臺灣農業機械化之發展

Agricultural Mechanization Development in Taiwan

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摘　　要

本文應用系統方法分析臺灣農業機械化之發展。其中導出含二次目標函數及線性限制條件之非線性模式以求最佳利用農業機械之結果。

"機械化潛力" 及" 機械利用率 "為本研究所用之兩個指標以說明所得之結果。如以本省當做一個系統，至民國72年，整地、挿秧、稻穀乾燥等之機械化潛力均已達 100%，其分別之機械利用率為84.7%，96.8%，及85.4%， 至於水稻收穫方面，其機械化潛力僅為90.8%；如欲達到100%， 則須特別計劃之支持。

根據全省及各區之分析，以上四種農耕作業之機械化潛力在民國76年均將達 100%。未來農業機械利用率之預測為：整地，68%；水稻挿秧，78.3%至 84.8%；水稻收穫，85.3%至92.3%；稻穀乾燥，77.9%至74.8%。

上述之模式，可擴大其範圍，利用或然率或動態分析而做進一步之研究。

Abstract

A systems approach is applied to analyze agricultural mechanization development in Taiwan in which, a nonlinear model with a quadratic objective function and linear constraints is developed to obtain optimal results for machinery utilization from island-wide analysis.

"Mechanization Potential" and "Machinery Utilization Ratio" are two indices introduced in the study for interpreting the results obtained. When taking the whole island as a system, by 1983, the Mechanization Potentials for land preparation, rice transplanting and drying had reached 100%, while the Machinery Utilization Ratios for the above farming practices were 84.7%, 96.8%, and 85.4% respectively. The irce harvesting Mechanization Potentials was only 90.8% by 1983 and requires a special program to promote rice harvesting mechanization to reach a 100% MP.

The model developed can be modified by a large-scale, a stochastic or a dynamic approach for further studies.

* 本文係根據第一作者之博士論文摘要而成，並已發表於1986年 1 月20日—24日在南非首都舉辦之國際農業工程研討會。

INTRODUCTION

Background

Taiwan is an island in the Republic of China which is located in the subtropical zone. It has an area of 35990 square km and a population of 18.5 million (1982). There are 830000 farm families farming 890830 hectares of cultivated land. The average farm family consists of six members and holds only 1.07 ha of land. Obviously, farming is small in scale.

More than half of the cultivated lands are paddy fields. Rice is the main food crop in Taiwan. There are many types of agricultural machinery in use by farmers or custom-operators. Most of the machinery is small compared with that used in the West. Our mechanization program started with mechanized land preparation (to make up for insufficient draft animals), then proceeded to mechanized rice culture for assuring food production.

The Problem

In our agricultural production system, there are two (potential) problems related to agricultural mechanization. They are human or animal power shortages and over-investment in machinery.

By the 1960's, rapid industrialization had occurred. It attracted many of the rural laborers to the factories and cities. Labor shortages in agricultural production were first experienced in 1965. This helped the farm mechanization program by diluting the arguments of those people who claimed that farm mechanization would cause un-employment problems.

Many researchers have reported that Japanese farmers have overinvested money on the procurement of farm machinery. Will we face the over-investment problem in machinery and can we avoid it?

Objectives of the Study

The study is aimed at:

1. Applying a systems approach to analyze mechanization development.
2. Minimizing farming costs.
3. Developing a model to represent the system for obtaining optimal results of machinery utilization.
4. Calculating Mechanization Potential.
5. Computing Machinery Utilization Ratio.
6. Predicting future development.

METHODOLOGY REVIEW

Application of Optimization Theory

An optimization approach usually includes defining variables, deriving an objective function to measure the performance of the decision and constructing constraint functions. Then, the objective function is optimized subject to the constraint functions.

In the study, a nonlinear programming problem with a quadratic objective function and linear constraints is derived for obtaining optimal machinery utilization results.

Application of Queueing Theory

The basic queueing process is shown in FIG. 1.

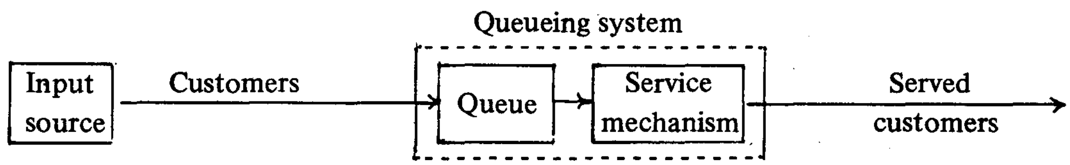

FIG. 1. The Basic Queueing Process (Hillier & Lieberman, 1974)

The use of agricultural machinery for conducting farm operations can be treated as a queueing system. Agricultural fields or products are customers while farm machines are the service mechanisms. This study applies the utilization factor (UF) which is defined as the arriving rate divided by the service rate. If UF is high, it means that services are expensive. If UF is low, it means that waiting is expensive.

Multiplying UF by time, we get total arrivals divided by total services available. This is the Machinery Utilization Ratio which is defined as total agricultural tasks divided by the maximum agricultural machinery capacity.

Hence, we can use UF to explain MUR. However, it must be kept in mind that a low MUR implies a low UF. We gain freedom by using more machines and reducing waiting, but we must pay for it. This increases farming costs.

A Systems Approach

It is suggested by Churchman (1979) that a systems approach includes:

1. Defining a system.
2. Determining measures of performance.
3. Identifying resources and environment.
4. Dividing the system into components.
5. Choosing management.

6. Analyzing humans involved.

In this study, agricultural production in Taiwan is considered a system for analysis as shown in FIG. 2.

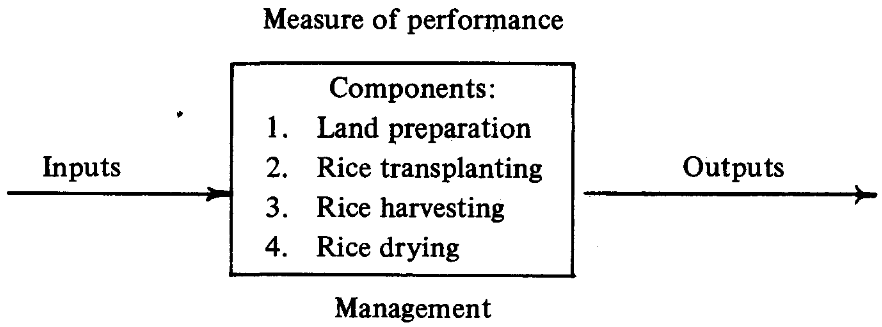

FIG. 2. The Agricultural Production System in Taiwan

PROCEDURES

The procedures for conducting the study are:

1. Thinking.
2. Formulating the problem.
3. Data collection.
4. Constructing a model.
5. Deriving a set of solutions.
6. Analyzing.

Thinking and formulating the problem are the most difficult parts of the study. Data collection is a time-consuming job but not intellectually difficult. Constructing a model and deriving solutions from it are usually not very difficult. The last part, analyzing, is a kind of harvesting, i.e. accomplishment.

THE MODEL

Based on the system defined in previous sections, a model can be developed. There are many types of models: deterministic vs. stochastic, static vs. dynamic, analytic vs. simulated, small scale vs. large scale, etc. A deterministic, static, analytic and relatively small scale model was chosen to represent the system.

Defining Variables

Four agricultural operations (land preparation, rice transplanting, rice harvesting, and rice drying) are included in the system. Each operation can be accomplished using different types of farm machinery or conventional methods.

Each machine type or method is considered a variable. There are 17 variables. If we had more detailed data describing the type of machinery used, we could assign more variables. Including more farm operations in the system would also increase the number of variables.

The Objective Function

A cost function having the form of c – dx is adopted for constructing the objective function. This type of cost function satisfies the economic condition that high utilization results in lowered machinery costs.

The objective function is constructed by summing up all the cost functions multiplied by the number of respective machines or conventional working units.

Constraint Functions

The objective function is subject to the following constraints:

1. Minimum agricultural tasks to be completed.
2. Maximum fuels and skilled labors available.
3. Maximum working days allowed.
4. Non-negative level.

The Primal Model

As the objective function and constraints develop, a primal model can be constructed as follows:

$$\text{Minimize} \quad c'x - x'Dx$$
$$\text{Subject to} \quad Ax \geqslant b$$
$$x \geqslant 0$$

where,

c, x	:	(17 x 1) column vector,
D	:	(17 x 17) diagonal matrix,
A	:	(20 x 17) matrix,
b	:	(20 x 1) column vector,
c' & x'	:	transpose of c & x, respectively.

The above model is a combination of a quadratic objective function and linear constraints. It is an assymmetric quadratic model (Paris, 1979).

The Dual Model

From the primal model, we can get a Lagrangean function L:

$$L = c'x - x'Dx + y'(b - Ax)$$

where, y is a (20 x 1) column vector and a set of Lagrangean multipliers. Then, the Kuhn-Tucker conditions can be derived. Using Kuhn-Tucker conditions, the dual model is constructed below:

$$\begin{array}{ll} \text{Maximize} & b'y + x'Dx \\ \text{Subject to} & A'y \leqslant c - 2Dx \\ & y \geqslant 0 \end{array}$$

The dual objective function can be expressed as the maximum amount that the farmers are willing to pay for contract farming by an outside agency assuming the agency performed all farming operations.

Solutions

For obtaining solutions of either the primal or the dual model, we need to use the Kuhn-Tucker conditions. However, there is a simple way to solve the primal model by using "MINOS", a computer program developed by Murtagh and Saunders (1977, 1983). The user needs only to prepare:

1. The SPEC file to specify certain run-time parameters.
2. The MPS file to specify the linear constraints in standard MPS format.
3. Subroutine CALCFG to compute the non-linear part of the objective function and its gradient (1977) or subroutine FUNOBJ and FUNCON instead of CALCFG (M & S, 1983).
4. Other subroutines needed, e.g. SETQ.

Then, connect the above files and subroutines to "MINOS" and run it. This process will produce optimal solutions if they exist.

DATA

In order to run the model data for vectors c and b and matrices D and A are needed. Elements in c and D are those constants and coefficients of the unit cost function, multiplied by the number of machines or conventional units. Elements in A are performance data multiplied by the above number. Data needed are shown in Table 1 and 2.

By using suitable estimating procedures, total number of machines/conventional units in use in 1981 is obtained as shown in TABLE 3. Similar procedures can be applied for obtaining any other year's data.

TABLE 1. Agricultural Data

Year	Agri. Popu. (persons)	Agri. Land (ha)	Rice Acreage (ha) 1st crop	Rice Acreage (ha) 2nd crop	Rice Yield (tons) 1st crop	Rice Yield (tons) 2nd crop	Draft Animals (head)
1972	5871969	891912	328968	405591	1514705	1522071	221261
1973	5792977	889038	323869	393988	1402071	1403094	199379
1974	5729289	908539	344944	427038	1612834	1439765	189914
1975	5522865	907250	357780	426940	1652780	1454784	190756
1976	5487842	910120	361028	420216	1758979	1620878	183913
1977	5498691	913335	357468	416229	1727376	1574552	119016
1978	5565503	909169	351914	397501	1694661	1354111	103335
1979	5568852	906284	338712	380149	1595505	1462169	92676
1980	5241391	898397	327325	309326	1691006	1249797	81424
1981	5059084	894348	318419	347657	1552322	1413803	76428
1982	4938477	885123	316477	342472	1582721	1519075	71740

TABLE 2. Accumulated Number of Farm Machinery

Units

Year	Power Tiller	Rice Combine	Rice Dryer Bin	Rice Dryer Circu.	Tractor	Rice Transplanter 2-row	Rice Transplanter 4-row	Rice Transplanter 6-row
1972	35218	154	209	–	–	453	–	–
1973	38359	440	353	–	–	1150	–	–
1974	42781	1134	696	–	–	1624	–	–
1975	49322	2053	1876	–	–	2787	–	–
1976	57888	3012	8615	1925	1062	5992	256	–
1977	66694	3925	12724	5426	1220	10503	635	–
1978	74469	7298	14493	7051	1638	18030	748	–
1979	84219	10567	15906	9125	2235	23487	2333	–
1980	93999	13818	17606	11502	3079	28695	4543	–
1981	102182	16463	19318	14381	4930	31646	8165	222
1982	107871	18979	20690	17878	6471	33498	11768	339
1983	113116	20948	22142	21462	8406	34864	14569	1044

TABLE 3. Total Number of Machines/Conventional units in Use (1981)

Equipment/Method	Number	Equipment/Method	Number
Big tractor	2951	2-row combine	6068
Small tractor	1979	4-row combine	7712
Big power tiller	26287	Hand harvesting	230000
Small power tiller	26573	Small bin dryer	11577
Draft animal	76428	Big bin dryer	7741
2-row transplanter	30496	Small cir. dryer	5853
4-row transplanter	8165	Big cir. dryer	8528
6-row transplanter	222	Sun-drying	230000
Hand transplanting	115000		

TABLE 4. Optimal and Practical Results (1981)

days/crop

Equipment/Method		Optimal		Practical	
		1st	2nd	1st	2nd
Big tractor,	x_1	30	30	29.88	29.88
Small tractor,	x_2	29.0055	29.0055	29.88	29.88
Big power tiller,	x_3	20	20	19.92	19.92
Small power tiller,	x_4	20	20	19.92	19.92
Draft animal,	x_5	0	0	0	0
2-row transplanter,	x_6	10	10	10	10
4-row transplanter,	x_7	10	10	10	10
6-row transplanter,	x_8	10	10	10	10
Hand transplanting,	x_9	4.38774	6.93017	4.38774	6.93017
2-row combine,	x_{10}	15	15	15	15
3-row combine,	x_{11}	20	20	20	20
Hand harvesting,	x_{12}	1.69167	3.81036	1.69167	3.81036
Small bin dryer,	x_{13}	25	25	25	25
Big bin dryer,	x_{14}	25	25	25	25
Small cir. dryer,	x_{15}	25	25	25	25
Big cir. dryer,	x_{16}	25	25	25	25
Sun-drying,	x_{17}	2.36734	1.16283	2.36734	1.16283
Total costs*		5.7249	6.0817	5.7257	6.0827

*Cost unit: NT$ 1 billion; 40NT$ = 1 US$.

RESULTS

To apply MINOS, we need to provide the SPEC file, MPS file, CALCFG subroutine and other required data such as SETQ subroutine. With these files and subroutines available, we can run them in conjunction with MINOS to get optimal solutions. 1981's optimal results are shown in TABLE 4. The same procedures can be applied to obtain optimal result for other year.

The results are used to calculate per hectare farming costs of each kind of operation for more meaningful comparisons as shown in FIG. 3.

FIG. 3. show a more than 50% cost reduction in the last 12 years due to the use of machinery. Labor saving has been included in the cost calculations. Another more difficult to measure result is reduction in farmers' drudgery. These are the key reasons that there is rapid development of agricultural mechanization in Taiwan.

MECHANIZATION ANALYSIS

Agricultural mechanization has been discussed by many researchers and government employees. In this study, Mechanization Potential is used as an indicator of total mechanization. There is one Mechanization Potential for a given condition; when farm

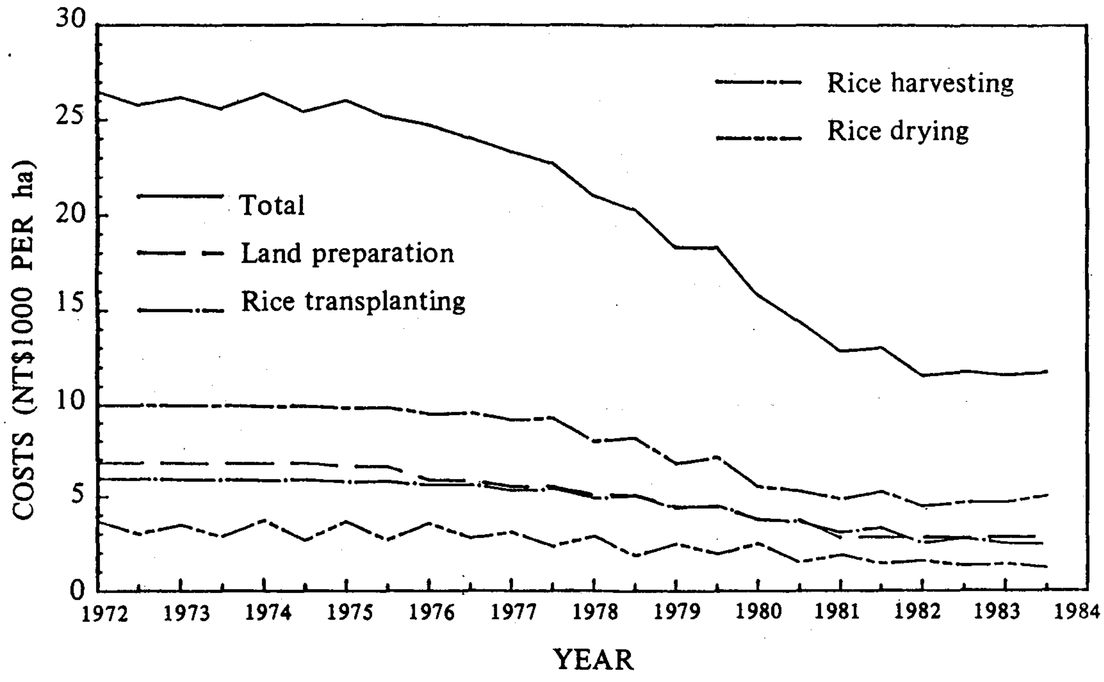

FIG. 3. Per Hectare Farming Costs

machinery is optimally utilized, that potential is reached.

Overinvestment in machinery has been discussed by many researchers, too, particularly in Japan. In this study, the utilization factor used in the queueing theory is applied as a Machinery Utilization Ratio not only for measuring utilization of farm machinery but also for indicating overinvestment in farm machinery.

Mechanization Potential

The 1972-1983 Mechanization Potential figures for Taiwan were obtained by using the optimal results performing the following calculation: (total farm tasks done by machines) divided by (total farm tasks required to be done) x 100, %. They are shown in FIG. 4.

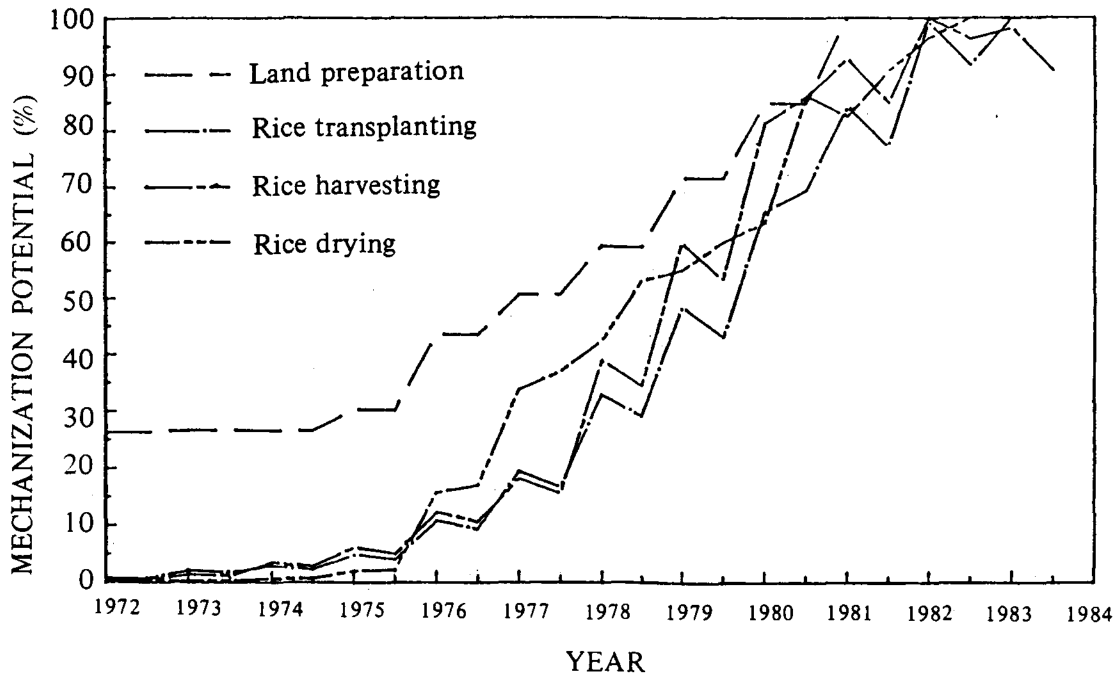

FIG. 4. Mechanization Development

From FIG. 4 we can see that mechanized land preparation started before 1972 and smoothly increased after 1976. This was followed by mechanized rice drying operations which had a big increase during 1976-1977, then mechanized rice transplanting and harvesting operations had a big increase during 1978-1980.

Machinery Utilization Ratio

After the Mechanization Potential of 100% is reached, another index is needed to measure overinvestment in farm machinery and thus better express the level of mechanization development.

The Machinery Utilization Ratio is defined as (total agricultural tasks) divided by (total farm machinery capacity) x 100, %. The MUR calculated are shown in TABLE 5.

TABLE 5. Machinery Utilization Ratio

%

Year	Crop	Land preparation	Rice transplanting	Rice harvesting	Rice drying
1980	1st	100	100	100	100
1980	2nd	100	100	100	100
1981	1st	99.6	100	100	100
1981	2nd	99.6	100	100	100
1982	1st	90.3	100	95.9	100
1982	2nd	90.3	100	100	99.4
1983	1st	84.7	89.4	100	88.9
1983	2nd	84.7	96.8	100	85.4

Low MUR indicates high machinery investment levels, and possibly overinvestment. However, with more machinery the farmer has more freedom in when and how he choose to use farm machinery to conduct his agricultural operations. Overinvestment in machinery and freedom of utilization of machinery go hand in hand. If farmers want freedom they must pay for it. So, how much must they pay at different MUR's? The authors propose the following approach to calculate the change in farming costs due to overinvestment in machinery.

Let us try utilizing every type of machine for each farming operation at the same level; the maximum level multiplied by the Machinery Utilization Ratio. In this way, the work to be accomplished by the machinery is the same as that reached in the optimal solution. This is more practical because it enables all farmers to reach the same machinery utilization level. 1981's practical results are also shown in TABLE 4.

By comparing the optimal results with respective practical ones in TABLE 4, we can see that there are increases in the farming costs for the latter. These increases can be described as the costs that farmers are willing to pay for getting freedom in utilizing machinery or for reducing waiting time during the farming seasons.

Per Hectare Cost Analysis

TABLE 6 shows the practical per hectare farming costs for 1981 through 1983.

Comparing the results of 1983 shown in FIG. 3 and TABLE 6, we can see that the per hectare costs of land preparation have been increased from NT$2884.1/ha to NT$2971.6/ha or 3% at a MUR of 84.7%. The cost of rice transplanting has been increased very little because of the high MUR; that of rice drying has been increased from NT$1434.8/ha to NT$1654.2/ha or 15% at an MUR of 88.9% in the 1st crop and from NT$1247.9/ha to NT$1510.7/ha or 21% at an MUR of 85.4% in the 2nd crop. As for the total per hectare costs of those four operations, it only increases from NT$11595/ha to NT$11918/ha or 2.8% for the 1st crop and NT$11750/ha to NT$12114/ha or 3.1% for the 2nd crop. With only these small increases in farming costs, we can be sure that our farmers can afford to buy farm machines at even lower Machinery Utilization Ratios.

All of the cost increases discussed can be attributed to a decrease in the MUR. Therefore, this part of costs can be described as that which farmers are willing to pay to increase their freedom in using farm machinery or for reducing waiting time. From the above analysis, we can get a range of MURs acceptable to farmers. This range of MUR can be set between 60% and 70%. This does not increase costs too much and farmers have greater freedom in choosing how to utilize their machines. With the freedom, farmers can choose an optimal time to plant and harvest their crops for greater returns, to have more leisure time to improve their living and field conditions, and most importantly, to get an off-farm job to make more money.

TABLE 6. Practical per Hectare farming costs

NT$

Year	Crop	Land preparation	Rice transplanting	Rice harvesting	Rice drying	Total
1981	1st	2839.4	3130.2	4939.7	1936.9	12846
1981	2nd	2839.4	3371.5	5365.3	1455.2	13031
1982	1st	2965.3	2556.3	4663.4	1612.0	11797
1982	2nd	2965.3	2817.7	4739.5	1360.6	11883
1983	1st	2971.6	2550.2	4742.4	1654.2	11918
1983	2nd	2971.6	2489.9	5141.5	1510.7	12114

FUTURE DEVELOPMENT

In the future, the steady state MUR for land preparation will be 68%. At that point, the per hectare cost for land preparation will be NT$2808.4/ha. The steady state MUR will be: 78.3% to 84.8% for rice transplanting; 85.3% to 92.3% for rice harvesting; 74.8% to 77.9% for rice drying. The steady state per hectare cost will be: NT$2100 to NT$2150/ha for rice transplanting; NT$4800 to NT$5800/ha for rice harvesting; and NT$1600 to NT$1750/ha for rice drying. Total steady state per hectare costs for mechanized rice culture will be in the range of NT$11287 to NT$11712/ha at 1981 prices. These costs are relatively low. Only mechanized rice culture has been analyzed in this study because rice mechanization is well developed in Taiwan. However, the experience obtained from the rice program can be applied to other mechanization promotion programs.

There is still a long way to go toward a total mechanization in Taiwan. It needs not only the efforts of agricultural engineers but also the cooperation of specialists in other agricultural related disciplines.

CONCLUSIONS

From this study, it is concluded that:

1. The model can be used for analyzing agricultural mechanization development in any region or country.
2. The model can also be used for analyzing mechanization development of a single crop.
3. Farming costs for each operation have been reduced more than 50% since 1972 to 1983 due to the use of machinery.
4. The MPs for all 4 farming operations will have reached 100% by 1987 or earlier.
5. The MURs will overshoot to a lower level then reach steady state in the range of 70% to 90% by the 1990's.
6. So far, there is no farm machinery overinvestment problem in Taiwan.

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