**	0.1824*
	(3.01)	(2.23)
Other cash expenses (C_t)	0.1027	0.1175*
	(1.82)	(2.03)
Farm size (A_t)	-0.0546	-0.0535
	(-1.13)	(-1.09)
Pump irrigation dummy (I_1)	0.2990	0.2201**
	(1.93)	(2.89)
Gravity irrigation dummy (I_2)	0.3101	0.6245**
	(1.53)	(6.45)
Fully mechanized pump irrigated (M_1*I_1)	0.0000	N.A.
	(.)	
Fully mechanized gravity irrigated (M_1*I_2)	0.9308**	N.A.
	(3.00)	
Partially mechanized pump irrigated (M_2*I_1)	-0.1590	N.A.
	(-0.90)	
Partially mechanized gravity irrigated (M_2*I_2)	0.3075	N.A.
	(1.39)	
R^2	0.590	0.559
F	25.09	30.87
N	204	204

N.A. = not applicable.

Model 1 is the unconstrained model with interaction terms.
Model 2 is the constrained model without interaction terms.
Figures in parentheses are t-statistics to test the significance of individual coefficients.

* significant at 5% level.
** significant at 1% level.

Table A13. Mechanization and land productivity in Central Luzon, Philippines, 1980 Wet Season.

Explanatory variables	Yield (kg/ha) Model 1	Model 2
Intercept	5.7463**	5.7698**
	(17.97)	(18.16)
Fully mechanized dummy (M_1)	0.1015	0.1764**
	(1.56)	(4.18)
Partially mechanized dummy (M_2)	0.1988	0.1928*
	(0.96)	(2.40)
Level of fertilizer use (F_t)	0.0756*	0.0653*
	(2.53)	(2.24)
Total labor use (L_t)	0.0810	0.1067
	(1.17)	(1.59)
Other cash expenses (C_t)	0.24856**	0.2277**
	(5.90)	(5.67)
Farm size (A_t)	-0.0846*	-0.1097**
	(-2.40)	(-3.56)
Pump irrigation dummy (I_1)	-0.0752	0.0164
	(-1.09)	(0.38)
Gravity irrigation dummy (I_2)	0.0125	0.0114
	(0.11)	(0.22)
Fully mechanized pump irrigated (M_1*I_1)	0.1926	N.A.
	(1.70)	
Fully mechanized gravity irrigated (M_1*I_2)	0.0153	N.A.
	(0.12)	
Partially mechanized pump irrigated (M_2*I_1)	0.0943	N.A.
	(0.37)	
Partially mechanized gravity irrigated (M_2*I_2)	-0.0859	N.A.
	(-0.35)	
R^2	35.2	0.344
F	12.9	18.21
N	287	287

N.A. = not applicable.

Model 1 is the unconstrained model with interaction terms.
Model 2 is the constrained model without interaction terms.
Figures in parentheses are t-statistics to test the significance of individual coefficients.

* significant at 5% level.
** significant at 1% level.

Table A14. Selected input requirements for rice production in Central Luzon, Philippines, 1979/80 wet season

INPUTS	Fully mechanized farms	Partially mechanized farms	Nonmechanized farms
	Quantity per hectare	Quantity per hectare	Quantity per hectare
Seeds	111.491 kg	105.308 kg	89.843 kg
Machinery:			
embodied and manufacture	2360.000 kg	200.000 kg	0.000 kg
repair and maintenance			
gasoline fuel	0.000 l	0.000 l	0.000 l
diesel fuel	4.259 l	1.503 l	0.000 l
oil	0.227 l	1.218 l	0.000 l
Land preparation	49.390 mh	79.948 mh	146.009 mh
Weeding	2.097 mh	11.490 mh	17.654 mh
Total other preharvest tasks	262.471 mh	255.613 mh	323.331 mh
Seedbed preparation	3.531 mh	7.949 mh	10.317 mh
Clearing	0.190 mh	2.079 mh	1.476 mh
Digging	0.000 mh	0.016 mh	0.000 mh
Plowing	26.720 mh	41.200 mh	96.311 mh
Cultivating	2.097 mh	11.490 mh	17.658 mh
Hoeing	0.000 mh	0.000 mh	0.003 mh
Planting	206.123 mh	172.223 mh	176.455 mh
Fertilizer application	8.564 mh	7.781 mh	6.237 mh
Pesticides application	15.027 mh	11.349 mh	9.984 mh
Irrigating	0.220 mh	1.526 mh	4.893 mh
Total post production tasks:	225.800 mh	264.847 mh	287.586 mh
Harvesting	213.598 mh	246.612 mh	264.335 mh
Cutting	0.000 mh	4.280 mh	6.874 mh
Threshing	5.187 mh	4.223 mh	8.230 mh
Sorting	0.000 mh	0.000 mh	0.030 mh
Other activities	7.015 mh	9.731 mh	8.148 mh
Nitrogen fertilizer	51.376 kg	43.807 kg	30.880 kg
Phosphate fertilizer	15.778 kg	17.988 kg	12.438 kg
Potassium fertilizer	13.985 kg	7.775 kg	6.019 kg
Calcium fertilizer	0.000 kg	0.000 kg	0.000 kg
Chemicals:			
Insecticides(carbofuran)	0.750 kg a.i	0.750 kg a.i	0.750 kg a.i
Herbicides (2,4-D)	0.700 kg a.i	0.700 kg a.i	0.700 kg a.i
Total animal hours:	0.056 ahr	43.236 ahr	118.398 ahr
Animal hrs soil preparation	0.000 ahr	41.464 ahr	115.932 ahr
Animal hrs cultivating	0.000 ahr	0.000 ahr	0.000 ahr
Animal hrs harvesting	0.000 ahr	0.137 ahr	0.389 ahr
Animal hrs other activities	0.056 ahr	1.634 ahr	2.077 ahr
Total tractor hours:	33.343 thrs	13.334 thrs	0.000 thrs
Tractor hrs soil preparation	33.053 thrs	13.275 thrs	0.000 thrs
Tractor hrs cultivating	0.000 thrs	0.029 thrs	0.000 thrs
Tractor hrs harvesting	0.048 thrs	0.000 thrs	0.000 thrs
Tractor hrs other activities	0.242 thrs	0.031 thrs	0.000 thrs
Irrigation	15.000 cm	15.000 cm	15.000 cm
Total labor hours	539.757 mh	611.898 mh	774.581 mh
Paddy output	3897.689 kg	3166.259 kg	2175.743 kg
Rice output	2689.405 kg	2184.719 kg	1501.262 kg

mh = man-hours; ahr = animal hours; thrs = tractor hours.

Table A15. Selected input requirements for rice production in Central Luzon, Philippines, 1980 dry season

INPUTS	Fully mechanized farms	Partially mechanized farms	Nonmechanized farms
	Quantity per hectare	Quantity per hectare	Quantity per hectare
Seeds	119.670 kg	122.711 kg	81.281 kg
Machinery:			
embodied and manufacture	2360.000 kg	200.000 kg	0.000 kg
repair and maintenance			
gasoline fuel	1.429 l	0.000 l	0.000 l
diesel fuel	0.000 l	1.432 l	0.000 l
oil	1.956 l	1.566 l	0.000 l
Land preparation	52.863 mh	85.107 mh	216.316 mh
Weeding	0.998 mh	1.107 mh	5.193 mh
Total other preharvest tasks	231.099 mh	281.453 mh	475.955 mh
Seedbed preparation	3.196 mh	9.928 mh	19.910 mh
Clearing	0.000 mh	0.993 mh	0.804 mh
Digging	0.000 mh	0.030 mh	0.000 mh
Plowing	22.992 mh	42.546 mh	146.313 mh
Cultivating	1.037 mh	1.124 mh	5.190 mh
Hoeing	0.000 mh	0.000 mh	0.000 mh
Planting	175.197 mh	192.053 mh	249.025 mh
Fertilizer application	11.933 mh	10.874 mh	11.333 mh
Pesticides application	16.676 mh	15.305 mh	18.304 mh
Irrigating	0.068 mh	8.633 mh	25.077 mh
Total post production tasks:	198.717 mh	251.927 mh	325.365 mh
Harvesting	185.464 mh	236.572 mh	315.177 mh
Cutting	0.388 mh	1.752 mh	0.000 mh
Threshing	3.175 mh	3.790 mh	4.428 mh
Sorting	0.000 mh	0.000 mh	0.000 mh
Other activities	9.691 mh	9.813 mh	5.760 mh
Nitrogen fertilizer	86.858 kg	87.702 kg	61.958 kg
Phosphate fertilizer	22.298 kg	19.286 kg	18.898 kg
Potassium fertilizer	9.963 kg	6.808 kg	7.325 kg
Calcium fertilizer	0.000 kg	0.000 kg	0.000 kg
Chemicals:			
Insecticides(carbofuran)	0.750 kg a.i	0.750 kg a.i	0.750 kg a.i
Herbicides (2,4-D)	0.700 kg a.i	0.700 kg a.i	0.700 kg a.i
Total animal hours:	0.376 ahr	48.062 ahr	179.742 ahr
Animal hrs soil preparation	0.000 ahr	45.935 ahr	175.340 ahr
Animal hrs cultivating	0.000 ahr	0.030 ahr	0.000 ahr
Animal hrs harvesting	0.000 ahr	0.158 ahr	0.857 ahr
Animal hrs other activities	0.376 ahr	1.969 ahr	3.545 ahr
Total tractor hours:	34.268 thrs	15.638 thrs	0.118 thrs
Tractor hrs soil preparation	34.116 thrs	15.495 thrs	0.118 thrs
Tractor hrs cultivating	0.000 thrs	0.000 thrs	0.000 thrs
Tractor hrs harvesting	0.013 thrs	0.000	0.000 thrs
Tractor hrs other activities	0.139 thrs	0.143 thrs	0.000 thrs
Irrigation	30.000 cm	30.000 cm	30.000 cm
Total labor hours	483.678 mh	619.595 mh	1022.826 mh
Paddy output	4876.878 kg	4187.472 kg	3438.312 kg
Rice output	3365.046 kg	2889.355 kg	2372.435 kg

mh = man-hours; ahr = animal hours; thrs = tractor hours.

Table A16. Selected input requirements for rice production in Central Luzon, Philippines, 1980 wet season

INPUTS	Fully mechanized farms	Partially mech farms	Nonmechanized farms
	Quantity per hectare	Quantity per hectare	Quantity per hectare
Seeds	126.154 kg	133.856 kg	117.401 kg
Machinery:			
embodied and manufacture	2360.000 kg	200.000 kg	0.000 kg
repair and maintenance			
gasoline fuel	0.000 l	0.000 l	0.000 l
diesel fuel	1.027 l	4.149 l	0.000 l
oil	0.045 l	5.640 l	0.000 l
Land preparation	76.079 mh	108.916 mh	147.825 mh
Weeding	6.494 mh	6.692 mh	16.247 mh
Total other preharvest tasks	248.899 mh	286.156 mh	317.251 mh
Seedbed preparation	7.182 mh	9.824 mh	11.185 mh
Clearing	0.969 mh	0.471 mh	1.778 mh
Digging	0.000 mh	0.000 mh	0.000 mh
Plowing	28.323 mh	57.273 mh	92.729 mh
Cultivating	6.787 mh	6.692 mh	16.269 mh
Hoeing	0.000 mh	0.000 mh	0.000 mh
Planting	178.527 mh	182.712 mh	174.428 mh
Fertilizer application	9.237 mh	9.815 mh	7.024 mh
Pesticides application	17.505 mh	17.406 mh	12.975 mh
Irrigating	0.369 mh	1.963 mh	0.864 mh
Total post production tasks:	278.575 mh	305.343 mh	282.874 mh
Harvesting	229.565 mh	260.255 mh	250.455 mh
Cutting	38.018 mh	34.497 mh	24.352 mh
Threshing	0.589 mh	0.044 mh	1.208 mh
Sorting	0.000 mh	0.000 mh	0.000 mh
Other activities	10.402 mh	10.546 mh	6.859 mh
Nitrogen fertilizer	64.253 kg	75.296 kg	86.218 kg
Phosphate fertilizer	18.694 kg	28.984 kg	36.447 kg
Potassium fertilizer	14.668 kg	13.277 kg	15.447 kg
Calcium fertilizer	0.000 kg	0.000 kg	0.000 kg
Chemicals:			
Insecticides(carbofuran)	0.750 kg a.i	0.750 kg a.i	0.750 kg a.i
Herbicides (2,4-D)	0.700 kg a.i	0.700 kg a.i	0.700 kg a.i
Total animal hours:	20.390 ahr	60.368 ahr	122.990 ahr
Animal hrs soil preparation	19.192 ahr	59.262 ahr	117.317 ahr
Animal hrs cultivating	0.000 ahr	0.000 ahr	0.000 ahr
Animal hrs harvesting	0.188 ahr	0.078 ahr	2.487 ahr
Animal hrs other activities	1.010 ahr	1.028 ahr	3.185 ahr
Total tractor hours:	24.158 thrs	13.541 thrs	1.268 thrs
Tractor hrs soil preparation	24.090 thrs	13.423 thrs	1.259 thrs
Tractor hrs cultivating	0.000 thrs	0.000 thrs	0.000 thrs
Tractor hrs harvesting	0.022 thrs	0.118 thrs	0.000 thrs
Tractor hrs other activities	0.046 thrs	0.000 thrs	0.009 thrs
Irrigation	15.000 cm	15.000 cm	15.000 cm
Total labor hours	610.047 mh	707.106 mh	764.197 mh
Paddy output	3127.919 kg	3048.730 kg	2380.672 kg
Rice output	2158.264 kg	2103.624 kg	1642.663 kg

mh = man-hours; ahr = animal hours; thrs = tractor hours.

APPENDIX A

Constants and Calculations

Item		References
1. Weight of Machinery:		
4 wheel tractor	= 2360 kg	Massey Ferguson Agricultural Machinery (1973).
2 wheel tractor (power tiller)	= 200 kg	IRRI specifications.
2. Energy value of inputs and outputs (megajoules - MJ):		
Seed	= 12.36/kg	Faidley (1977), Leach (1976) and Rutger and Grant (1980)
Machinery	= 85.00/kg	Smil, et al (1983).
Gasoline	= 34.475/l	Smil, et al (1983).
Diesel	= 47.80/l	Gupta, et al (1980).
Lubricating oil	= 40.10/l	Baumiester (1958).
Fertilizers:		
Nitrogen	= 61.00/kgN	Smil, et al (1983).
Phosphate (P_2O_5)	= 13.00/kgP	Smil, et al (1983).
Potassium (K_2O)	= 7.00/kgK	Smil, et al (1983).
Calcium (CaO)	= 10.08/kgCa	Rutger and Grant (1980).
Insecticide -		
carbofuran	= 405.5/kg a.i.	Rutger and Grant (1980), Faidley (1977), Green (1978).
Herbicides (2,4-D)	= 110.00/kga.i.	Rutger and Grant (1980), Green (1978).

Energy in paddy	= 12.36/kg	Rutger and Grant (1980).
Milled paddy	= 15.07/kg	Rutger and Grant (1980).

3. Human energy expenditure in farm operations by task (MJ/h):

Land preparation		
with 4wt (tillage)	= 1.0548	Stout et al (1979).
Seedbed preparation	= 0.79	Kuether and Duff (1979).
Weeding (average of		
(hand and manual rotary)	= 1.3320	Stout et al (1979).
Clearing (shrub and grass)	= 1.7820	Stout et al (1979).
Digging (tillage)	= 1.4580	Stout et al (1979).
Plowing	= 1.5444	Stout et al (1979).
Cultivating	= 1.4580	Stout et al (1979).
Hoeing (as digging)	= 1.4580	Stout et al (1979).
Planting	= 0.9288	Stout et al (1979).
Fertilizer application	= 1.72	Kuether and Duff (1979).
Pesticide application	= 1.72	Kuether and Duff (1979).
Irrigating	= 0.79	Kuether and Duff (1979).
Harvesting (mechanical)	= 1.67	Kuether and Duff (1979).
Harvesting (manual)	= 1.7064	Stout et al (1979).
Cutting (and stacking)	= 1.7064	Stout et al (1979).
Threshing (mechanical)	= 1.67	Kuether and Duff (1979).
Threshing (manual)	= 1.31688	Stout et al (1979).
Threshing (partly mech)	= 1.3824	Stout et al (1979).
Sorting	= 0.79	Author estimate.
Other mechanized activities in post-production	= 1.31688	Stout et al (1979).

Other manual actilies

in post- production = 1.080 Stout et al (1979).

4. Animal energy expenditure (MJ/h):

Soil preparation (tillage/

plowing/harrowing) with

water buffalo (carabao) = 1.3824 Stout et al (1979) average for two different plows.

Cultivating/harvesting/

other activities = 1.080 Stout et al (1979).

5. Human energy expenditure using tractor (MJ/h):

Soil preparation = 1.0548 Stout et al (1979).

Cultivating (similar to

soil preparation) = 1.0548 Stout et al (1979).

Harvesting = 1.69 Kuether and Duff (1979).

Other activities = 1.0548 Stout et al (1979).

6. Energy for Irrigation:

Energy for irrigation was calculated or estimated based on the formula presented by Batty et al (1974) depending on irrigation requirements, irrigation and pumping efficiencies, and the pumping head

$$PE = K (A \times D \times H)/(E_i \times E_p)$$

where

PE = pumping energy (MJ/ha)

K = conversion factor depending on the units used

A = area irrigated (ha)

D = net depth of irrigation (15cm for wet seasons and 30cm for the dry season)

H = pumping head or the sum elevation differences, operating pressure, and friction and minor losses (m)

E_i = irrigation efficiency or the percentage of the water applied that is stored in the root zone, expressed as a percentage. In the present study, E_i was assumed to be 40%.

E_p = pumping efficiency, expressed as a percentage. In this study E_p was assumed to be 60%.