A Computer Model to Select Optimum Size of Farm Power and Machinery for Paddy-Wheat Crop Rotation in Northern India

R.C.Dash[1] and N.P.S.Sirohi[2]

[1] Department of Farm Machinery and Power,
College of Agricultural Engineering and Technology,
OUAT, Bhubaneswar – 751 003 Orissa, India
[2] Division of Agricultural Engineering,
IARI, New Delhi – 110 012, India

E mail: ramadash@gmail.com

ABSTRACT

Selection of proper size of farm power and machinery is the most important component of any farm enterprise. Among the various inputs to the crop production system, power and machinery jointly represent the largest single item of expenditure constituting about 60% of the total investment on a farm. The decision on optimum size of machinery is quite critical not only because of the high proportion of total cost attributed to machinery but also due to the infrequency and irrevocability of such decisions. Computer based least cost models were developed in C programming language for the selection of optimum size power and machinery system for paddy-wheat cropping system with the input like area under the crop, soil type, number of operations for each crop, crop rotation and time available for each operation etc. The model selected the optimum tractor size from amongst the available sizes and its matching implements keeping in view the capacity of machinery to complete the operation in scheduled time for the given farm. The model also computes the working hours and energy requirement for different field operations along with various cost components. The model output was found to be sensitive to various input parameters like farm size, tillage intensity and crop rotation. Chi-square test revealed that there was no significant difference between the actual size of farm power owned by the farmers of the study area and the prediction of the model. Thus, the model predictions are good for paddy-wheat crop rotation of the study area and can be used successfully for selection of optimal power and machinery.

Keywords: Computer model, optimization, power, machinery, crop-rotation, India

1. INTRODUCTION

Tractor and machinery selection is an important part of machinery management in any farm enterprise as power and machinery jointly represent the largest single item of expenditure constituting about 60 per cent of the total farm investment on a farm. The size or capacity and number of equipment should match the power required by the various sequences of cropping operations that must be performed within specified time periods. The main aim of tractor and machinery selection studies is to complete the field operations during the specified time at minimum cost. Since, the capacity or size of the power-machinery system is directly proportional to their costs, the appropriate selection of these components is important for determining the profitability of the given farming system. Over sizing the power source or the machinery help to reduce the labour cost as well as timeliness costs. However, this benefit may be off set by higher fixed cost. Selection and use of under sized implements on the other hand, may result in higher labour and timeliness cost, thereby, ultimately reducing the net returns. Selection of optimum size farm machinery is quite critical not only because of the high proportion of total cost attributed to machinery but also due to the infrequency and irrevocability of such decisions (Hetz and Esmay, 1986).Modern farming systems require large capital investment, complex economic decisions and higher levels of technical management to minimize cost of production and maximize profit. This kind of enterprise is, however, accompanied by serious economic risks due to uncertainty of weather, timeliness, soil type and conditions, type of crops and crop rotation, management practices, labour availability and high cost of inputs relative to product value. Hence, selecting proper size farm power and equipment to permit economic production in a farm is of paramount important.

Several models have been developed to simulate field machinery selection (Rotz et al., 1983; Ozkan et al., 1986; Siemens et al., 1990). Selection criteria in those models are based on a combination of economic analysis and life, operational requirements (Krutz et al., 1980), timeliness of operation and machine reliability (Edward and Boehlje, 1980), and least cost technique (Singh and Gupta, 1980; Hetz and Esmay, 1986; Isik and Sabanci, 1993; Butani and Singh, 1994; Behera *et al*., 1998; Vatsa and Saraswat, 2008). Most of these models are suitable for use of the research workers for a particular crop or crop rotation. These models are either limited to a crop specific enterprise or too comprehensive with a broad application resulting in lower sensitivity.

A few location specific studies have been conducted in India for the selection of power and machinery for different farm sizes. However, no information is available for the selection of machinery for paddy-wheat cropping system, an important cropping system of India occupying an area of 10.50 m ha. In this cropping system, farmers, generally, do not have sufficient time for field preparation and sowing of wheat (Gangwar and Sharma, 1998). Hence, timeliness of operation is very important for this crop rotation. Keeping these points in view, the main objective of this present study was to develop a user-friendly computer model based on the least cost technique for selection of optimum size of power and machinery for paddy-wheat cropping system.

2. METHODOLOGY

2.1 Selection of the Optimization Technique

Optimization techniques, like, linear programming (LP), integer programming, mixed integer linear programming, non-linear programming, dynamic programming, conditional optimization approach, least cost technique etc., have been used by different research workers for selecting optimal system of farm machinery. Linear programming technique has limitations of solution algorithm as it may give some impracticable specification and may result in some fractional figure of the resources. Integer programming and mixed integer linear programming take a long time to solve a problem with comparatively few variables and several constraints. Non-linear and dynamic programming are very difficult to handle and require expertise to use them efficiently. In the conditional optimization approach, the user must provide inputs for a specific set of equipment. After obtaining the output for the particular set of equipment, user must provide the input for the next revised set of equipment in an interactive manner until a suitable set of equipment is determined. Keeping the above limitations of different optimization techniques, least cost method or minimization of the total cost method was used in this study for optimization of farm power and machinery for different farm size.

2.2 Selection of Optimum Size of Tractor

Optimum size of the tractor was determined based on the energy used for the field operations, transportation and threshing as follows:

$$\text{Optimum tractor size, kW} = \text{Max}\left[\left(\frac{OCF_i}{FCF}\right)^{0.5}\right] \quad \ldots (1)$$

Where,
OCF_i : Operational cost factors for i^{th} season,
FCF : Fixed cost factor.

Operational cost factor for i^{th} season was calculated by using the equation (2)

$$OCF_i = \left[\sum_{j=1}^{NC} \left\{ \sum_{k=1}^{NF_j} \left(\frac{A_j \times NP_{jk} \times EFO_{jk}}{TT_k \times LFF_k} \right)\left(LC + \frac{A_j \times YLF_{jk} \times PC_j}{H} \right) + \sum_{m=1}^{NT_j} \left(\frac{ET \times DT_{jm} \times WT_{jm} \times A_j \times LC}{LFT} \right) + \sum_{n=1}^{NP_j} \left(\frac{A_j \times Y_j \times EPO_{jn}}{EPTS \times EFP_{jn} \times LFP} \right)\left(LC + \frac{YLP_{jn} \times A_j \times PC_j}{H} \right) \right\} \right] \quad \ldots (2)$$

Where,

A_j : Area under j^{th} crop, ha
DT_{jm} : One way distance for transporting m^{th} material of j^{th} crop, km
EFO_{jk} : Energy required for k^{th} field operation of j^{th} crop, kW h ha^{-1}
EFP_{jn} : Efficiency of n^{th} post harvest equipment for j^{th} crop, decimal
EPO_{jn} : Energy required for n^{th} post harvest operation of j^{th} crop, kWh ton^{-1}
EPTS : Efficiency of tractor transmission system, decimal
ET : Energy required for transportation, kWh ton^{-1} km^{-1}
H : Working hour per day
LC : Labour cost, Rs.ha^{-1}
LFF_k : Load factor of k^{th} field operation, decimal
LFP : Load factor for post harvest operation, decimal
LFT : Load factor for transportation, decimal
NC : Number of crops in a year
NF_j : Number of field operations for j^{th} crop
NP_j : Number of post harvest operations for j^{th} crop
NP_{jk} : Number of passes of implement for k^{th} field operation of j^{th} crop
NT_j : Number of transport operations for j^{th} crop
PC_j : Price of the j^{th} crop, Rs.kg^{-1}
TT_k : Tractive and transmission coefficient for k^{th} field operation, decimal
WT_{jm} : Weight of m^{th} material of j^{th} crop, ton
Y_j : Yield of j^{th} crop, ton ha^{-1}
YLF_{jk} : Yield loss due to delay in k^{th} field operation of j^{th} crop, kg day^{-1} ha^{-1}
YLP_{jn} : Yield loss assigned to risk involved due to delay in post harvest operation of j^{th} crop, kg day^{-1} ha^{-1}

The fixed cost factor, FCF was determined by using equation (3)

:

$$FCF = \frac{MUC}{NSY}\left[\frac{(1-S)}{EL} + \frac{(1+S)}{2}\times RI + \frac{(1+S)}{2}\times RIN + \frac{(1+S)}{2}\times SC + \frac{STR}{EL}\right] \quad \ldots(3)$$

Where,

EL	:	Estimated economic life of machine/tractor, year
MUC	:	Machine unit cost, Rs m^{-1}
NSY	:	Number of crop seasons in a year
RI	:	Rate of interest per year, decimal
RIN	:	Rate of insurance per year, decimal
S	:	Salvage value factor, decimal
SC	:	Shelter charge of implement per year, decimal
STR	:	Sales tax rate, decimal

2.3 Selection of Optimum Field Machinery

Optimum sizes of the field machinery were determined based on the time available and power match with the tractor using equation (4)

$$\text{Optimum size of field machinery, m} = \text{Max}\left[\left(\frac{CFF_i}{FCF}\right)^{0.5}\right] \quad \ldots(4)$$

Labour and timeliness cost factor for field operations of i^{th} season (CFF_i) was determined by using equation (5)

$$CFF_i = \sum_{J=1}^{NC}\left[\left(\frac{10\times A_J\times NP_{JK}}{S_{JK}\times E_K}\right)\left(LC + TFCH + \frac{YLF_{JK}\times A_J\times PC_J}{H}\right)\right] \quad \ldots(5)$$

Where,

E_k	:	Field efficiency of k^{th} field operation implement, decimal
S_{jk}	:	Speed of operation of j^{th} implement for k^{th} field operation, km h^{-1}
TFCH	:	Tractor fixed cost per hour, Rupee

Agricultural implements are tax free and farmers usually do not insure their agricultural implements in study area, hence, sales tax rate (STR) and rate of insurance (RIN) is taken as zero in the selection model for agricultural machinery.

2.4 Input Data and Model Description

The basic management data needed as input to select optimum size of farm machinery and power are summarized in figure 1.

A lot of technical and economical data are required for selection of power like tractor and farm machinery (fig.1). The data were collected from both the primary and secondary sources. The soil and crop parameters collected from the farmers and agriculture personnel of the Karnal district of Haryana state by personal interview method using a well-designed pre-tested questionnaire. Field experiments were conducted to collect some of the machinery performance parameters while others were used from published literature. Economical parameters were collected by survey of tractor and implement manufacturing industries and field survey. Based on the above information, three data files namely paddy.dat, wheat.dat and machine.dat were prepared and linked with the programme as input data files. Provision was made to modify any of the default values to suit the requirements of local conditions and temporal variations of the parameters in an interactive manner.

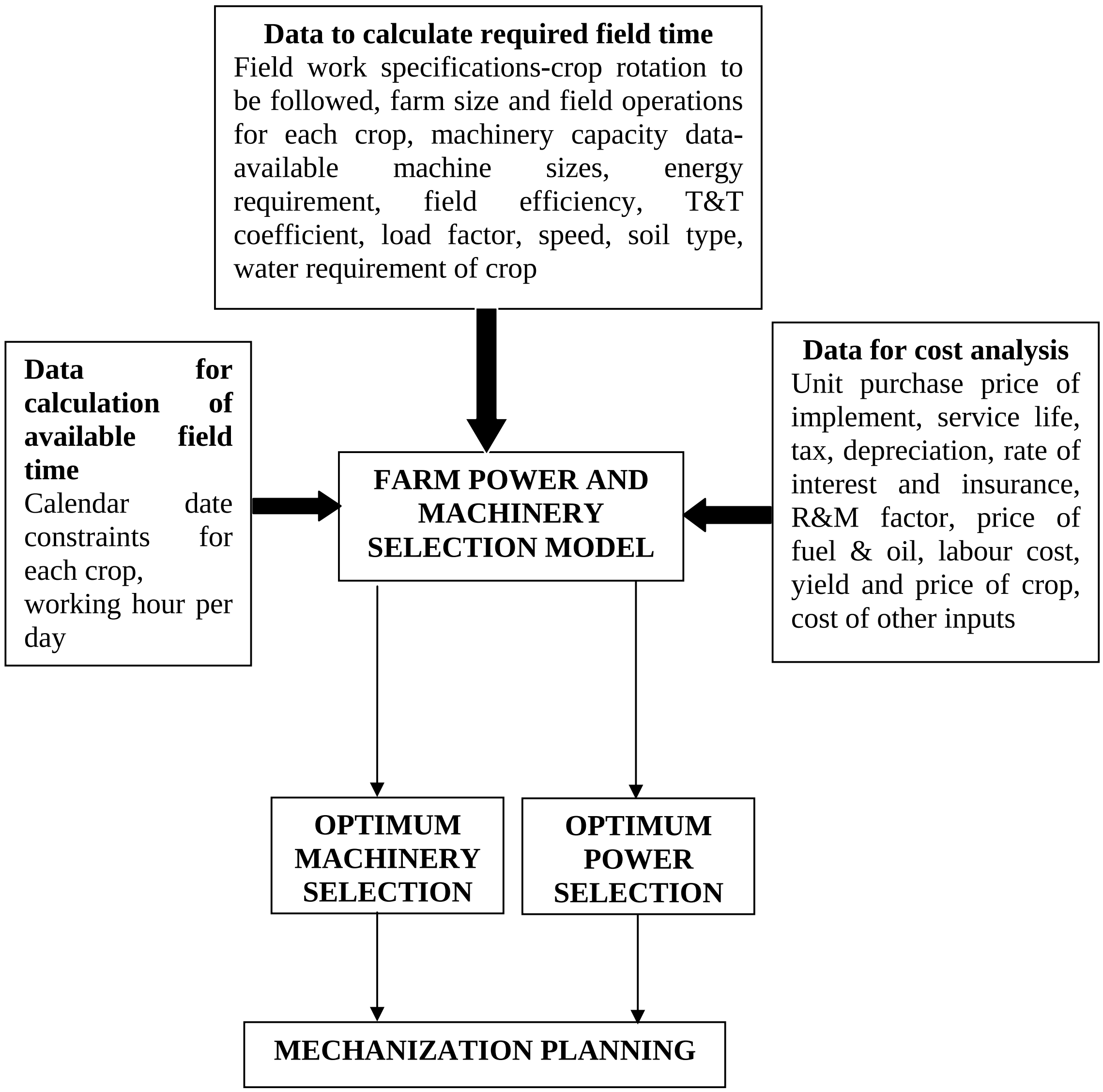

Figure1. Data used in the model for the selection of optimum farm power and machinery and their relationship with mechanization

The Power and Machinery Selection Model (PMSM) was written in C programming language. The computer model PMSM, consisted of two sub-models namely, Tractor and Machinery Selection Model (TMSM) and Stationary Power Selection Model (SPSM). Optimum size of tractor and its matching implements are selected in the first model, while the second model selected the optimum size of stationary power sources like electric motor and/or diesel engine for irrigation. Tractor and Machinery Selection Model (TMSM) is only

presented in this paper. The computer programme was divided in to a series of sub-modules to maintain the flexibility and user friendliness and portability.
The selection of the farm machinery system used in this study was based on the following assumptions

- The crop, crop related parameters, cultural practices and area under each crop grown in the farm are known.
- The purchase price of tractor and machinery is proportional to the power of the tractor and size of the machinery, respectively.
- Yield of crop suffered no loss if the operations are completed with in the given optimum period.

The flow chart illustrating the procedure and logic of the developed computer programme is given in figure 2-3. The programme uses some of the information from the built in data files and others from the users in an interactive manner during the programme run. Power requirement for paddy and wheat were computed separately. The selected model for the tractor was based on the crop requiring higher power and market availability of the tractor size. Optimum sizes of equipment were determined based on power match with the tractor and capacity match with the available time.

2.5 Model Validation

Two stages of analysis were performed to validate the out put of the model. In the first stage, the model output was tested for its sensitivity to changes in major input parameters like farm size, tillage intensity and crop rotation to verify that the changes produced the reasonable changes in the machinery set selected. In the second stage, comparisons were made between the actual farm power complements owned by the farmers of the study area and model prediction of farm power for those farmers using Chi-square test.

3. RESULTS AND DISCUSSION

Tractor was the main mobile power source to perform various farm operations of paddy-wheat crop rotation in the study area. Agricultural machinery like disc harrow, cultivator, bund former, seed drill, winnower and threshers were used by the farmers in the area.

3.1 Selection of Tractor and Machinery

The model predictions of optimum size of tractor and field machinery for different farm sizes are given in table 1. The tractor size for the given farm size was selected in terms of the PTO power from amongst the commercially available standard power ratings of tractors. The smallest size of tractor available in the market was 11.76 kW and it was selected, by default option, for the smallest farm size of 1 ha even though the power requirement of the farm was much less. The limitations of market availability of tractor imposed restriction on the selection of exact and required power rating of tractor for a given farm size. Hence, one particular size of tractor was selected for a certain clusters of farm size. It may be seen from the table that the tractor power selected for 1 to 3 ha, 7 to 8 ha, 10 to 11 ha, 12 to 13 ha, 14 to 16 ha and 17 to 20 ha were same. The highest available 44.12 kW tractor in the market was selected for the farm size ranging from 17 to 20 hectares. Beyond 20 ha farm size, a single tractor was not adequate to meet the power demand.

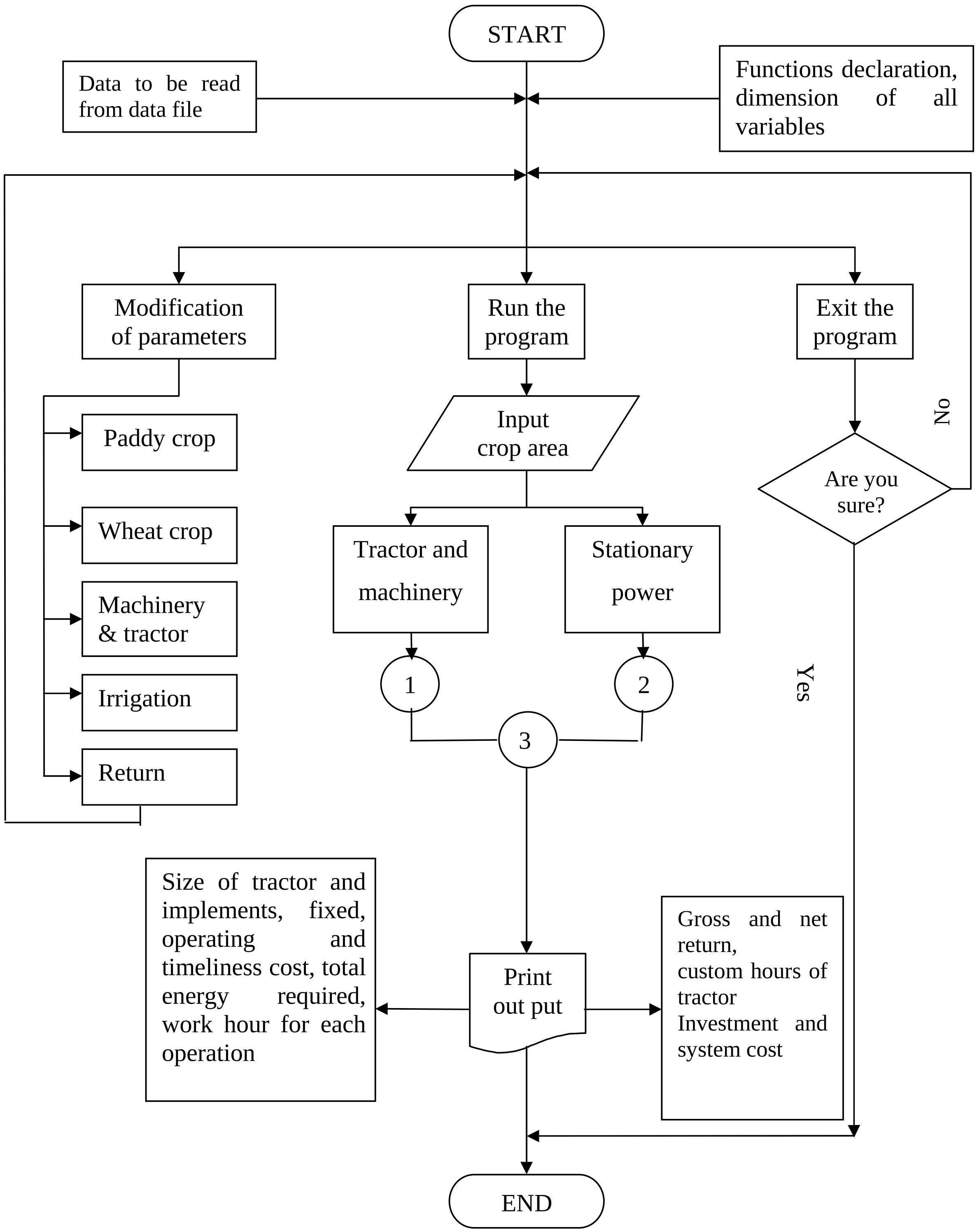

Figure 2. Flow chart for model developed for selection of power and machinery

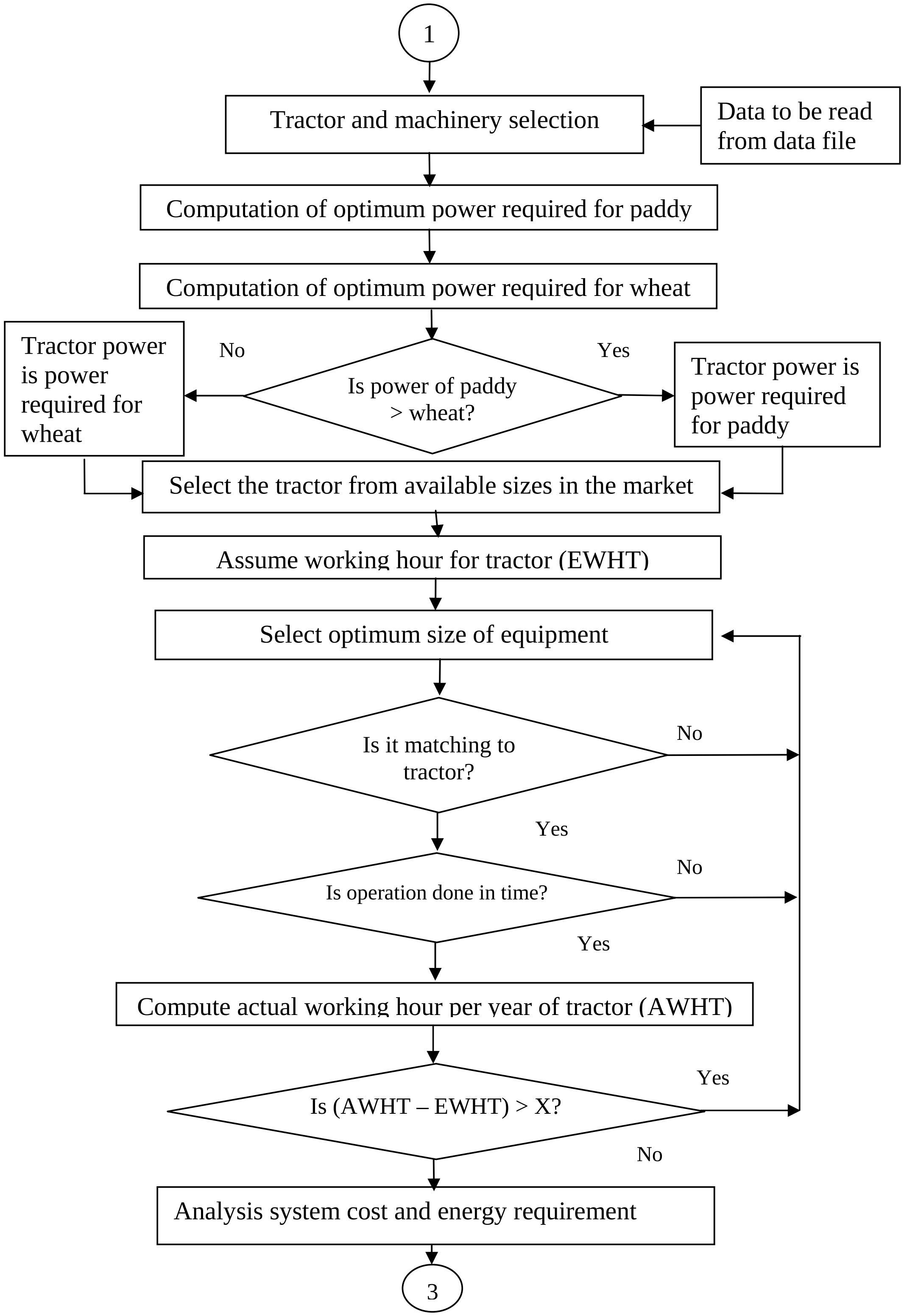

Figure 3. Flow chart for model developed for selection of tractor and machinery

Table 1. Selected size of tractor and machinery for different farm sizes

Farm size, ha	Tractor size, kW	Size of machinery, m						
		MB plough	Cultivator	Puddler	Disc harrow	SCFD	VCR	Thresher, t/h
1	11.76	0.3	1.50	1.65	1.25	1.8	2.20	0.50
2	11.76	0.3	1.50	1.65	1.25	1.8	2.20	0.50
3	11.76	0.3	1.50	1.65	1.25	1.8	2.20	0.50
4	13.97	0.3	1.50	1.65	1.25	1.8	2.20	0.50
5	16.18	0.3	1.96	1.65	1.25	1.8	2.20	0.50
6	18.38	0.3	1.96	1.65	1.25	1.8	2.20	0.60
7	22.06	0.6	2.41	1.65	1.40	2.2	2.20	0.70
8	22.06	0.6	2.41	1.65	1.40	2.2	2.20	0.70
9	24.26	0.6	2.41	1.65	1.55	2.2	2.20	0.70
10	27.94	0.9	2.41	1.95	1.70	2.6	2.38	0.90
11	27.94	0.9	2.41	1.95	1.70	2.6	2.38	0.90
12	30.88	0.9	2.83	2.25	1.70	2.6	2.38	1.25
13	30.88	0.9	2.83	2.25	1.70	2.6	2.38	1.25
14	36.76	0.9	2.83	2.25	1.70	2.6	2.38	1.25
15	36.76	0.9	2.83	2.25	1.70	2.6	2.38	1.25
16	36.76	0.9	2.83	2.25	1.70	2.6	2.38	1.25
17	44.12	0.9	2.83	2.25	1.70	2.6	2.38	1.25
18	44.12	0.9	2.83	2.25	1.70	2.6	2.38	1.25
19	44.12	0.9	2.83	2.25	1.70	2.6	2.38	1.25
20	44.12	0.9	2.83	2.25	1.70	2.6	2.38	1.25

Size of the tractor was found to be increasing with the farm size (fig.4). The regression equation between the tractor power and farm size is given by

$$Y = 7.2955 + 1.9556 X \qquad (R^2 = 0.9818) \qquad \dots (6)$$

Where,

Y = PTO power of the tractor, kW

X = Farm size, ha

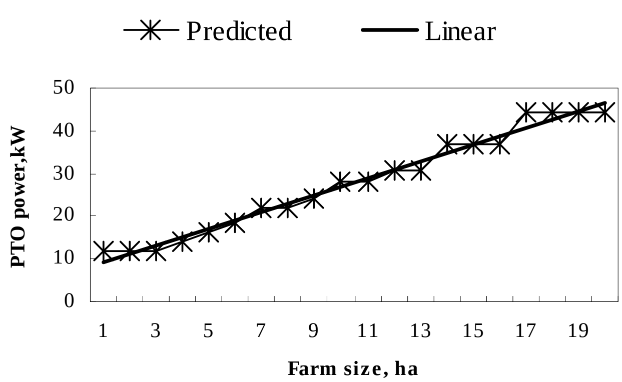

Figure 4. Relation between tractor power and farm size

The unit power requirement followed an inverse relationship with the farm size (fig.5). The unit power requirement decreased rapidly from 1 to 3 ha of farm size, and thereafter, it tends to be asymptotic with the abscissa (farm size) with a value of 2.3 kW/ha. This observation was in agreement with the previous research works (Hetz and Esmay, 1986; Isik and Sabanci, 1993).

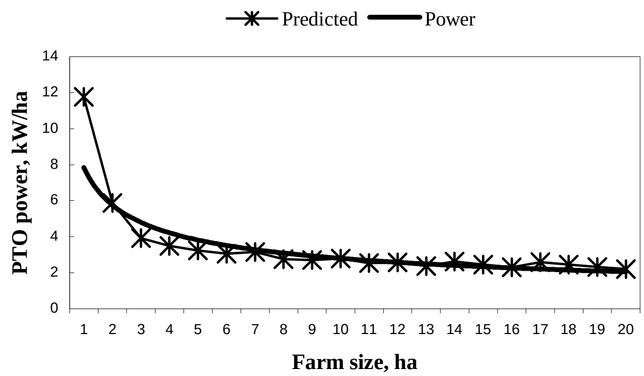

Figure 5. Relation between unit power of tractor and farm size

The regression relationship between the unit power and the farm size was found to be of the following form

$$Y = 1.6798 + \frac{9.4115}{X} \qquad (R^2 = 0.974) \qquad \ldots.(7)$$

Where,
Y = PTO power of tractor per unit area, kW/ha
X = Farm size, ha
The model selected different agricultural machinery based on the matching of tractor power and machinery capacity to complete the operation in the scheduled time (table 1). In deciding the machinery sizes, power match with tractor was given higher preference than the capacity match of the equipment to complete the operation in time. It was observed that size of the machinery increased with increase in farm sizes.

3.2 Tractor and Machinery Cost

The fixed and variable cost of tractor-machinery system was found to increase with the farm size. The variable cost increased at a much faster rate than the fixed cost as the farm size increased (fig.6). The fixed cost or the ownership cost decreased from 88.10 to 42.90 % of the total tractor machinery system cost, where as variable cost increased from 11.90 to 56.60 % of the total tractor machinery system cost. The increase in timeliness cost was insignificant in comparison to ownership cost and variable cost. The difference between the fixed and variable cost for 1 ha farm was nearly Rs.40000.00 and it gradually narrowed down as farm size increased. The ownership cost and variable cost of the selected tractor-machinery system became equal for the farm size of about 16 ha and beyond which variable cost was higher than the ownership cost. Tractor-machinery cost per unit area decreased from Rs 52918.00 to Rs 12397.00 as the farm size increased from 1 to 16 ha and beyond 16 ha the same increased due to increased timeliness cost.

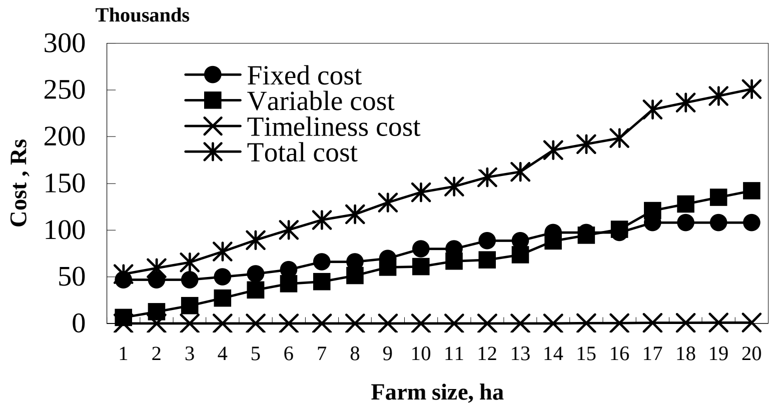

Figure 6. Cost of tractor-machinery vs farm size

Table 2. Chi-square test of observed and predicted tractor size for different categories of farmers of the study area

Category of farmers	Land holding, ha	No. of farmers	Significance level	Chi-square value		Decision
				Computed	Tabulated	
Small & semi-medium	1 – 4	19	0.05	27.698	28.869	Accept H_o
Medium	4 - 10	48	0.05	34.467	43.773	Accept H_o
Large	>10	28	0.05	29.692	36.414	Accept H_o

3.3 Validation of the Model

Chi-square (χ^2) test was performed to compare the observed and predicted power corresponding to different categories of farmers. In applying Chi-square test, the null (H_0) and alternate (H_1) hypothesis were as follows:

H_0: There was no significant difference between the observed and predicted tractor size

H_1: The observed and predicted tractor size was significantly different.

It was observed that the differences between the predicted and observed tractor power for all the categories of farmers were statistically insignificant. Thus, it was concluded that the model prediction was good for the farmers of the study area growing paddy and wheat crops.

4. CONCLUSIONS

The conclusions drawn from this study on selection of optimum tractor and machinery size under paddy-wheat crop rotation are given below

1. Optimum tractor power requirement was found to increase linearly with farm size, whereas unit power requirement decreased initially with increase in farm size and thereafter, it became constant. The size of machinery was found to increase with the farm area.
2. Break-even area for the given tractor-machinery combination is 16 ha.

3. The developed model was found to be sensitive to the input parameters. The model prediction was found to be in close agreement with the observed power-machinery complements owned by the farmers of the study area.
4. The developed model is useful in selection of tractor and machinery for paddy-wheat crop rotations.

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