THE CONSEQUENCES OF SMALL RICE FARM MECHANIZATION PROJECT

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A Simulation Model to Evaluate Mechanization of Rice Postharvest Operations in the Philippines

by

Cielito Habito and Bart Duff
AGRICULTURAL ENGINEERING DEPARTMENT
International Rice Research Institute
Los Baños, Laguna

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A SIMULATION MODEL TO EVALUATE MECHANIZATION OF RICE POSTHARVEST OPERATIONS IN THE PHILIPPINES

by

Cielito F. Habito and Bart Duff*

Abstract

This paper describes a simulation model that has been formulated to study the farm-level post-production system for rice, consisting of harvesting, threshing-cleaning, and grain drying. The bulk of the work has been in deriving the various interrelationships among factors within the system, which are in the nature of agronomic and agricultural engineering relationships. Having formulated and validated the model, it has been used to compare the patterns of net returns that a rice farmer could earn using two alternative technological systems in performing the post-production processes. The model is expected to be useful in exploring other interesting questions regarding the rice post-production system.

*Instructor, University of the Philippines at Los Baños and Associate Agricultural Economist, International Rice Research Institute, respectively.

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INTRODUCTION

The mechanization issue has moved into the post-harvest phase of rice production with the recent emergence of small paddy threshers and mechanical dryers in the Philippine rice industry. Unlike the case of land preparation, the surplus labor argument appears not to hold in this situation due to the seasonal peaks in labor demand which tend to accompany the harvest seasons. In fact, indications are that labor shortages at such times make mechanization of threshing operations both desirable and economically justified.[1]

Mechanization of rice post-production[2] operations is claimed to offer three major advantages: (a) reduction of physical grain losses, (b) improvement of grain quality, and (c) reduction of risk and uncertainty for the rice farmer. Recent machine developments at research institutions like the International Rice Research Institute (IRRI) and the University of the Philippines at Los Baños (UPLB) have been directed specifically at reducing quantitative and qualitative grain losses. Major scope for loss reduction lies in the grain drying operation, where delays due to unfavorable weather can result in biological and microbial deterioration of the paddy. The use of mechanical dryers help prevent such losses because they eliminate the dependence of the drying operation on the weather. Moreover, research has shown that significant improvement in milling quality could be achieved through more closely controlled drying conditions made possible by mechanical grain dryers. Such increased control over the postharvest system reduces risk and uncertainty for the farmer, particularly during the wet season crop in double-cropped areas.

However, employing mechanized postharvest techniques involves a significant increase in cash costs over the traditionally-employed methods. IRRI reports indicate that the labor savings from the use of mechanical dryers are insufficient to compensate for the corresponding increase in cash costs.[3] Hence, a straightforward accounting of costs and returns may dismiss mechanized drying techniques as uneconomical and therefore not suitable for Philippine rice farms.[4] But such a conclusion is readily reached in an analysis that fails to consider the advantages of mechanized techniques described above. Since the reduction of quantitative and qualitative losses as well as of risk and uncertainty represent real economic benefits to the farmer, an evaluation of alternative techniques explicitly considering these factors would be considerably more enlightening. Assessing this apparent trade-off between increased costs and the above-named advantages of mechanization would provide a more complete and meaningful evaluation of the advisability (or inadvisability) of mechanizing the rice postharvest tasks.

To investigate the nature of this tradeoff, a stochastic computer simulation model of the rice post-production system has been constructed. Simulating the post-harvest system[5] is useful in several ways: (a) uncertainties in the system (particularly the effect of the weather) can be accounted for as fully as possible, (b) interdependencies among processes within the system can be explicitly considered, (c) a comparison of mechanized versus non-mechanized techniques can be made to cover wide variation in circumstances that affect the system (e.g. weather patterns, labor availability), (d) as a result of (c), the variability in the outcomes of the alternative techniques can be determined and included in the choice decision, along with the mean outcomes, and (e) the simulation model lends itself to the study of other problems concerning the postharvest system.[6] A farm level model has been constructed, representing the field post-production processes (harvesting, threshing, and drying) of a typical small rice farm in the Southern Luzon region of the Philippines. Use of traditional and mechanized techniques are alternatively provided in the model, making it possible to compare the respective distribution patterns of costs and returns over a range of possible circumstances. It is hypothesized that there will be differences in the average net returns (after considering grain losses) as well as their variability, between the mechanized and non-mechanized system. It is expected that these differences will affect the relative desirability of each technological system to the rice farmer, and to society as a whole.

NATURE OF THE MODEL

The model simulates the farm post-production operations of a hypothetical 1.5 hectare rice farm consisting of 15 plots of varying sizes. Two basic technological systems are modelled: (a) the traditional system, employing manual harvesting, threshing and cleaning, and solar drying; and (b) the mechanized system, employing manual harvesting, threshing with the IRRI-designed axial-flow thresher, and drying with a twin-bed 2-ton batch dryer. Mechanized harvesting has not been included in the model due to the unavailability of data; however, this is not regarded as a serious shortcoming because the predominance of small farms in the Philippine rice industry makes it unlikely that mechanized harvesting will be of any significant importance in the foreseeable future. Intermediate combinations can also be modelled to compare, for example, systems both using mechanical threhsers but differing only in the drying method employed. There is no reason why mechanization in the rice postharvest processes has to be an "all-or-nothing" decision. It is entirely possible that a system mechanized only in the threshing phase could prove more advisable than either a purely traditional or purely mechanized system. This possiblity can be investigated using the same model framework.

In Southern Luzon, the field harvesting operations (harvesting, threshing and cleaning) are normally carried out under a special arrangement between laborers and farmer known as the gama arrangement.[7] Here, a group of laborers obtain the exclusive right to harvest and thresh the yield of a specific plot, usually agreeing to weed the plot during the crop's growing stage. As payment, the laborers receive a share of the plot's output, ranging from one-eight to one-sixth. Where a mechanical thresher is rented to perform the threshing task, a rental fee of one ganta (slightly over two kilos) is paid for every cavan (approximately 45 kilos) of paddy threshed, before the yield is partitioned. Here, the share of the laborers is normally reduced (from 1/6 to 1/7 in most cases).[8]

Sources of Data

The main sources of data for the model were the results of the field-level trials conducted by the IRRI Agricultural Engineering Department in Central Luzon in 1976 and in the Bicol region in 1977. These field trials were designed to evaluate the performance of the IRRI axial-flow thresher and the IRRI twin-bed batch dryer under actual farm conditions, in comparison with traditional farm post-production methods. Complete data on labor requirements, fuel consumption, time spent on each operation, moisture content at each stage, grain losses and paddy analyses were collected. Summary results of these trials are reported in Toquero et al. (1977) and IRRI Agricultural Engineering Department (1978). Other components of the model have been formulated on the basis of information generated in other published studies, which are referred to in the relevant portions of the text. Weather data have been obtained from the UPLB Weather Station.

Weather Generation

Historical weather data have been used directly in generating weather patterns for the model. Daily observations for rainfall, solar radiation and minimum/maximum temperatures were obtained for the years 1961-1978. This has permitted iteration of the model 36 times, given two cropping seasons per year. The dry harvesting season takes place in March-April and the wet harvesting season, in September-October. For the initial runs of the model, it has been assumed that planting has been timed such that the exact maturity date of the crop (and therefore the intended start of harvesting) falls on April 2 for the dry season and October 2 for the wet season. The particular weather parameters for each day determine whether the day is a full, half or non-working day for field operations. Changes in the moisture content of the paddy while in the field are also influenced by the weather observations for each day of the harvesting season. Finally, daily weather conditions in the model determine whether solar drying is possible, and if so, the extent of drying that takes place.

The Traditional System

The model for the traditional harvesting system simulates the following components and stochastic variables:

(a) Harvesting phase
- (i) potential yields
- (ii) daily attendance of workers
- (iii) working rates
- (iv) harvest losses
- (v) moisture content

(b) Threshing/Cleaning phase
- (i) work rates
- (ii) daily attendance of workers
- (iii) threshing/cleaning losses
- (iv) grain purity

(c) Solar Drying
- (i) effect of weather on drying
- (ii) effect of weather on decision to sell
- (iii) drying labor
- (iv) drying losses
- (v) sale value of the output

The Harvesting Phase

Each plot in the model rice farm is harvested independently by a separate group of workers comprising the gama contracting team. Thus, the rate of work and time of completion of the harvesting-threshing tasks can differ among plots. Furthermore, the potential yields (per hectare) of each plot need not be equal, since slight differences in factors like plant spacing, soil quality and the like may result in interplot differences in yield levels. Hence, each plot is modelled separately all the way to solar drying. It is assumed that expectation of strong rain within the following days will cause the farmer to postpone the start of harvesting. This is usually true because he would like to avoid having to store wet paddy, which could lead to sprouting and grain damage. This situation is accounted for in the model by assuming that if total rainfall for the next three days exceeds 150 millimeters, harvesting will not be started.[9]

Potential yields. Slight differences in mean yield levels were observed between the wet and dry seasons from the IRRI data, with higher yields attained in the latter. Since the observations approximated normal distributions, potential yields for each plot were generated by sampling the appropriate normal distribution depending on the season. The mean potential yield was 4480 kilos for the dry season and 4058 kilos for the wet season, with standard deviations of 689 and 469, respectively.

Number of workers. Under the contractual labor system (gama) two or three persons usually work on a contracted plot. However, the number of workers to show up on any particular day of the harvest season could range from none to five. Cases when as many as five workers show up for a plot arise when the contracting team are joined at work by friends or family members. It is common for the contracting workers to enter similar commitments with other farms, resulting in a division of their time. Hence, there are days when nobody may show up for work on a particular plot. Based on interviews conducted among farmers in the study area, a discrete probability distribution has been derived to determine the number of workers who appear for work on a given day (Table 1). From this distribution, the number of workers on any day can be randomly generated.

Harvesting labor requirement. The IRRI data were examined for relationships between harvesting labor requirement and likely explanatory variables like plot area, crop moisture content and yield level. Only plot area exhibited a significant relationship with harvesting labor, giving the following prediction equation:[10]

$$HLR - 0.5943 + 0.0137*AREA + V$$

where HLR gives harvesting labor in manhours, AREA gives the plot area in square meters, and V is a randomly generated residual with a mean of zero and standard deviation (S_V) of 6.0. This residual term accounts for effects not explicitly included in the model.

Harvest losses. A number of studies have examined the relationship between harvesting delays and physical harvest losses.[11] Data from these studies were pooled and analyzed for a functional relationship between the two variables. The pooled data used for the regressions are shown in Table 2. Varieties were classified into low-, medium- and high-shattering varieties on the basis of the IRRI standard evaluation system. The results of separate regressions on each group revealed no significant difference between the estimated equations for the low and medium-shattering varieties. Thus, only two equations have been used, to account for low- and high-shattering varieties of rice as follows:

$$\text{High: } PHL = 2.46 + 0.026*DAYS^2 + V$$
$$\text{Low : } PHL = 1.05 + 0.004*DAYS^2 + V$$

where PHL gives the total harvesting losses as a percentage of potential yield, DAYS gives the number of days from physiological maturity of the crop plus 16, and V is a random residual where S_V = 5.9 for high-shattering and 0.95 for low-shattering varieties. Thus, each day's delay in harvesting arising fron unfavorable weather or absence of workers results in increased loss rates.

Moisture content model. A moisture content model has been constructed to simulate changes in the moisture content of the crop while it remains in the field. The behavior of moisture content depends on the minimum and maximum temperatures for a given day and the rainfall. The model has been based largely on work by Chang et al. (1978) on natural air drying of grain crops. The model assumes a starting point of 28 percent (wet basis) at the exact date of maturity, which changes over the succeeding periods for as long as the paddy is in the field. Thus, it has been possible to determine the moisture content of the paddy at each stage of the postharvest system.

Overtime and undertime work. Whenever the extra time needed to complete harvesting in a given day does not exceed one hour, provision for overtime work is made. Otherwise, work is assumed to stop when the working time available (eight hours for a full working day, four hours for a half day) has elapsed. On the other hand, if harvesting is completed before the end of the day and less than one working hour remains, threshing is not assumed to start until the next working day. Sunday is treated like any other day, as is normally the case during the harvest seasons.

The Threshing/Cleaning Phase

The number of workers who report for work on a given day for a plot is determined in the same manner as in harvesting, that is, by randomly sampling the distribution given in Table 1. Overtime work is also provided for in the same manner as in harvesting. In addition, it is assumed that threshers work overtime to complete the task if the next few days are expected to be rainy, i.e. noted rain for the next three days exceeds 150 millimeters.

Labor requirement. The IRRI data were examined for relationships between threshing/cleaning labor and likely explanatory variables like potential plot output, potential yield per hectare (as a proxy for grain-straw ratio) and moisture content at threshing. The last variable did not exhibit any significant relationship with threshing/cleaning labor. The prediction equation used for the model is:

$$TLR = 5.0038 + 0.0331*PYK - 0.0015*PY + V$$

where TLR is threshing/cleaning labor in manhours, PYK is the potential output of the plot in kilos, PY is the potential yield per hectare in kilos, and V is a random residual with $S_V = 4.6$. The random residual accounts for variability in labor requirement due to unmeasured factors like variable wind conditions during grain winnowing (this affects time required to carry out the task rather than effort).

Threshing losses and grain purity. Possible explanatory variables tested for threshing losses were threshing moisture content and yield per hectare.

Only moisture content showed a significant effect on threshing losses, with the following regression equation:

$$PTL = 1.032*TMC - 0.0206*TMC^2 - 10.84 + V$$

where PTL is the unthreshed loss as a percentage of potential yield, TMC is the moisture content at threshing and V is a random residual with $S_V = 0.9$. An additional 2.5 percent is added to PTL to cover spillage losses and occacional losses to dishonest workers.[12] The purity of the threshed grain is determined from the equation:

$$PTY = 103.38 - .26*TMC$$

which shows that the efficiency of the cleaning operation is largely affected by the grain moisture content.

Solar Drying and Sale of Paddy

Solar drying is assumed to commence immediately after threshing/cleaning if these tasks are completed no later than 3:00 p.m.; otherwise it is assumed that the paddy is bagged and stored until the next available drying day. Under the gama system, the farmer retains only 5/6 of the actual threshing yield of the plot; therefore, this is the amount that he dries at his own charge. However, the model has been programmed such that two alternative situations can be accounted for: one, where the gama system applies, and the other, where all labor is paid a fixed wage of ₱2.00 per manhour and the farmer gets to keep his entire produce.

A solar drying model has been constructed on the basis of work done by Chancellor (1965). The drying rate is a function of solar radiation and minimum/maximum daily temperatures, and the amount of drying that takes place in each hour of a drying day is determined from these weather readings. In the model, a drying day is defined as one wherein there are more than three hours in which actual drying is made possible by the weather.

To determine the total labor requirement for drying, it is assumed that it takes four manhours to load and unload 20 cavans (about 900 kilos) of paddy for each drying day, and five man-minutes to stir it every hour. A fixed one percent handling loss is allowed for in the drying operation. The value of the output is determined on the basis of the standard pricing scheme adopted by the National Grains Authority procurement stations; here, the price depends only on the purity and moisture content of the paddy (Table 3 explains the pricing scheme). The highest price paid is ₱1.30 per kilo, for grain of 14 percent moisture content and at least 95 percent purity.

It is assumed that if two non-drying days are encountered while the paddy has not been dried down to 14 percent, the paddy is sold by the farmer in order to minimize his losses. In this case, the price paid for the paddy is further discounted to cover the risks assumed by the buyer; this discount rate in the model has been set at 90 percent.[13] Deducting all the expenses in the post-production system gives the net returns for the season.[14] Two figures for net returns are output by the model in one iteration: (a) a net return based on the gama system, where it is given by the gross revenue from sale of the farmer's share of the output (5/6) minus the drying labor cost, and (b) a net return based on a fixed wage system where it is given by the gross revenue from sale of the entire output minus total labor costs. Capital costs have been assumed negligible in the traditional system.

The Mechanized System

As mentioned earlier, the model for the mechanized system also involves manual harvesting. In other words, the mechanized system is mechanized only in the threshing/cleaning and drying operations. The following conditions hold for the model of the mechanized system:

(a) No threshing takes place until all plots have been harvested. Thus, threshing commences on the day after all plots have been harvested (if weather permits).

(b) Threshing is carried out continuously, one plot after another.

(c) Drying is carried out regardless of weather conditions, commencing as soon as enough threshed paddy for a two-ton batch is accumulated.

Threshing/Cleaning

The mechanical thresher serves each plot on the farm consecutively. Fifteen minutes are assumed to be required for moving and setting up the thresher before a new plot can be threshed, following completion of the preceding plot.[15] Analysis of the IRRI field trials data have led to the following prediction equations for gasoline consumption, machine threshing time and labor requirement:

$$TGAS = 0.0031*PYK - 0.0003*PY + 0.0642*TMC - 0.2227 + V$$

$$TMIN = 6.2144*+ 0.0761*PYK - 0.0063*PY + 0.9457*TMC + V$$

$$TLR = 1.88 + 0.008*PYK - 0.0006*PY + V$$

where TGAS gives the amount of gasoline consumed in liters, TMIN gives the machine threshing time in minutes, TLR gives the threshing labor requirement in manhours, PYK gives the plot's output in kilos, PY gives the potential yield per hectare in kilos (as a proxy for grain-straw ratio), and TMC is the moisture content at threshing. The standard deviations for the random residual V are 0.8, 17.0 and 1.7, respectively.

Threshing losses are determined with the following equation:

$$PTL = 1.1876*TMC - 0.0234*TMC^2 - 13.3011 + V$$

where PTL gives the unthreshed loss as a percentage of potential yield, TMC gives the moisture content at threshing, and V is a random residual with $S_V = 1.0$. An additional 0.5 percent is added to PTL to cover spillage losses.[16] Paddy purity is again determined mainly by the threshing moisture content of the grain, through the following equation:

$$PTY = 102.41 - 0.2594*TMC$$

Both threshing and cleaning are carried out by the axial-flow thresher. Under the gama system, 5 percent is deducted from the plot's output as threshing fee, after which the yield is partitioned between farmer and laborers. The latter are assumed to be paid one-seventh of the yield in this case. As in the model of the traditional system, an alternative situation is also accounted for wherein all labor is paid a fixed wage rate and the farmer is assumed to own the thresher. In this case, the capital costs involved are also determined for purposes of computing net returns later.

Mechanical Drying

In each of the two situations (with or without yield sharing with the harvesting/threshing workers), the paddy output is assumed to be dried in batches of 2000 kilos, except for the last batch which could be smaller. The drying time, gasoline and kerosene consumption, and drying labor requirement are determined for each batch, using the following prediction equations:

$$DT = 0.2626*WCD + 0.0024*DW - 0.4551 + V$$

$$DG = 0.2171*WCD + 0.003*DW - 1.22 + V$$

$$DK = 0.6306*WCD + 0.009*DW - 4.9109 + V$$

where DT is the drying time in hours, DG and DK are the gasoline and kerosne consumption of the dryer in liters respectively, WCD gives the percentage points of moisture removed (i.e., initial moisture content minus 14), and DW gives the initial weight of the drying batch in kilos. V has a standard deviation of 0.8, 0.56 and 1.75 respectively. Labor requirement is computed based on the assumption that it takes 2.5 manhours to load and unload one ton of paddy in the dryer, and 5 man-minutes to attend to the dryer every hour. A fixed 0.5 percent handling loss is assumed for the mechanical drying operation.

Total Revenue, Total Costs and Net Returns

The value of the dried paddy output is again determined on the basis of the NGA pricing schedule based on purity and moisture content. The moisture content is always assumed to be 14 percent in this case, since it is expected that complete drying is always possible given a mechanical dryer.

Labor costs are again computed on the hasis of a ₱2.00 wage per manhour. When the gama system prevails, only drying labor comprises cash labor costs; labor costs in harvesting and threshing have already been included in the 1/7 share of the yield paid to the workers. The capital costs in threshing are also accounted for in the 5 percent threshing fee. Capital costs in drying have been computed on the basis of the assumptions given in Table 4. Hence, total non-labor drying costs are given by the equation:

$$DCC = GASLN*2.08 + DKRSN*1.43 + TIMEDR*4.086$$

where DCC gives total non-labor drying costs, GASLN gives total gasoline consumption of the dryer, DKRSN gives total kerosene consumption of the dryer, and TIMEDR gives the total number of hours that the dryer was in operation.

In the alternative situation where the farmer is assumed to own the machines and all labor is paid a fixed wage, threshing capital costs are computed based on the assumptions in Table 5. Non-labor threshing costs are then computed as

$$TCC = TGAS*2.08 + THOURS*8.67$$

Drying costs are computed as in the gama case (i.e. in both cases ownership or payment of an hourly rental of ₱4.09 is assumed).

Two figures for net returns are therefore output by the model for the mechanized system: (a) a net return based on the gama system with a rented thresher, where it is given by the gross revenue from the farmer's share of the output (6/7 x 0.95 x yield) minus total drying labor and non-labor costs; and (b) a net return based on fixed wages, where it is given by the gross revenue from sale of the entire output minus total labor and capital costs.

MODEL VALIDATION

The generated variables in the model have passed either formal or informal validation tests. The following methods were used for this purpose wherever possible:

(a) Regression of observed values against generated values

(b) The Kolmogorov-Smirnov test

(c) The t-test on the means of observed and generated values

(d) Subjective comparison with other authors' observations

The regression test entails testing the hypothesis that the intercept and slope coefficients do not differ significantly from zero and unity, respectively. This test was carried out for the labor requirements in the different operations, the fuel consumption of the thresher and the dryer, and the operating times of the machines. The test was passed satisfactorily in the case of labor requirements for the different operations (harvesting, threshing-cleaning, and drying). For the other variables, the intercept term tended to be greater than zero, although this was compensated by a corresponding downward deviation of the slope coefficient from unity. This indicates that the variables tend to be overestimated in the lower ranges and underestimated in the higher ranges. However, these effects are expected to compensate for each other because the observed deviations from the desired magnitudes of the coefficients were relatively small.

The Kolmogorov-Smirnov test[17] was used to test the hypothesis that the distribution of generated values was the same as the distribution of actual (observed) values. The generated potential yields passed the 10 percent level two-tailed test satisfactorily.

For all variables on which actual data were available for comparison (i.e. all the variables named above except for grain losses), the means of the observed and the generated values were compared using the t-test. In all instances, the hypothesis that the means of the observed and the generated values were the same was accepted at the 75 percent confidence level at the least, with most being accepted at the 90 percent level.

Finally, the average physical losses generated in the model were compared with average loss figures reported in other grain loss studies. Average total losses in the model (about 13 percent in the traditional system and 10 percent in the mechanized system) compared favorably with average loss figures accepted by agriculutral engineers.

The model is therefore considered to adequately represent the actual behavior of the rice farm post-production system. Nevertheless, it must be admitted that further refinement is both possible and desirable, especially in connection with the other possible uses for the model named below. As pointed out earlier, the singlemost important refinement to the model which could greatly increase its usefulness is the inclusion of grain quality as affected by relevant variables in the system. Most of these likely variables have already been identified and accounted for in the present form of the model, e.g. length of harvesting delays (which also affects harvesting losses), moisture content at the different field operations, length of time stalk paddy is stacked prior to threshing, and probably the most important, drying delays. However, absence of adequate studies on the joint effects of all these variables on grain quality makes it hazardous to attempt any modelling at the present time. Available studies have at most examined effects of some of these variables singly.[18] Nevertheless, final grain quality (i.e. quality after milling) would not really concern the Filipino rice farmer at the present time as his selling price is determined solely by characteristics of the unmilled paddy, particularly purity and moisture content.

RESULTS AND DISCUSSIONS

The model in its present form has been intended primarily to determine and compare the patterns of returns obtainable by the rice farmer from employing two alternative technological systems in the rice harvesting, threshing-cleaning and drying operations. This exercise was expected to reveal a significant difference between the distributions of returns obtained under the two alternative systems, given the varying circumstances over a large number of cropping seasons. In turn, such a difference, if present would be expected to influence the relative desirability of each technological system from the point of view of the farmer.

Results of two runs of the model under two wage rate assumptions are given in Tables 6 and 7. Each run consisted of 36 iterations, representing 18 years of successive dry and wet harvesting seasons.

Gross Returns. The results indicate that with mechanization, average gross revenues of the farmer would be higher by about 4.4 percent if a fixed wage is paid to the laborers, and by 3.7 percent if the gama system prevails. The difference between the set of gross revenues obtained under the alternative assumptions on labor payment simply reflects the fact that gross revenue under the wage arrangement comes from proceeds of the entire harvest, while that under the gama arrangement comes from proceeds only of the farmer's net share of the harvest (i.e. net of labor payments in kind). In either case, the mechanized system yields slightly higher gross revenues. The above result is to be expected because mechanically dried paddy would always be able to command the full undiscounted price for grain of 14 percent moisture content, whereas under the traditional system, the farmer would have to sell wet paddy for a lower price duirng 'bad seasons' (referred to as bad years, inasmuch as the unfavorable season will invariably be the wet season of a particular year anyway). However, the relatively small difference in gross revenues appears to indicate that such 'bad years' do not occur frequently enough to give mechanical drying a significant advantage. That is, even with pure reliance on solar drying, the farmer will be able to dry his paddy down to 14 percent most of the time. In fact, out of the 36 iterations run for the model, only four turned out to be bad seasons.

On the other hand, the difference in gross revenues between the two systems is likely to become more substantial if grain quality played a role in price determination. This is because mechanically dried paddy would be expected to have significantly higher quality on the average. Since the present pricing system does nothing to reward such higher quality,[19] the direct advantage of mechanization to the farmer would not be so great.

Cash Costs. The relative magnitudes of cash costs were found to be significantly affected by the wage rate. With a fixed wage arrangement, a wage rate of ₱1.50 per manhour makes the mechanized system more expensive than the traditional by about 3 percent However, with a wage rate of ₱2.00 (which more closely approximates the actual harvest season rates), the traditional system becomes costlier by about 8 percent. If the gama arrangement prevails, the total cash costs are higher for the mechanized system under both wage rates, by 187 percent and 124 percent for wages of ₱1.50 and ₱2.00, respectively. This is simply because labor payments in this arrangement do not constitute cash costs. This being the case, coupled with the fact that capital costs under the traditional system are negligible, the considerable difference in cash costs need not be of much consequence.

Net Returns. The interesting figure to the farmer would be the net returns he obtains from the postproduction operations. For the purpose of this analysis, the word 'net returns' is used loosely to refer to the difference between gross revenue and costs incurred in the postproduction operations alone. Strictly speaking, the final net returns would be derived by further subtracting all other production costs, but since these other costs could be considered independent of the postproduction system employed, they need not be taken into account in this analysis.

Simulation runs using an assumed wage rate of ₱1.50 and a fixed wage arrangement resulted in a mean net return of ₱5083.33 for the mechanized system as against ₱4856.56 for the traditional, a difference of about 4.7 percent. For both systems, net returns are similarly distributed around their means, with a standard deviation slightly over 400 and a slight positive skewness (i.e. the mode is less than the mean). If the wage rate is assumed to be ₱2.00, the mean net returns are ₱4973.02 for the mechanized system and ₱4675.42 for the traditional system, a difference of about 6.4 percent. The same observation about the shapes of the distributions holds in this case. Under the gama arrangement, the advantage of mechanization becomes even smaller. With a wage of ₱1.50, mean net returns in the mechanized system are greater by only 1.8 percent, and by 2 percent with a wage of ₱2.00. The variability of net returns for the mechanized system is somewhat smaller, with a standard deviation of 336 as against 426 for the traditional system. However, the distribution is negatively skewed for the traditional system, while positively skewed for the mechanized system. Without having to undertake formal statistical tests, it should be apparent that these mean net returns are not significantly different from each other.

Given these results, it is hardly surprising that efforts to get Filipino farmers to use mechanical grain dryers have been largely unsuccessful. As long as the present practice of basing paddy prices solely on purity and moisture content prevails, no significant advantages appear to be offered by mechanization to the farmer. Adopting a grading system that would reward higher quality could change the picture somewhat. But even here, the advantages of mechanization from the farmer's viewpoint may not be considerable. This is partly indicated by the results of the present analysis, because as it is, the model includes a penalty for failure to dry paddy promptly (in the form of a discount on the price over and above the discount on purity and grain moisture content). Since it is this situation that could lead to depressed quality in the case of solar drying, the present model already partly penalizes lower grain quality, albeit indirectly. Of course it is also claimed that in itself, the use of mechanical dryers increases grain quality due to greater control over drying conditions. Whether this would present a significant advantage to the farmer when a grading system is in effect remains to be seen, as the model fails to account for this in its present form.

OTHER APPLICATIONS OF THE MODEL

The model, both in its present and in extended form, could be used for investigating a number of other interesting problems concerning the rice postproduction system. Among these other applications are the following:

(a) Optimal timing in planting/harvesting schedules. In the present application of the model, it has been assumed that the modelled rice farm follows a rigid planting/harvesting schedule that had crop maturity falling on exactly the same dates each year (April 2 and October 2 for the dry and wet seasons, respectively). Thus, the weather and labor availability during the weeks following these dates have been major determinants of the performance of the system. It is interesting to investigate whether varying this assumed crop maturity date (and therefore the associated harvesting schedule) could lead to significant differences in the performance of each alternative technological system. If so, it may be possible to pinpoint instances wherein mechanization becomes the clear choice, the main determinant being the farmer's customary cropping timetable. Alternatively, it may be possible with this approach to determine the optimal cropping timetable (optimal in the sense of maximizing net returns from the postproduction system alone[20]) that the farmer should adopt. In this latter case, the variables become both the cropping timetable and the technology to be employed, the objective being to maximize returns from the post-production system. The results of this extended analysis would permit either

(i) prescription of either the traditional or mechanized system to a farmer with a fixed cropping timetable, or

(ii) prescription of the optimal cropping timetable for a farmer wishing to make the most out of traditional technology.

To carry out this extended analysis, one would need additional daily weather data for other parts of the year. It may also become necessary to define new probability distributions for labor availability, because the distribution described in Table 1 may no longer be applicable if the assumed schedule differs significantly from that modelled here.[21] Even more difficult would be to redefine the distribution of potential yields, which again could vary with the cropping timetable because of the effect of climate on the growing stages of the crop. But given these modifications, the basic framework for the model has been constructed and could be applied directly to this extended analysis.

(b) Effect of alternative grading systems. With the expressed intention of the NGA to implement a rice grading scheme in the near future, it would be interesting to examine how alternative schemes would affect the rice farmer. Questions one could ask include:

(i) Would farmers be led to mechanize the post-production processes under the grading scheme?

(ii) Would the grading scheme tend to raise farmers' incomes?

(iii) Would a significant improvement in grain quality be realized?

In short, experimentation with the model could show whether the grading scheme would be able to attain its objectives. The grading scheme (or alternative grading schemes) could be incorporated in the part of the model where the sale value of the farmer's output is assessed (based on the grain characteristics determined in the model). This will require extension of the model to include determination of the relevant quality characteristics of the paddy output by the system. Even more useful, if it could be done, would be a determination of the expected quality of the milled rice output of the system. Given a grading scheme, it would then be possible to fully determine whether mechanization of the post-production processes pays or not.

(c) Incorporation into a more aggregative simulation of the rice post-production system. The present work has examined and modelled some of the important relationships within the post-production system, including the effect of uncontrollable variables on moisture content, grain losses, labor requirements and others. This farm level model lays the groundwork for a model of the rice post-production system on a village level, and perhaps on a regional level. Such aggregated models would in turn be useful in investigating further issues like optimal product flows, machine ownership and operating schemes, coordination of harvesting timetables, and the like.

SUMMARY AND CONCLUSIONS

A framework for simulating the rice post-production system at the farm level has been developed to model the nature of various interrelationships in the system. The value of this exercise lies in its ability to incorporate uncertainties affecting different processes in the system, particularly weather effects and availability of labor. Grain losses are also accounted for in the analysis. With this it is then possible to examine the range of possible outcomes of the farm post-production operations as the exogenous factors vary across cropping seasons. In practical terms, such an analysis could reveal the expected patterns of income that could be realized from alternative methods of carrying out the tasks involved.

In the present analysis, two alternative technological systems were compared: a purely traditional system employing no mechanization, and a system wherein threshing and grain drying are accomplished using popular machines developed by the International Rice Research Institute. By simulating these two alternative systems for a single hypothetical farm, it has been shown that the distributions of net returns over 36 cropping seasons were such that the mechanized system showed a slight advantage over the traditional system. This advantage is in the form of higher average net returns with a lower variability. This result could be interpreted to mean that there is a slightly <u>higher probability</u> of achieving higher and more stable net returns if one mechanized the threshing-cleaning and grain drying tasks. Nevertheless, the advantage was not significant in statistical terms, indicating that there is no strong incentive for farmers to mechanize these operations. Thus, as far as rice farmers are concerned, the traditional and the mechanized systems are probably equally profitable in the long run.[22] That farmers have tended to be rather unreceptive to mechanized grain drying at the farm level appears to support this. Mechanized threshing, on the other hand, seems to have enjoyed much wider acceptance in past years.

This points to one of the limitations of the present analysis, that is, it has not examined intermediate combinations of technology such as one wherein only threshing is mechanized. However, such analysis could be carried out with little additional effort, and has been reserved for further work with the model. The present model could also be profitably used, perhaps with some further refinement, in examining other questions arising in the choice of rice post-production technology, e.g. optimal timing of production and harvesting and appropriate grading schemes. Lastly, the derivation of the fundamental technical relationships in the system (which has comprised the bulk of the present work) lays the groundwork for a more aggregated modelling procedure (at the village or regional level, perhaps), which in turn would open the way for even more interesting analyses.

NOTES

[1]A previous economic analysis has indicated that mechanization of the threshing operation is indeed economically advisable given the appropriate wage rate for the peak harvest seasons (Habito, 1977).

[2]This term has come to be used to refer to all processes from harvesting to the milling and storage of rice. "Farm-level postproduction operations" refers to the harvesting, threshing-cleaning and drying processes.

[3]The IRRI Agricultural Engineering Department has estimated the drying cost to be about $6.95 per ton (1000 kilos) of paddy when a mechanical dryer is used, compared to only $1.61 per ton with solar drying.

[4]This is particularly true for mechanized grain drying.

[5]What has been modelled covers only the harvesting, threshing-cleaning and drying phases, which are regarded as the operations which directly involve the rice farmer.

[6]Other suggested uses for the model are described later in the paper.

[7]Kikuchi et al. (1978) have described the different types of contractual arrangements that have prevailed in major rice areas of the Philippines. The gama system is most prevalent in the Southern Luzon region.

[8]For the purpose of the present analysis, this assumption has been employed. Other variations on this arrangement exist which depend on who shoulders the fuel costs.

[9]This practically involves the assumption that the farmer is able to predict correctly when the next few days would be rainy. This is not an unreasonable assumption if one considers that a storm or typhoon is usually forecast days ahead of its arrival.

[10]All prediction equations used in the model have been derived by performing a backward elimination stepwise regression procedure using all available candidate explanatory variables for the dependent variable in question. In all cases, the final equations used had significant coefficient estimates at the 10 percent level, and had a minimum multiple coefficient of determination of 50 percent.

[11]Samson and Duff (1973), Ruiz and Castelo (1965), Horiuchi et al. (1971), Cristal and Ravalo (1967), Chung et al. (1977), Chung (1978) and Sarath (1978) are among the studies that have been available to the authors. See Table 2.

[12]It is not uncommon for threshing laborers to connive with gleaners by purposely leaving much grain attached to the stalks (when manual threshing is used). By tradition, gleaners could keep all grain they can salvage from the fields.

[13]That is, the seller is paid only 90 percent of the price that would have been paid following the NGA schedule on Table 3.

[14]"Net returns" here refers only to gross sales revenue less post-production costs.

[15]Actually, 15 minutes is an average, because what actually happens is that the thresher does not need to be moved until after two adjacent plots have been worked on. The harvested stalks are usually stacked near the boundary between adjacent plots, to minimize movement of the machine. When the thresher is moved, an interval of about 30 minutes normally elapses before the machine is restarted.

[16]The available threshing loss data have only accounted for "unthreshed losses", i.e. grain remaining on the stalks.

[17]See Conover (1971) or any book on nonparametric statistics for details on this test.

[18]For example, the effect of timing of harvest on final milling quality has been examined by Umali et al. (1956), Silverio (1956), Chung et al. (1977), Nangju (1969), Seetanum (1971), Seetanum and De Datta (1973) and Chung (1978). The effect of drying delays and aeration on the quality of paddy and milled rice has been studied by Rapusas et al. (1978).

[19]It has often been observed that Filipino rice consumers have been concerned more with rice quality characteristics having to do with milling degree and variety, and less with percentage of broken grains. This is one major reason why there had been little pressure in the past to adopt a standard grading system for the domestic rice market.

[20]See section on "Net Returns" (p. 13).

[21]It must be noted that the distribution described on Table 1 is valid for the modal harvesting schedule, and therefore reflects the high demand for labor among rice farms that need to be harvested at the same time. If one deviates from this modal timetable, there is likely to be a less erratic attendance of workers for the field post-harvest tasks performed under the gama contract.

[22]If cash flow requirement is a major determinant in the far-decision, there would in fact be a clearcut advantage to the traditional system, which requires very little cash outlay compared to the mechanized system. With the availability of post-production credit, this factor may be of less importance; nevertheless, there seems to be little point in making such credit available, given the results of the present analysis.

Table 1. Discrete probability distribution for the number of workers reporting on a specific day[a]

Number of workers	Probability[b]
0	0.10
1	0.20
2	0.30
3	0.30
4	0.05
5	0.05

[a] Applies to the peak harvest season.
[b] Derived from rice farmers' estimates obtained through personal interviews.

Table 2. Harvest grain losses versus days from maturity at harvest and moisture content (pooled data from various authors).

Days from maturity	Moisture content, %	Harvest loss, %	Variety[a/]	Author
-12	24.7-25.7	0.307	BG 34-8	Sarath (1978)
-12	25.8-26.0	0.105	BG 94-1	Sarath (1978)
-8	16.8-24.9	0.328	BG 34-8	Sarath (1978)
-8	21.6-25.4	0.227	BG 94-1	Sarath (1978)
-7	23.9-25.8	0.513	BPI-121	Ruiz and Castelo (1965)
-7	23.9-25.8	0.920	BPI-121	Ruiz and Castelo (1965)
-7	23.9-25.8	1.498	BPI-121	Ruiz and Castelo (1965)
-7	23.9-25.8	0.401	BPI-121	Ruiz and Castelo (1965)
-7	NA	0.40	Bahagia	Horiuchi et al. (1971)
-6	23.4	0.45	IR-20	Samson and Duff (1973)
-6	23.7	0.40	IR-20	Samson and Duff (1973)
-5	22.4	1.00	IR-20	Samson and Duff (1973)
-5	23.1	0.79	IR-24	Samson and Duff (1973)
-5	23.0	1.64	C4-63	Samson and Duff (1973
-5	23.2	2.47	IR-253	Samson and Duff (1973)
-4	NA	1.87	Bahagia	Horiuchi et al. (1971)
-4	NA	1.98	Bahagia	Horiuchi et al. (1971)
-4	NA	1.17	Bahagia	Horiuchi et al. (1971)
-4	16.2-25.2	0.521	BG 34-8	Sarath (1978)
-4	19.8-21.8	0.333	BG 94-1	Sarath (1978)
-4	31.4-34.8	1.71	IR-8	Cristal and Ravalo (1967)
0	20.8	0.80	IR-20	Samson and Duff (1973)
0	19.5	0.97	IR-20	Samson and Duff (1973)
0	20.0	1.43	IR-20	Samson and Duff (1973)
0	20.1	1.27	IR-24	Samson and Duff (1973)
0	20.6	2.17	C4-63	Samson and Duff (1973)
0	20.5	3.03	IR-253	Samson and Duff (1973
0	20.8-22.8	3.575	BPI-121	Ruiz and Castelo (1965)
0	20.8-22.8	3.001	BPI-121	Ruiz and Castelo (1965)
0	20.8-22.8	3.237	BPI-121	Ruiz and Castelo (1965)
0	20.8-22.8	3.636	BPI-121	Ruiz and Castelo (1965)
0	26.0-30.5	3.40	IR-8	Cristal and Ravalo (1967)
0	NA	0.57	Bahagia	Horiuchi et al. (1971)
0	14.2-18.5	0.503	BG 34-8	Sarath (1978)
0	18.6-21.1	0.445	BG 94-1	Sarath (1978)
+4	21.2-23.6	6.16	IR-8	Cristal and Ravalo (1967)
+4	13.5-16.0	0.867	BG 34-8	Sarath (1978)
+4	16.8-20.6	0.525	BG 94-1	Sarath (1978)
+5	16.6	2.06	IR-20	Samson and Duff (1973)
+5	18.2	1.73	IR-24	Samson and Duff (1973)
+5	16.6	2.10	C4-63	Samson and Duff (1973)
+5	19.7	3.19	IR-253	Samson and Duff (1973)
+6	18.0	1.30	IR-20	Samson and Duff (1973)
+6	16.8	1.65	IR-20	Samson and Duff (1973)
+7	19.1-19.9	8.356	BPI-121	Ruiz and Castelo (1965)
+7	19.1-19.9	3.917	BPI-121	Ruiz and Castelo (1965)
+7	19.1-19.9	7.037	BPI-121	Ruiz and Castelo (1965)
+7	19.1-19.1	3.781	BPI-121	Ruiz and Castelo (1965)
+8	13.8-18.1	0.962	BG 34-8	Sarath (1978)
+8	16.5-18.8	0.834	BG 94-1	Sarath (1978)
+10	15.3	2.08	IR-20	Samson and Duff (1973)
+10	15.6	2.00	IR-24	Samson and Duff (1973)
+10	15.4	2.68	C4-63	Samson and Duff (1973)
+10	16.3	4.06	IR-253	Samson and Duff (1973)
+12	16.2-17.2	16.30	IR-8	Cristal and Ravalo (1967)
+12	15.3-26.0	1.443	BG34-8	Sarath (1978)
+14	16.9-17.7	3.797	BPI-121	Ruiz and Castelo (1965)
+14	16.9-17.7	9.959	BPI-121	Ruiz and Castelo (1965)
+14	16.9-17.7	7.787	BPI-121	Ruiz and Castelo (1965)
+14	16.9-17.7	12.721	BPI-121	Ruiz and Castelo (1965)
+21	15.5-15.7	51.253	BPI-121	Ruiz and Castelo (1965)
+21	15.5-15.7	54.062	BPI-121	Ruiz and Castelo (1965)
+21	15.5-15.7	30.706	BPI-121	Ruiz and Castelo (1965)
+21	15.5-15.7	27.857	BPI-121	Ruiz and Castelo (1965)
+21	15.5-15.7	27.857	BPI-121	Ruiz and Castelo (1965)
+21	NA	3.08	Bahagia	Horiuchi et al. (1971)
+21	NA	3.61	Bahagia	Horiuchi et al. (1971)
+21	NA	2.53	Bahagia	Horiuchi et al. (1971)
+28	13.3-13.6	65.364	BPI-121	Ruiz and Castelo (1965)
+28	13.3-13.6	56.051	BPI-121	Ruiz and Castelo (1965)
+28	13.3-13.6	54.042	BPI-121	Ruiz and Castelo (1965)
+28	13.3-13.6	66.192	BPI-121	Ruiz and Castelo (1965)

a/ BG 34-8, BG 94-1, Bahagia, IR-20, and IR-24 are classified as low-shattering; C4-63 and IR-253 are classified as medium-shattering; and BPI-121 and IR-8 are classified as high-shattering varieties.

Table 3. Discounting table for palay procurement prices implemented by the National Grains Authority*

Moisture content, %	PURITY OF SAMPLES, %			
	95-100	90.94.9	85-89.9	80-84.9
14.1-15.0	0.99	0196	0.91	0.86
15.1-16.0	0.95	0.93	0.88	0.82
16.1-17.0	0.94	0.91	0.86	0.81
17.1-18.0	0.92	0.89	0.84	0.79
18.1-19.0	0.90	0.88	0.83	0.78
19.1-20.0	0.88	0.86	0.81	0.76
20.1-21.0	0.87	0.84	0.80	0.75
21.1-22.0	0.85	0.83	0.78	0.73
22.1-23.0	0.84	0.82	0.77	0.72
23.1-24.0	0.83	0.80	0.76	0.71
24.1-25.0	0.81	0.79	0.74	0.70
25.1-26.0	0.80	0.77	0.73	0.68

*The price paid to a farmer is determined by multiplying the full undiscounted price of ₱1.30 per kilo by the appropriate discount factor from the table, depending on the purity and moisture content of the paddy being sold.

Table 4. Assumptions for computing capital costs associated with the mechanical dryer.

Item	Value	Unit
Acquisition cost	8,500	pesos
Useful lifetime	5,000	hours
Scrap value	500	pesos
Interest rate	12	percent p.a.
Gasoline cost	2.08	pesos per liter
Kerosene cost	1.43	pesos per liter
Oil cost	6.90	pesos per liter
Annual utilization	600	hours per year
Repair and maintenance cost	425	pesos per year
Oil consumption	80	hours per liter

Cost computation:

Capital charge per hour (₱8,500 x 0.12)/600	=	₱1.70
Depreciation per hour (₱8,500-₱500)/5000	=	1.60
Repair-maintenance cost per hour (₱425/600)	=	0.70
Oil consumption cost per hour (₱6.90/80)	=	0.09
Total cost per hour excluding fuel cost		₱4.09

Table 5. Assumptions for computing capital costs associated with the axial flow thresher.

Item	Value	Unit
Acquisition cost	15,000	pesos
Useful lifetime	3,500	hours
Scrap value	500	pesos
Interest rate	12	percent p.a.
Annual utilization	600	hours
Oil consumption	2	liters per 50 hours
Repair and maintenance cost	750	pesos per year

Cost computation:

Capital charge per hour (₱15,000 x 0.12)/600	=	₱3.00
Depreciation per hour (₱15,000-₱500)/3500	=	4.14
Repair/maintenance cost per hour (₱750/600)	=	1.25
Oil consumption cost per hour (₱6.90 x 2)/50	=	0.28
Total cost per hour excluding fuel cost		₱8.67

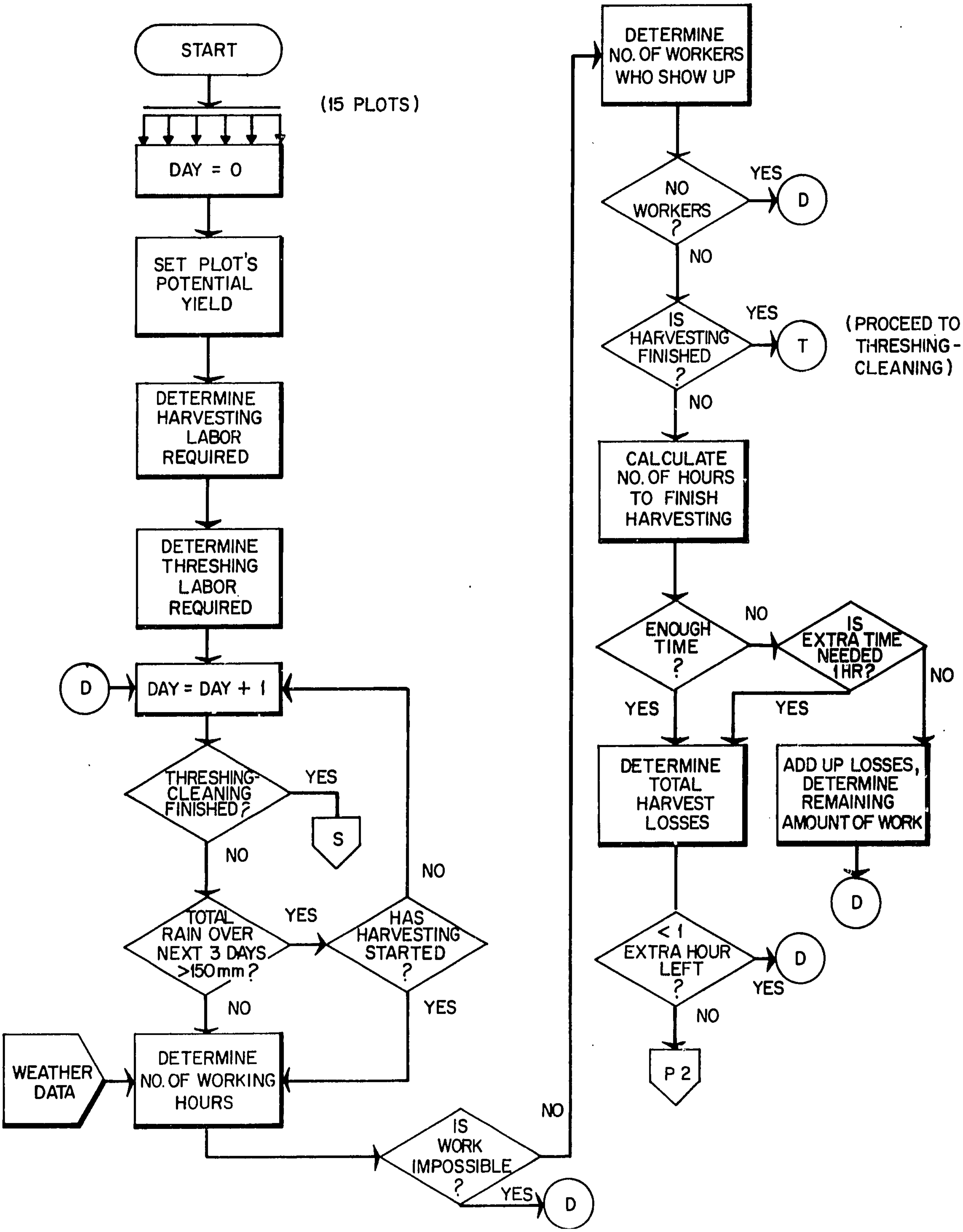
Table 6. Results of 36 iterations of the traditional and mechanized system models assuming a wage rate of ₱1.50 per manhour.

	Gross Revenue (₱)			Total Cash Costs (₱)			Net Returns (₱)		
	Traditional	Mechanized	Percent Difference	Traditional	Mechanized	Percent Difference	Traditional	Mechanized	Percent Difference
FIXED WAGE PAYMENTS									
Mean	5408.90	5645.96	4.4	544.49	560.63	3.0	4856.56	5085.33	4.7
Standard deviation	410.44	400.30	-	46.31	52.84	-	403.82	406.10	-
Skewness	0.00	0.07	-	-0.06	0.02	-	0.01	0.13	-
Kurtosis	-1.32	-1.29	-	-0.11	-0.55	-	-1.36	-1.19	-
CONTRACTUAL LABOR ARRANGEMENT									
Mean	4434.14	4597.09	3.7	48.99	140.70	187.0	4377.31	4456.39	1.8
Standard deviation	436.10	326.04	-	15.49	29.49	-	428.44	336.74	-
Skewness	-0.51	0.07	-	-0.17	1.11	-	-0.48	0.11	-
Kurtosis	-0.81	-1.29	-	1.16	1.17	-	-0.88	-1.32	-

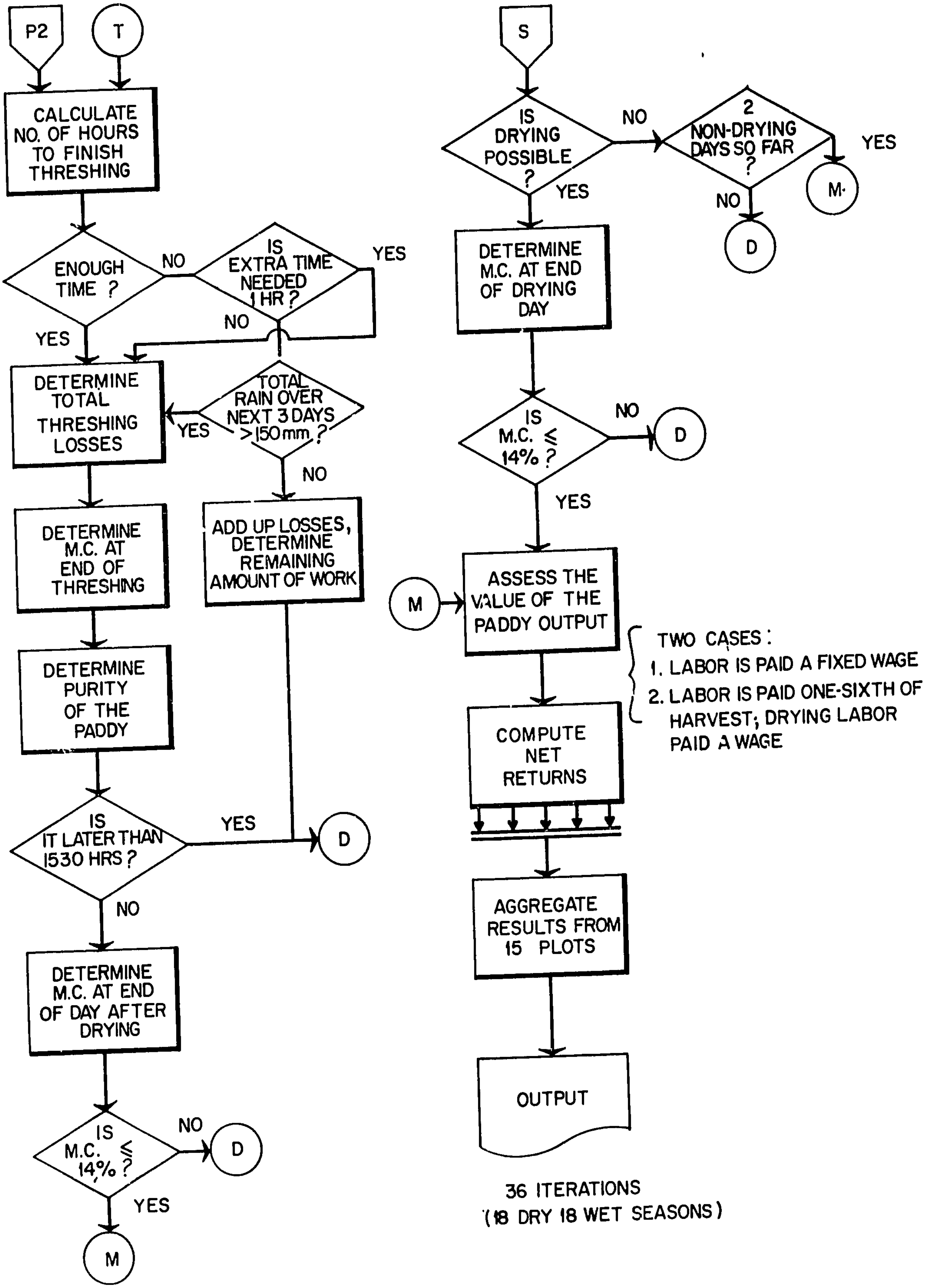
Table 7. Results of 36 iterations of the traditional and mechanized system models assuming a wage rate of ₱2.00 per manhour.

	Gross Revenue (₱)			Total Cash Costs (₱)			Net Returns (₱)		
	Traditional	Mechanized	Percent Difference	Traditional	Mechanized	Percent Difference	Traditional	Mechanized	Percent Difference
FIXED WAGE PAYMENTS									
Mean	5408.90	5645.96	4.4	725.99	672.94	8.0	4675.42	4973.02	6.4
Standard deviation	410.44	400.30	-	61.75	60.28	-	402.54	404.29	-
Skewness	0.00	0.07	-	-0.06	-0.08	-	0.02	0.13	-
Kurtosis	-1.32	-1.29	-	-0.11	-0.67	-	-1.35	-1.13	-
CONTRACTUAL LABOR ARRANGEMENT									
Mean	4434.14	4597.09	3.7	65.33	146.10	124.0	4361.44	4451.00	2.0
Standard deviation	436.10	326.04	-	20.66	29.64	-	426.06	336.54	-
Skewness	-0.51	0.07	-	-0.17	1.11	-	-0.47	0.11	-
Kurtosis	-0.81	-1.29	-	1.16	1.20	-	-0.90	-1.32	-

APPENDIX 1: Flowchart of the Traditional System Model



Appendix 1 : (continued)



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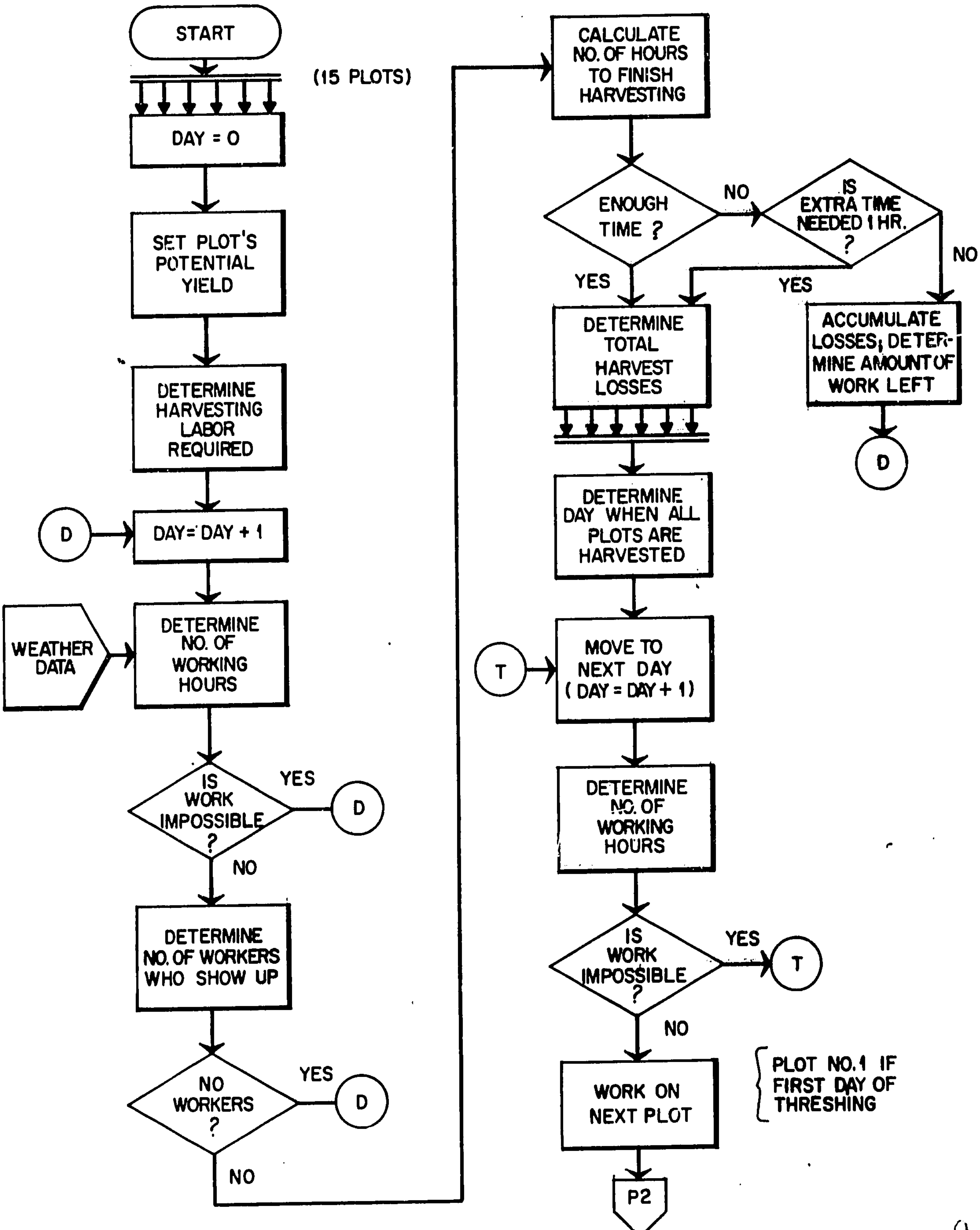
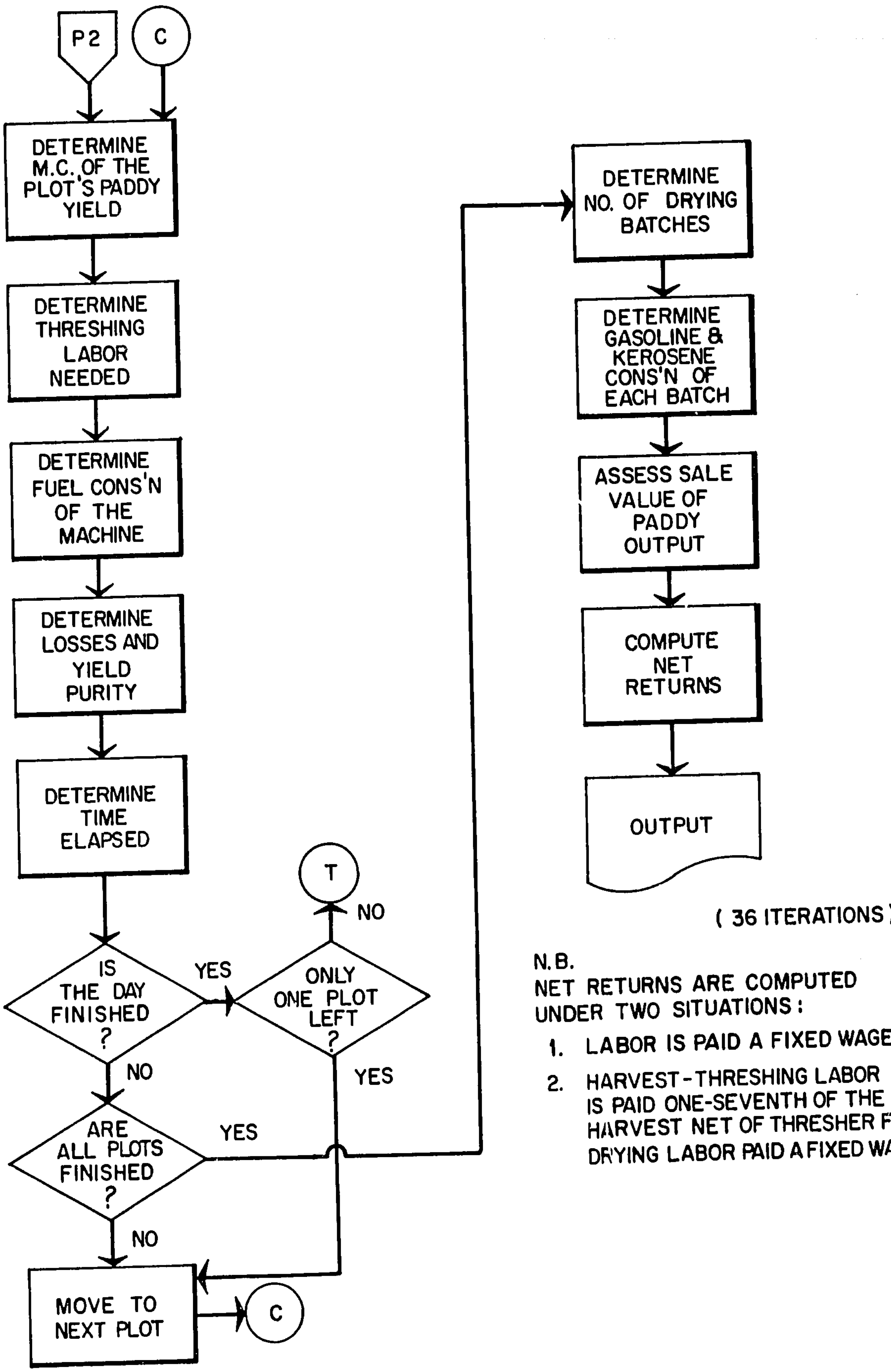
APPENDIX 2: Flowchart of the Mechanized System Model



Appendix 2: (continued)



N.B.
NET RETURNS ARE COMPUTED UNDER TWO SITUATIONS:

1. LABOR IS PAID A FIXED WAGE
2. HARVEST-THRESHING LABOR IS PAID ONE-SEVENTH OF THE HARVEST NET OF THRESHER FEE; DRYING LABOR PAID A FIXED WAGE

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