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Development of Computer Software for Determination of Optimum Tractor Power and Machinery Sizes

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Abstract: Choice and usage of optimum tractor power and agricultural machinery size is important to decrease machinery cost and complete agricultural operations in a reasonable time. Also, the usage of improper size machinery increases the production costs in the farms. Agricultural operations and machinery usage during cultivation season are affected by many factors such as crop pattern, economic input and output, properties of soil and crop, and climate. Under these circumstances, determination of optimum tractor power and machinery size is a tedious and complex procedure that requires many calculations and computational work. In this study, a computer software was developed to determine optimum size of mechanization vehicles used in farms. In this program, the method named as "the least cost method" was employed. Programming language of the software was Visual Basic.NET. Microsoft SQL Server 2005 database was used for the storage of processing parameters and results. The program developed in this study was applied to the representative farm size and crops such as wheat, corn, and cotton.

Key words: Machinery selection, optimum, mechanization vehicles

INTRODUCTION

Agricultural sustainability depends on farm profitability. Thus, farmers are under constant pressure to produce more with less and to reduce production costs through improved operating efficiency (Griso et al., 2007). 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 (Dash and Sirohi, 2008). 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). A careful approach to matching tractor and implement can increase efficiency of operation and farm profitability. When they are correctly matched, the results include reduced power loss, improved operating efficiency, reduced operating costs and optimum use of capital on fixed costs (Taylor et al., 1991). The matching process of tractor and implement is something that farmers often do "subconsciously" with much dependence on their experience. While this approach may enable the farmer to carry out the intended operation, the system may not be operating at optimum operating efficiency (Ishola et al., 2010).

The process of matching tractor and implement may start with the implement or with the tractor. For proper sizing, one must (Grisso et al., 2007):

- Predict the draft and power requirement of the implement considering factors such as depth and speed of operation, implement width, and soil condition.
- Predict the tractive ability and the drawbar power of the tractor considering factors such as vehicle configuration, weight distribution, ballasting, tractive device type, and terrain conditions.

Labor and machinery are important input factors dominating all other cost categories and, potentially, it should be possible to make reductions in machinery costs by adapting and operating the machines optimally within the boundaries of the actual needs arising from farm size, crop plan, and other factors (Poulsen and Jacobsen, 1997). Generally, the identification of an optimal mechanization level is a very complex process and involves the interactions between machines and between the farm machinery system and biological and meteorological subsystems such as crop, soil and weather conditions (Henning and Sorensen, 2004). Also, machinery recommendations must be based on the characteristics of each individual farm. The following factors influence machinery selection:

- Production area
- Labor supply
- Number of tillage practices
- Crop pattern
- Weather conditions
- Planting and harvesting dates

There is a need to develop programs to assist in the decision making process for the selection and management of machinery (Mehta et al., 2011). Considerable research has been conducted in developing computer based models and simulation programs to determination of optimum tractor power and machinery sizes. According to Dash et al. (2008), 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).

Grisso et al. (2007) demonstrated the use of spreadsheet for matching tractors and implements. They predicted tractor performance and implement draft based on the Brixius model and ASABE Standard D 497.5, respectively. Sahu and Raheman (2008) developed a decision support system in Visual Basic 6.0 programming language for matching tillage implements with 2 WD tractors for predicting the field performance of tractor–implement system. Vatsa and Saraswat (2008), developed a computer program in turbo C^{++} language to compute power of power tiller and size of equipment based on inputs like area under different crops, cropping pattern and soil type for a particular farm situation. The program processed these data with the help of two options i.e. pre-defined parameters (default values) and user-defined parameters. Actual power required as calculated through computer programming was compared with that of the power tiller owned by the farmers with respect to area.

Dash et al. (2008) developed a computer model to select optimum size of farm power and machinery for paddy-wheat crop rotation. Computer based least cost models were developed in C programming language for the selection of the 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. Ishola et al., (2010) developed an object-oriented program in Visual C^{++} to predict the performance of tractor-implement system. The Brixius Model and ASAE Standards D497.5 were used to predict the tractor performance and implement draft respectively. Tractor and implement performance parameters such as field speed, drawbar pull, drawbar power, total implement draft, field capacity, and actual operating hours are predicted for the selected tractor implement system.

Mehta et al., (2011) developed computer software to select either an implement to match the tractor or to select a tractor in order to match the implement under different soil and operating conditions. Computer software developed in Visual Basic programming provided the intuitive user interfaces by linking databases such as specifications of tractors and implements, tractor performance data, soil and operating conditions, to support the decision on selection of tractor–implement system.

In this study, a computer software was developed to determine optimum tractor PTO power and farm machinery widths, and the program was used for an example farm which cultivates some field crops.

MATERIALS and METHOD

Selection model of optimum tractor PTO power and field machinery sizes

Some optimization techniques or methods have been used by different research workers to select optimum tractor and farm machinery sizes. One of the used methods developed by Hunt (1973) is "least cost method" and it was preferred many researches (Evcim, 1982; Işık and Sabancı, 1993; Akıncı et al., 2001; Dash and Sirahi, 2008; Vatsa and Saraswat, 2008).

The developed software was based on the least cost method and it was benefited from equations of the method in determination of mechanization implements sizes. The main equations used to determine the optimum farm machine width, the near optimum machinery widths and the tractor PTO (power take off) power in the software program are seen in below (Hunt, 1973; Evcim, 1982; Işık and Sabancı, 1993; Akıncı et al., 2001; Vatsa and Saraswat, 2008).

$$W_{opt} = \sqrt{\sum_{i=1}^{n} \frac{10 \cdot A_i}{FC \cdot p \cdot S_i \cdot e_i} \left(L + T + TC \right)} \tag{1}$$

where,

W_{opt}	optimum machine width, m
A	annual use in hectare, ha
FC	annual fixed cost percentage, decimal
p	machine purchase price for unit width, \$/m
S	forward speed, km/h
e	field efficiency, decimal
L	labor cost, \$/h
T	cost of tractor use by the machine, \$/h
TC	timeliness cost, \$/h
i	subscript denoting the operating type or crop type of all the crops, (i= 1,2,…n)

In the determination of the timeliness cost, the following equation was used. This input is more important for seeding and harvesting operations. Therefore, it was considered only for these operations in the developed software.

$$TC = \frac{K \cdot A_c \cdot V \cdot Y}{X \cdot U \cdot h} \tag{2}$$

where,

K	timeliness cost factor, 1/day
A_c	crop production area, ha
V	value of the crop, \$/kg
Y	potential crop yield, kg/ha
X	planning factor, 2 (for premature or delayed) or 4 (for balanced)
U	the ratio of workable days in the planned operation period, decimal
h	daily work period, h

$$W_{1,2} = W_{opt} + \frac{d}{2 \cdot FC \cdot p} \pm \sqrt{\frac{d}{FC \cdot p} (W_{opt} + \frac{d}{4 \cdot FC \cdot p})} \tag{3}$$

where,

$W_{1,2}$	the double answer obtained which defines a range in machine width wherein the annual cost of operation are approximately minimum.
d	the arbitrary money amount that the farm can pay above minimum cost of the machine size desired to reach. This value was taken about 2% of the purchase prices of the machines.

$$P_{PTO} = \sqrt{\sum_{i=1}^{n} \left[\frac{A_i \cdot E_i \cdot}{FC \cdot T_p \cdot r_1} .(L+TC) \right] + \sum_{i=1}^{n} \left[\frac{L}{FC \cdot T_t} (\frac{0.27 \cdot D_i \cdot \cdot W_t}{r_2} \right]} \tag{4}$$

where,

P_{PTO}	total optimum PTO power.
E	total energy requirement for unit production area, kW h/ha
T_p	Tractor purchasing price for unit PTO power, \$/kW
r_1	tractor loading ratio for field machinery, decimal
D	transport distance, km
Wt	the amount of transported material annually, tones/year
r_2	tractor loading ratio for transportation operations, decimal

For the model the other required parameters like annual fixed cost percentage; cost of tractor use by the machine, salvage value and real interest rate are calculated by using standard equations (Hunt, 1973; Evcim, 1982; Akıncı et al., 2001).

Software description

The software was written in Visual Basic.NET 2008 programming language (Microsoft Corp., Redmond, WA, USA) to determination of optimum tractor power and farm machinery sizes. Microsoft SQL Server 2005 (Microsoft Corp., Redmond, WA, USA) database was used for the storage of processing parameters and results. In database, relational database management system was used. Relational database architecture and the flowchart of the developed program are shown in Figure 1 and Figure 2, respectively.

In the software, determination of the tractor power and machinery sizes is associated with farm production area, crop pattern, agricultural operations, operation numbers, timeliness parameters, economic and technical data, transport distance etc. In the developed program, the values of tractor PTO power found in the equations were increased % 20 by to take into consideration reserved power (Akıncı et al., 2001).

Regional or specific farm conditions should be taken into account in the determination process of all the appropriate data. The appropriate technical data, which will be used in the program, can be obtained with field studies or taken from previous studies. While some of the economic data such as economic life can be found from literature, some of them such as interest rate, purchase price can be taken from current market data.

All the data needed for the calculations were entered into developed software. Farm, product, machinery, agricultural process, economy and tractor data were entered on separate tabs into the software.

RESULTS and DISCUSSION

The developed software program was run on a sample farm to check the validity. The assumed farm size was 45 hectare and the area was consisted of 18 ha wheat, 18 ha cotton and 9 ha corn. The used technical data and agricultural operations depending on these crops were chosen for irrigating field farms in Antalya Region of Turkey. Annual tractor usage period was taken the value as 750 h/year. Values of field working speeds, field efficiencies, energy requirements, rates of load, economic life and timeliness coefficients were taken from a previous research carried out in Antalya region (Akıncı et al., 2001). The economic data was determined by considering of 2011 of Turkey market conditions.

There are six tabs in which the related data should be entered. As an example tab can be explained. One of them is the machinery description tab and the data related with some machinery management values should be entered into the separated cells. Some agricultural machinery management data used in the tab are seen in Figure 3.

As shown in Figure 3, there are a total of 11 agricultural machines in the sample production. The highest purchase prices for unit width were determined for pneumatic vacuum seeder and heavy disc harrow with the values of 1938.6 and 1009 $/m respectively. The least of that was 63.4 $/m for centrifugal fertilizer. According to the economic data, calculated values of salvage and fixed cost percentage were 0.096-0.177 and 0.099-0.119 ranges, respectively.

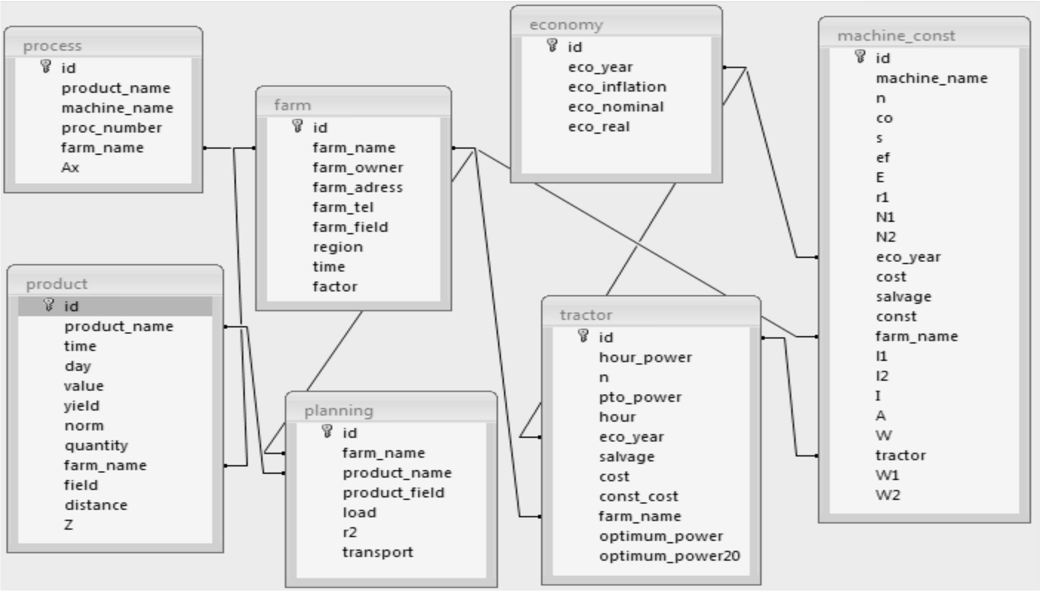


Figure 1. Relational database architecture for the software

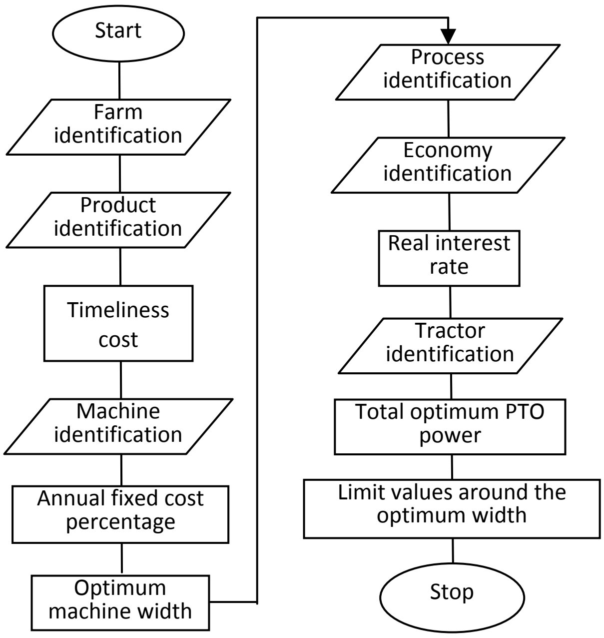
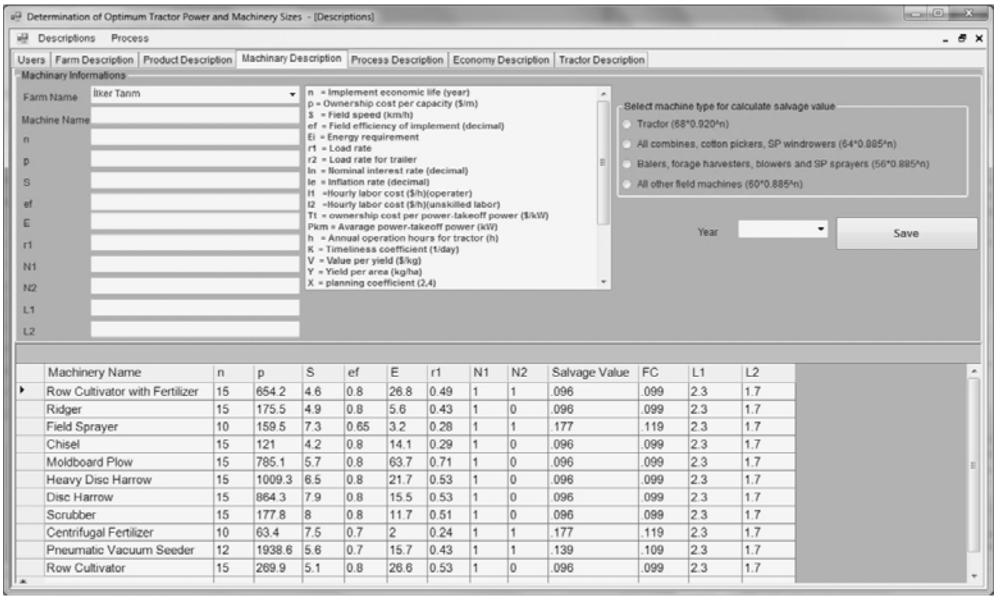


Figure 2. Flowchart of developed software for optimum PTO power and machinery sizes

The optimum tractor PTO power and farm machinery width values calculated by running the developed program are seen in Figure 4. As shown in Figure 4, optimum tractor PTO power was 55.1 kW. Selection of real engine power and tractor type can be made taking into account the tractor PTO power. It was found that the machine width had the highest value in centrifugal fertilizer followed by field sprayer, scrubber and ridger. These values were calculated at 12.93, 10.06, 6.62 and 6.6 m, respectively. The minimum values were determined at the tillage machines. The machine width had the least value in heavy disc harrow followed by moldboard plow, row cultivator with fertilizer, and row cultivator. These values were found at 3.24, 3.34, 3.68, and 3.69 m, respectively. Also the upper and limit values around the optimum are seen in that Figure. The limit values were calculated in order to make the process easy to find farm machinery in the markets.

CONCLUSIONS

Determination of optimum tractor power and machinery size is a tedious and complex procedure that requires many calculations and computational work. These complex procedures are quickly calculated by the developed programs. In this study, computer software was developed for this purpose the program helps in selection of a tractor and an implement of optimum size from the markets. The program is user-friendly and could be run on Windows XP, Vista and 7 operating systems. In current stage, the program can calculate the required numerical values which indicate working widths of farm machinery (m) and tractor PTO power (kW). Expert systems, which can determine real number of tractor and farm machinery from the markets for different crop patterns and different regions, should be developed in the future researches.



Farm Name: İlker Tarım

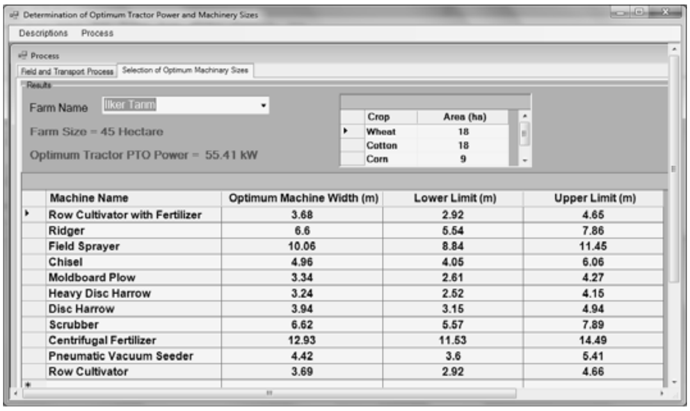
n = Implement economic life (year)
p = Ownership cost per capacity ($/m)
S = Field speed (km/h)
ef = Field efficiency of implement (decimal)
Ei = Energy requirement
r1 = Load rate
r2 = Load rate for trailer
In = Nominal interest rate (decimal)
Ie = Inflation rate (decimal)
l1 =Hourly labor cost ($/h)(operater)
l2 =Hourly labor cost ($/h)(unskilled labor)
Tt = ownership cost per power-takeoff power ($/kW)
Pkm = Avarage power-takeoff power (kW)
h = Annual operation hours for tractor (h)
K = Timeliness coefficient (1/day)
V = Value per yield ($/kg)
Y = Yield per area (kg/ha)
X = planning coefficient (2,4)

Select machine type for calculate salvage value
○ Tractor (68*0.920^n)
○ All combines, cotton pickers, SP windrowers (64*0.885^n)
○ Balers, forage harvesters, blowers and SP sprayers (56*0.885^n)
○ All other field machines (60*0.885^n)

Year:

Machinery Name	n	p	S	ef	E	r1	N1	N2	Salvage Value	FC	L1	L2
Row Cultivator with Fertilizer	15	654.2	4.6	0.8	26.8	0.49	1	1	.096	.099	2.3	1.7
Ridger	15	175.5	4.9	0.8	5.6	0.43	1	0	.096	.099	2.3	1.7
Field Sprayer	10	159.5	7.3	0.65	3.2	0.28	1	1	.177	.119	2.3	1.7
Chisel	15	121	4.2	0.8	14.1	0.29	1	0	.096	.099	2.3	1.7
Moldboard Plow	15	785.1	5.7	0.8	63.7	0.71	1	0	.096	.099	2.3	1.7
Heavy Disc Harrow	15	1009.3	6.5	0.8	21.7	0.53	1	0	.096	.099	2.3	1.7
Disc Harrow	15	864.3	7.9	0.8	15.5	0.53	1	0	.096	.099	2.3	1.7
Scrubber	15	177.8	8	0.8	11.7	0.51	1	0	.096	.099	2.3	1.7
Centrifugal Fertilizer	10	63.4	7.5	0.7	2	0.24	1	1	.177	.119	2.3	1.7
Pneumatic Vacuum Seeder	12	1938.6	5.6	0.7	15.7	0.43	1	1	.139	.109	2.3	1.7
Row Cultivator	15	269.9	5.1	0.8	26.6	0.53	1	0	.096	.099	2.3	1.7

Figure 3. Some agricultural machinery management data



Farm Name Ilker Tarım

Farm Size = 45 Hectare

Optimum Tractor PTO Power = 55.41 kW

Crop	Area (ha)
Wheat	18
Cotton	18
Corn	9

Machine Name	Optimum Machine Width (m)	Lower Limit (m)	Upper Limit (m)
Row Cultivator with Fertilizer	3.68	2.92	4.65
Ridger	6.6	5.54	7.86
Field Sprayer	10.06	8.84	11.45
Chisel	4.96	4.05	6.06
Moldboard Plow	3.34	2.61	4.27
Heavy Disc Harrow	3.24	2.52	4.15
Disc Harrow	3.94	3.15	4.94
Scrubber	6.62	5.57	7.89
Centrifugal Fertilizer	12.93	11.53	14.49
Pneumatic Vacuum Seeder	4.42	3.6	5.41
Row Cultivator	3.69	2.92	4.66

Figure 4. The calculated optimum tractor PTO power and machinery sizes

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