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# Assessment of Optimum Farm Size According to the Different Machinery Systems by a PC Model

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**Abstract:** Two different programming models are described. One model, Computed Tractor Workable Days (CTWD) determines the tractor workable days in the field operations taking into account weather uncertainty, temperature, raining and snowing. The second model is Linear Programming Model (LPM) determining optimum field size depend on the data determined by CTWD for different six machine sets. In the CTWD model workable days can be determined for 50, 60, 70, 80 and 90% probability levels. However, in this study calculations were done according to the 80% probability level. CTWD was used to determine workable days between two selected dates' days. Firstly it calculates average workable days for each crop term according to the uncertainty whether conditions, then determine probably workable days. Finally, full workable days determined by program extracting the religion and national festival days from probability workable days. LPM allows an economic comparison to be made of tractor capacity and optimum field size. For example, 57.7 kW tractor was used for 17.67 ha in Harran plain in Sanliurfa, Turkey. According to the results of LPM, however, it was determined that the same tractor could operate 57.88 ha and 17.67 ha needed 20.48 kW tractors.

**Key words:** Optimum farm size, machinery systems, tractor power, tractor workable days, PC model

## INTRODUCTION

In this research, the aim is a focus on a production planning related to the usage of machine that can be supplied maximum profit. Production planning should be carried out accurately and efficiently for increasing the quality and quantity of production on farm.

Agricultural mechanization provides that agricultural operations are done easily, quality, quickly and on time and it increases the efficiency of farm production. Increasing the efficiency in the production can be provided with the decreasing production costs related input usage and the increasing the production quantity (Isik and Sabanci, 1987; Vatandas, 1987).

One of the important inputs in agricultural production is the one that related to equipments of agricultural mechanization. Investment inputs of tractor and its equipments compose of 30-60% of the production costs (Ozkan *et al*., 1984; Sabanci *et al*., 1993).

Some studies on subject of machine selection and demand estimation have been carried out in Southeast Anatolia Project area, but several of these studies are those determined the machine models for a certain field sizes (Isik *et al*., 1995; Sindir, 1993; Yavuzcan *et al*., 1989). In this study, different machine systems were taken into account and maximum field sizes cultivated by these determined machine systems. In addition maximum field sizes and gross margin values were compared with the available farm field sizes and gross margin values.

Farm planning models used for scheduling labor, machinery, optimum farm size and other farm resources, are often based on Linear Programming (LP) (McCarl *et al*., 1978; Dobbins *et al*., 1992). Due to uncertainties related to weather, the constraints for this type of model may involve random variables, either as coefficients or right-hand sides. Typically, these constraints are replaced by deterministic constraints to approximate the constraints involving random variables. The formulation of these deterministic constraints is often based on rules of thumb fixed even when technology changes (Etyang *et al*., 1998). A PC program named CTWD was developed to determine tractor workable time located in right side on constraint equation of LP model. Weather conditions such as uncertainty, temperature, raining and snowing was taken into account for determining tractor workable days in the field operations.

Harran plain is the region enclosed in Southeast Anatolia Project and firstly irrigated by Atatürk Dam in 1996. In the plain, with the irrigating, the usage levels of the tractor and farm machines have been increased. Yet,

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the efficient rantable usage of available capacity of tractor and machine cannot be carried out because it has not been made a plane related to the usage of machine in this region.

## MATERIALS AND METHODS

**Materials:** The study was conducted between 2000 and 2001 years in Harran Plain, Sanliurfa, Turkey. To form database for a PC program, data were collected from 62 irrigated farms located in the plain. In addition, 20 year climate data of the region were collected for the evaluation tractor workable days. Also, six machinery systems were used to evaluate optimum field size.

Average of 20-year monthly climate data of the region were given in Table 1. Tractor types, tractor powers and related equipments for each machine system were shown in Table 2.

### Methods

**Method applied to separate farms in to groups:** After sampling 10 villages that having 461 farms from the population of 90 villages considered, frequency table showing distribution according to farm size are arranged. Distribution graph are drawn and according to the result of the distribution farms are divided into three groups. They are 5-15.5 ha (Group I), 15.6-22.5 ha (Group II) and 22.6 and over (Group III). Because most of farms between 1-5 ha have no tractor, they were neglected. To determine sample farm numbers Stratified Random Sampling Method was applied. Accordingly, sample numbers of farms determined are as follows (Yamane, 1967):

$$n = \frac{N\sum N_h S_h^2}{N^2 D^2 + \sum N_h S_h^2} \quad (D^2 = d^2 / z^2)$$

Where, n: Number of sample farms; N: Number of farms in population; $N_h$: Number of farms in $h^{th}$ stratified; $S^2_h$: Variance of $h^{th}$ stratified; d: Permitted error ratio deviated from average of population; z: Its value is 1.6445 according to 90% confidence interval and 10% error ratio.

According to the above equation 62 farms were determined as sample farms. Sample farms determined were stratified by $[N_h/N]$. n formula. They divided into three groups as identified before, Group I, II and III. Distribution of simple farms according to stratifies are given in Table 3.

**CTWD program:** The Computed Tractor Workable Days (CTWD) was developed to determine the tractor workable days in the field operations taking into account weather uncertainty, temperature, raining and snowing.

Table 1: Twenty-year average climate data in sanliurfa

| Months | Average temp.°C | Max. temp. °C | Min. temp. °C | Average rain (mm) | Relative moisture (%) |
|---|---|---|---|---|---|
| January | 4.90 | 21.6 | -10.60 | 101.90 | 71 |
| February | 6.50 | 22.7 | -12.40 | 69.50 | 67 |
| March | 10.00 | 29.0 | 5.40 | 63.70 | 60 |
| April | 15.60 | 33.3 | -3.20 | 50.90 | 53 |
| May | 21.70 | 39.5 | 2.50 | 25.40 | 43 |
| June | 27.60 | 42.2 | 8.30 | 2.60 | 30 |
| July | 31.50 | 46.5 | 15.00 | 0.50 | 27 |
| August | 31.10 | 46.2 | 16.00 | 0.30 | 28 |
| September | 26.60 | 41.7 | 10.00 | 0.90 | 32 |
| October | 19.90 | 37.8 | 1.90 | 19.90 | 42 |
| November | 12.90 | 38.0 | -6.00 | 40.50 | 58 |
| December | 7.30 | 22.7 | -6.40 | 85.70 | 69 |

Implemented in Visual Basic (Windows Inc., Version 6.0), it can be run on a PC Microsoft Windows. Three terms of tractor workable days are determined according to heavy tractor workable in field for Harran region in Sanliurfa, Turkey.

To evaluate tractor workable days, average temperature, average raining and snowing quantity are considered as constraints factors in the CTWD Program. Because of this reason 20 years data related to the climate conditions of the plain were used as input data of the program. Constraints parameters and equations related to the program are given as follows (Vatandas, 1987):

- Rainfall quantity of the last day <= 2.5 mm,
- Rainfall quantity of the day before last day <= 5.1 mm,
- Rainfall quantity of two day before last day <= 7.6 mm,
- Rainfall quantity of a week from the last day to back <= 12.7 mm,
- Average temperature of the last day >= 4.4 °C,
- Snowing of the last day = 0 mm

In the CTWD model workable days can be determined for 50, 60, 70, 80 and 90% probability levels. However, in this study calculations were done according to the 80% probability level (Vatandas, 1987). CTWD was used to determine workable days between two selected dates' days. Firstly it calculates average workable days for each crop term according to the uncertainty weather conditions and then determines probable workable days. For probability of workable days following equation is used:

$$WD = \overline{X} - tS_{\overline{x}}$$

Where, WD: Probability of workable days; $\overline{X}$:20 years average workable days (concerned term); t:t distribution value depend on the degrees of freedom (v = n-1) and probability level (0.80); $S_{\overline{x}}$ : Standard error of the sample and it can be calculated as follows:

Table 2: Tractor types, tractor powers and related equipments for each machine systems

| S1 (MF285;57 kW) | S2 (F7056; 57.7 kW) | S3 (MF398; 75 kW) | S4 (Fd7740; 65 kW) | S5 (F8066; 62.6 kW) | S6 (F640; 44.5 kW) |
|---|---|---|---|---|---|
| Plough (3 nit) | Plough (3 unit) | Plough (3 nit) | Plough (3 nit) | Plough (3 nit) | Plough (3 nit) |
| Cultivator (9 Foot) | Cultivator (9 Foot) | Cultivator (9 Foot) | Cultivator (11 Foot) | Cultivator (9 Foot) | Cultivator (7 Foot) |
| Disc harrow | Disc harrow | Disc harrow | Disc harrow | Disc harrow | Disc harrow |
| Harrow | Harrow | Harrow | Harrow | Harrow | Harrow |
| Cotton planting | Cotton planting | Cotton planting | Cotton planting | Cotton planting | Cotton planting |
| machine (4 row) | machine (4 row) | machine (4 row) | machine (4row) | machine (4 row) | machine (3row) |
| Canal plough | Canal plough | Canal plough | Canal plough | Canal plough | Canal plough |
| Hoeing machine (4 row) | Hoeing machine (4 row) | Hoeing machine (4 row) | Hoeing machine (4 row) | Hoeing machine (4 row) | Hoeingmachine(3row) |
| Field sprayer | Field sprayer | Field sprayer | Field sprayer | Field sprayer | Field sprayer |
| Grain planting | Grain planting | Grain planting | Grain planting | Grain planting | Grain planting |
| machine (16 row) | machine (22 row) | machine (24 row) | machine (20 row) | machine (20 row) | machine (20 row) |
| Fertilizer sprayer | Fertilizer sprayer | Fertilizer sprayer | Fertilizer sprayer | Fertilizer sprayer | Fertilizer sprayer |
| Trailer (1050 kg) | Trailer (1150 kg) | Trailer (1800 kg) | Trailer (1780 kg) | Trailer (1109 kg) | Trailer (1058 kg) |

Table 3: Distribution of simple farms according to stratifies

| Group of farms | The number of farms in the sample villages | Rate (%) | The number of farms in the sample villages | Rate (%) |
|---|---|---|---|---|
| 5-15.5 | 313 | 67.9 | 42 | 67.74 |
| 15.6-22.5 | 77 | 16.7 | 10 | 16.13 |
| 22.6 + | 71 | 15.4 | 10 | 16.13 |
| Total | 461 | 100.00 | 62 | 100.00 |

Table 4: Gros margin of crops according to machinery systems ($/ha)

| Machine systems | Cotton | Wheat | Wheat+second crop corn | Vegetable |
|---|---|---|---|---|
| S1 (MF 285) | 1080.44 | 457.99 | 1094.1 | - |
| S2 (Fiat 7056) | 1148.76 | 461.00 | 778.83 | 3330.38 |
| S3 (MF 398) | 1187.33 | 570.29 | 1043.54 | - |
| S4 (Ford 7740) | 1156.13 | 525.53 | 1093.32 | - |
| S5 (Fiat 8066) | 1111.20 | 630.60 | 1118.71 | 3189.74 |
| S6 (Fiat 640) | 1141.74 | 458.05 | 838.78 | 2982.73 |

$$S_{\bar{x}} = S/(n)^{1/2}$$

Where, S: Standard deviation; n: Number of observations of 20 years.

Final, full workable days determined by program extracting the religious and national festival days from probability of workable days.

The analysis reported here proceeds as follows: First, the stochastic process generating the number of tractor workable days in farm field is estimated by the CTWD. The data used to estimate these tractor workable days are constructed from daily records of actual climate data between 1979-1998 reported by the Sanliurfa Meteorology Service Department, Turkey. Three terms of tractor workable days are determined according to heavy tractor workable in field for Harran region in Şanliurfa, Turkey. Term I, Term II and Term III were between October 20 and November 30, April 10 and May 5 and June 1 and July 15, respectively. Second, a LP farm-planning model is constructed to estimate optimum field size for each machine system. Present field size of farms was lower than that of output of the program in standpoint of their machinery system capacity. Third, present field size of farms and optimum field size of output of the program were compared.

**Linear Program (LP):** Linear-programming technique is common used in agricultural mechanization models. Reason of common using of this programming technique is due to its simplicity, giving nearly true result, giving chance to develop great models and easy understandable.

A linear programming model consists of objective function and its variables that limited by constraints (Evsahibioglu, 1994). Objective in problems of the linear programming is to determine the values of variables ($X_1, X_2, X_n$) that make the objective function (Z) maximum or minimum. Z is maximized or minimized for profit or for cost problems, respectively. Constraints determine the probable limits of decision variables in model. Constraint values of the decision variables are positive values and denote the limits of present resources of the system.

**Empirical model:** Using the principle of linear programming technique presented above, an empirical model was applied to Harran plain to maximize total profit of present farms. Decision variables, objective function and constraints are defined for this study as follows:

**Decision variables (as ha):** $X_1$: Cotton planting area; $X_2$: Wheat planting area; $X_3$: Wheat+second crop corn planting area; $X_4$: Vegetable planting area;

**Objective function**

$$Z = C_1 X_1 + C_2 X_2 + C_3 X_3 + C_4 X_4$$

Where, $C_1$, $C_2$, $C_3$, $C_4$ ($/ha) were the gross margin of cotton, wheat, wheat + second crop corn, vegetable, respectively. Gross margin values were given in Table 4 according to the machinery systems.

**Constraints**

- Average area size (A) should be greater or equal to the total planted area of crops

$$X_1 + X_2 + X_3 + X_4 <= A$$

- For each Term, total tractor workable time (h), $b_{1-3}$

Term I: $B_1 X_1 + B_2 X_2 + B_3 X_3 + B_4 X_4 <= b_1$ (181.52 h)
Term II: $B_1 X_1 + B_2 X_2 + B_3 X_3 + B_4 X_4 <= b_2$ (180.56 h)
Term III: $B_1 X_1 + B_2 X_2 + B_3 X_3 + B_4 X_4 <= b_3$ (426.30 h)

Where, $B_1$, $B_2$, $B_3$ and $B_4$ as h/ha were the tractor workable times for cotton, wheat, wheat + second crop corn and vegetable crops. $b_1$, $b_2$ and $b_3$ as hour were total tractor workable times for Term I, Term II and Term III.

**Agro technique constraints**

$$X_1 <= 0.50.A;\ X_2 <= 0.50.A;\ X_3 <= 0.20.A;\ X_4 <= 0.10.A$$

Daily workable time supposed 8 h for Term I and 10 h for Term II and III according to the region conditions.

## RESULTS AND DISCUSSION

**Gross margin, coefficients of constraints and total tractor workable time:** Gross margin values of crops ($/ha), coefficients of constraint (h/ha) and total workable time (h) for tractor systems are given in Table 4 and 5. For Term I, Term II, Term III the number of tractor workable days determined as 22.69 days (181.52 h), 18.06 days (180.56 h) and 42.63 days (426.30 h), respectively. Vegetable (tomato, pepper and eggplant) has been produced only for three machinery systems (S1, S5 and S6) and related constraint coefficients of vegetables are determined for these machinery systems.

Table 5: Coefficient in constraints equations ($B_1$-$B_4$) and total tractor workable time on field

| Machinery systems | Tractor work efficiencies on field (h/ha) $B_1$ | $B_2$ | $B_3$ | $B_4$ | Total tractor workable times (h) |
|---|---|---|---|---|---|
| S1 (MF 285) | 13.17 | 6.10 | 17.76 | - | 788.38 |
| S2 (Fiat 7056) | 11.49 | 6.09 | 16.03 | 7.4 | 788.38 |
| S3 (MF 398) | 11.29 | 6.12 | 16.17 | - | 788.38 |
| S4 (Ford7740) | 13.48 | 6.28 | 16.55 | - | 788.38 |
| S5 (Fiat 8066) | 11.58 | 5.74 | 15.57 | 6.36 | 788.38 |
| S6 (Fiat 640) | 14.86 | 7.13 | 18.58 | 7.54 | 788.38 |

**Present and Optimum Crop Planting Areas for Each Crop:** Table 6-7 show present and optimum planting areas for each crop according to the machine systems of 62 present farms. As it can be seen from Table 6 that the maximum present planting area was the area of cotton and vegetables have the lowest value of area size for all machinery systems. The highest value of cotton area size among in the machinery systems was the S4 and has 24.0 ha. This area value consists 72.73% of total planting area. The minimum planting area was, the area of vegetables, 0.15 ha. This value determined for machinery System 5 and it consists 0.73% of total planting area in this machine system. Minimum cotton planting area was 11.11 ha and appears in S2, this value consist 62.87% of total planting area in S2. Maximum vegetable planting area was 1.51 ha and determined for S6. This value consists 7.02% of total planting area in S6. Maximum value of second crop corn was determined for S1 and S3. Planting area for these machine sets was 2.5 ha and consists 12.20% for S1 and 10.29% for S3 of total areas.

In according to agro technique constraints in irrigated farms, it is suggested that cotton, second crop corn and vegetable production ratios are to be 50, 20 and 10% of crop pattern, respectively (Celik, 2000). It can be seen from Table 6 and 7 that cotton has bigger planting areas than suggested value and second crop corn and vegetable have less planting areas. These results were shown that cotton production has densely been carried out in the region and second crop corn and vegetable have been produced at fewer rates than necessary quantities. This condition was shown that agricultural production has not been carried out in the area according to crop pattern suggested previously (Celik, 2000).

**Present and optimum planting area of farms:** Optimum farm planting area was much higher than present farm area when compared according to used machinery system capacity. Increasing tractor capacity results in fixed cost and decreases net margin (Table 8).

The maximum average present farm planting area was determined for S4 and it was 33 ha. Maximum and minimum farm planting areas among optimum values determined by LP were 57.88 and 39.23 ha and appeared

Table 6: Present crop planting area (ha) according to machine systems

| Machine systems | Cotton Planting size (ha) | (%) | Wheat Planting size (ha) | (%) | Wheat+second crop corn Planting size (ha) | (%) | Vegetable Planting size (ha) | (%) |
|---|---|---|---|---|---|---|---|---|
| S1 (MF 285) | 13.45 | 65.61 | 4.55 | 22.19 | 2.5 | 12.20 | - | - |
| S2 (Fiat 7056) | 11.11 | 62.87 | 4.72 | 26.71 | 0.79 | 4.47 | 1.05 | 5.94 |
| S3 (MF 398) | 16.00 | 65.84 | 5.80 | 23.87 | 2.5 | 10.29 | - | - |
| S4 (Ford 7740) | 24.00 | 72.73 | 7.75 | 23.48 | 1.25 | 3.79 | - | - |
| S5 (Fiat 8066) | 16.50 | 80.49 | 3.14 | 15.32 | 0.71 | 3.46 | 0.15 | 0.73 |
| S6 (Fiat 640) | 14.87 | 69.16 | 4.12 | 19.17 | 1.00 | 4.65 | 1.51 | 7.02 |

Table 7: Optimum crop planting area (ha) according to machine systems

| Machine systems | Cotton | | Wheat | | Wheat+second crop corn | | Vegetable | |
|---|---|---|---|---|---|---|---|---|
| | Planting size (ha) | (%) | Planting size (ha) | (%) | Planting size (ha) | (%) | Planting size (ha) | (%) |
| S1 (MF 285) | 24.45 | 50 | 14.95 | 30 | 9.98 | 20 | - | - |
| S2 (Fiat 7056) | 28.94 | 50 | 11.57 | 20 | 11.58 | 20 | 5.79 | 10 |
| S3 (MF 398) | 25.79 | 50 | 15.47 | 30 | 10.32 | 20 | - | - |
| S4 (Ford 7740) | 24.65 | 50 | 14.79 | 30 | 9.86 | 20 | - | - |
| S5 (Fiat 8066) | 25.66 | 50 | 15.4 | 30 | 10.26 | 20 | - | - |
| S6 (Fiat 640) | 19.61 | 50 | 11.76 | 30 | 7.85 | 20 | - | - |

Table 8: Present and optimum planting areas of farms and ratios of unused field size

| Machine systems | Present field size (ha) | Optimum field size (ha) | Unused field size (ha) | Unused ratio (%) |
|---|---|---|---|---|
| S1 (MF 285) | 20.50 | 49.89 | 29.39 | 58.91 |
| S2 (Fiat 7056) | 17.67 | 57.88 | 40.21 | 69.47 |
| S3 (MF 398) | 24.30 | 51.59 | 27.29 | 52.90 |
| S4 (Ford 7740) | 33.00 | 49.30 | 16.30 | 33.06 |
| S5 (Fiat 8066) | 20.50 | 51.32 | 30.82 | 60.05 |
| S6 (Fiat 640) | 21.50 | 39.23 | 17.73 | 45.19 |

Table 9: Present and optimum gross margin

| Machine systems | Present gross margin ($/ha) | Optimum gross margin ($/ha) | Loss of gross margin ($/ha) | Ratio of loss (%) |
|---|---|---|---|---|
| S1 (MF 285) | 19351.02 | 44727.63 | 25376.61 | 56.73 |
| S2 (Fiat 7056) | 19050.81 | 66880.63 | 47829.82 | 71.51 |
| S3 (MF 398) | 249.13.81 | 50212.96 | 25299.15 | 50.38 |
| S4 (Ford 7740) | 33186.63 | 47051.32 | 13864.69 | 29.47 |
| S5 (Fiat 8066) | 21587.62 | 49635.47 | 28047.85 | 56.51 |
| S6 (Fiat 640) | 24207.54 | 34360.61 | 10153.07 | 29.55 |

for S2 and S6, respectively. Accordingly, S6, minimum-planting area determined by LP, can easily cultivate the maximum present farm planting areas that have 33 ha. It can be concluded that systems used for present farm planting area have much capacity and power for those farm planting area. Used systems are not economical to cultivate present farm areas. For example, S2 cultivating 17.67 ha in present farm, but if S2 used with its maximum capacity it can cultivate 57.88 ha that are nearly 3.3 bigger than that of present farm area. In this case highest margin can be obtained by reducing capacities of machinery systems or renting tractor and systems to be used with its full capacity. S4 is also used for its 66.94% capacity.

A dynamic programming model is described in determining the cost of autumn plowing and drilling taking into account weather uncertainty, soil compaction and timeliness of sowing. The model allows an economic comparison to be made of machinery with different compaction characteristics. For example, on a 200 ha winter wheat farm, two 90 kW tractors are optimum at three sites although the average workable days range from 33 to 56. A gantry system needs to work considerably faster than a 120 kW tractor to be profitable (Audsley, 1984). Demirci (1986) has determined that two tractors owned 37 and 55 kW powers can do an agricultural production on 67.5 and 110 ha field sizes in 850-1000 h/year work times. Isik *et al.* (1995) determined optimum tractor powers for different field sizes on irrigated farms for Southeast Anatolia Project area. The researchers estimated that 20 and 50 ha farm fields could be cultivated by tractors possessed 24.84 and 43.14 kW powers. According to the results of this study, it might be rantably cultivated 57.88 and 39.23 ha farm fields with the tractors owned 57.7 and 44.5 kW powers.

**Present and optimum total gross profit:** Minimum value of present total gross profit and maximum value of optimum total gross profit was determined for S2 and they were calculated as $ 19050.81 and $ 66880.63, respectively (Table 9). The difference between present and optimum total gross profit values was the least for S6 ($ 10153.07). This value was composed from 29.55% of optimum total gross profit. This condition has shown that farms owned S6 machine system earned 29.55% less profit according to determined maximum profit value. S2 had the least total gross profit ratio of machinery sets, which is 71.51% less than maximum total gross profit. For S4, this value had been determined as 29.47%. In the other machinery sets, the loss total gross profit ratios were more than 50%. These results have shown that farms in the region were not carried out an economic agricultural production according to total gross profit.

## CONCLUSIONS

It can be concluded that suitable tractor power for available machinery capacities should be selected or rented a suitable tractor for their farm operation. Also, tractor capacities used by farmers must be suitable for production technique and farm field size to decrease the production costs and increase the profit. On the other hand, the planting ratios of second crops and vegetable crops in agricultural production should be increased maximum profit in irrigated fields of the plain.

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