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Optimization of Machinery Use on Farms with Emphasis on Timeliness Costs

B. Najafi[1*], and S. Torabi Dastgerduei[2]

ABSTRACT

This study was conducted to determine timeliness costs in using machinery and their effects on farmers' revenues. In addition, optimum cropping pattern was compared with the existing one assuming removal of timeliness cost. For the purpose of the study, mixed integer and linear programming methods were used. The study was conduced in Marvdasht region in southern Iran. The data were collected through interviews with a sample of 80 farm managers. Selected farmers were divided into six groups in terms of farm size and farm machinery use, and in each group a representative farm was selected. Findings of the study showed that 19 percent of farmers owned and 81 percent rented tractor and, as a result, timeliness cost was considerable for the latter group. The results also showed that for the farmers whose farm size was more than 10 hectares, it was justified to buy tractor and rent a combine. The results revealed that there was a gap between the optimum and existing cropping patterns with respect to timeliness cost and gross margin increased mostly in the groups that owned tractor and more than five hectares of land. Finally, in order to minimize timeliness cost, joint ownership of machinery by neighboring farms was recommended.

Keywords: Cost minimization, Cropping pattern, Linear programming, Machinery selection.

INTRODUCTION

Increasing international competition is putting pressure on farming in both developed and developing countries to increase productivity and decrease production costs. Machinery cost is considered a major component of production cost. More efficient use of machinery for crop production could help to increase productivity. Agricultural development has taken place in Iran for several decades and has got momentum during recent development plans. Since the majority of farms are small, farmers are used to rent farm machinery, especially for plowing, planting, and harvesting. Under these circumstances, farmers may not have access to farm machinery at optimum time and incur a cost which is called timeliness cost. When a farm operation is performed, there is optimal time for that with respect to crop value. When the operation is not performed on time, value of the crop may decrease in quantity and or quality. The economic consequences of performing a field operation at non-optimal time are called timeliness costs. Gunnarsson (2008) and Edwards and Boehlije (1980) believe that optimum machinery operation from economic point of view is selection of cost minimization for operation costs such as labor and timeliness cost. Timeliness has received considerable attention in the machinery selection literature. With increasing prices for energy and rapid rate of mechanization, it is becoming increasingly important for farmers to minimize machinery cost. Different kinds of

[1] Islamic Azad University, Marvdasht Branch, Islamic Republic of Iran.
[2] Natural Resources Research Institute, Ministry of Agriculture, Tehran, Islamic Republic of Iran.
*Corresponding author; e-mail:banajfi@gmail.com

machinery are used for farm operations, notable among them, especially in Iran, are tractor and combine. As a result of rapid expansion of mechanical technology, share of machinery cost in the total production costs has been increased. For example, in Swedish farms, share of machinery cost in the total production cost is about 25 percent (Gunnarsson, 2008).Therefore; performing farm operation by machinery at optimal time could decrease production costs and increase the value of the crop. If operation is performed with delay, value of crop may decline due to changes in quantity and/or quality (ASABE, 2006a).

Timeliness costs have received special attention for efficient crop management and machinery selection, particularly crop establishment, spraying, harvesting, and soil compaction (Ekman, 2000, Chapman *et al*., 2008). Timeliness costs are significant in regions with short periods available for sowing and harvesting and since they are affected by weather such costs would increase and are subject to annual variations (de Toro, 2005). To obtain accurate results, it is important to calculate timeliness losses in terms of changes in both quantity and quality of yield, since quality parameters such as the nutrient content change as a result of delay in farm operations, especially in harvesting (Bernes *et al*., 2008). However, few data are available on timeliness losses due to quality since timeliness costs are often measured based on yield decrease (de Toro, 2005). ASABE (2006b) cites timeliness coefficients showing changes in crop return due to timing of sowing and harvesting for various states in the USA.

Most of the previous researches are related to planting delays caused by excess soil moisture. Baker and Mc Carl (1982) showed that planting delays postpone crop maturity and harvesting, which may preclude fall tillage operations in preparation for spring planting in the following year. Delays in harvesting spring planted crops directly affect the timeliness of fall operations. Total acreage planted in fall then affects the crop enterprise mix and, thus, influences yield and income in the following year. From risk management point of view, this inter-temporal stochastic variation in yield, acreage, and income may be of considerable importance. Wetzstein *et al*. (1990) have presented a case study on the effect that timeliness in machinery operations had on machinery selection for a soybean and wheat double-crop production system in the southern coastal plain. They investigated the importance of inter-temporal production linkages and inadequate soil moisture on machinery selection and concluded that failure to include these dimensions could result in erroneous machinery selection.

Since finding minimum cost with simple mathematical methods is not feasible, most of the models used are based on the mathematical programming. By using adaptation model, Sorensen (2003) has forecasted optimal harvesting time under various soil moisture situations for thirty years. The results indicated that optimal time, to a large extent, depends on the selected crop and moisture levels. The American Association of Agricultural Engineers has proposed a model which has been used by Sorensen (2003) and plenty of other studies in which farm machinery timeliness cost has been calculated. Field machinery capacity must be enough to complete operation at proper time not only in good but also in bad climatic conditions. De Toro (2004) is of the opinion that determination of optimum machinery capacity in relation to farm size is not easy due to the fact that machinery costs are related to timeliness cost that, in turn, are related to days which the operation could be performed on the farm. This factor is not predictable and is not under control and affects farm production.

Some possible solutions have been mentioned to minimize timeliness cost. Serivatava *et al*. (2006) believed that increasing machine capacity is one way to decrease timeliness costs, as larger machines with greater capacity can accomplish more timely work. A solution may not be applicable in regions dominated by small farms. Optimal work organization and machinery utilization are important in achieving cost reduction (Sorensen, 2003). Another way to decrease timeliness costs is planting different crops or varieties with different maturation dates. Another possible solution is joint use of farm machinery which farmers could take advantage of using advanced technology. De Toro and Hansson (2004) studied six farms which used machinery jointly by using simulation method. The results indicated that joint use of machinery enabled farmers to reduce the total cost of machinery including timeliness cost by 15 percent and the needed investment for machinery by 50 percent. Michael *et al*. (1990) studied the importance of timeliness in selection of machinery complements for double–crop wheat and soybean production in the southern coastal plain. The research investigated the importance of inter-temporal production on linkages and inadequate soil moisture on machinery selection. They concluded that failure to include these dimensions could result in erroneous machinery choices.

Gunnarsson and Hansson (2004) made a study on optimization of farm machinery operation in Sweden. Results indicated that machinery costs per hectare in organic products were 58 percent more than ordinary ones. Brown and Schoney (2008) stated that proper machinery sizing for a given farm had the potential of reducing costs, and thereby increasing profits substantially. They calculated least-cost machinery size for grain farms using electronic spreadsheets and microcomputers.

Survey of available literature demonstrates that nearly all studies related to the effects of timeliness cost have been made in developed countries. In most of the developing countries including Iran, it seems that the problem is more serious mainly due to dominance of small farms and financial constraints, in which case, most farmers have to rent the needed machinery for farm operations through contractors and in most cases they have to wait a while, and this could delay the operation and increase the costs. Agricultural mechanization started about four decades ago in Iran and has got momentum in recent years. In spite of some progress, level of mechanization is far from optimum. According to available statistics, the average horsepower per hectare in the country is around 0.5, which is considered to be low compared to world standards. Rasouli *et al*. (2009) showed that the main constraints of farm mechanization were "small farm size" and "land fragmentation". Assessing challenges facing development of farm machinery in Iran, they concluded that the most important challenges were insufficient subsidy, aged farm machinery, insufficient equipment and spare parts, farmers' slow acceptance of new technology, weak financial position, and inefficient extension services. Reviewing current status of agricultural mechanization in Iran, Tabatabaeifar and Omid (2005) reached the conclusion that to speed up agricultural mechanization in Iran, government must support investment in research and development and strengthen manufacturing of farm machinery along with distribution of tractor power based on regional and technical needs. Fazlolahi *et al*. (2012) in their case study in Marand Township in Eastern Azarbaiejan Province indicated that the situation was critical mainly due to worn out power resources and low efficiency rate. They recommended increasing the number of tractors with medium power. Amjadi and Chizari (2006) made a research on agricultural mechanization in Iran and stated that the number of tractors and combines was not sufficient and this situation led to yield quantity loss and waste due to delay in cultivation and harvesting. They mentioned that while the average number of plant harvesters per hectare was six in the world, it was only 0.5 per hectare in Iran. In case of wheat, for example, deficient number of combine causes nine percent loss in yield quantity.

The purpose of this research was to conduct a case study in Marvdasht region in southern Iran to determine timeliness cost and its effects on cropping mix. The attempt was made to illustrate the effects of removing timeliness on crops yields and farmers' revenue. In addition, the study aimed to show for which group of farmers it is advisable to rent or to buy their needed machinery.

MATERIALS AND METHODS

To achieve the objectives of the study, timeliness cost was calculated following a method developed and used in mixed integer programming model by Gunnarsson and Hansson (2004) for optimization of machinery cost. The model was adjusted based on available data and the case under study. Linear programming method was used for crop mix optimization with respect to timeliness cost. Timeliness cost was calculated by using the following formula:

$$W = \frac{KA^2YV}{ZGC_i(pwd)} \quad (1)$$

Where, W denotes timelines cost per year (Rials), K for timelines cost coefficient, A for cultivated area (ha), Y for yield per hectare (ton), V for yield value (ton-Rials), Z= 2 for harvesting and 4 for other operations, G denotes time for work on farm per day, pwd for probability of working days, C_i for machine capacity (ha per hour).

To minimize the total cost, the objective function in linear programming model was used as follows:

Min:

$$Z=C_1X_1+C_2X_2+C_3X_3+C_4X_4+\sum_{k=1}^{l}\sum_{j=1}^{h}EkjW_{Kj} \quad (2)$$

Subject to:

$X_1+X_2\geq 1$

$X_3+X_4\geq 1$

$W_{Kj}\geq E_{kj}$

j= 1… h

k= 1… l

Where, C_1 denotes annual cost of buying tractor ha^{-1}, X_1 stands for number of tractors, C_2 is total cost of rent and timeliness ha^{-1}, X_2= Renting or not renting tractor, C_3 is cost of buying combine ha^{-1}, X_3 stands for number of combines, C_4 is total cost of rent and timeliness ha^{-1}, X_4 = Renting or not renting combine, W_{kj} is the amount of each input, kj for quantity of input per unit of product, and E_{kj} is the minimum of each input to produce each unit of product. Timelines costs for cultivating and harvesting were calculated and included in matrix (d):

$$dj= Lj\times P_{j\times}Aj \quad (3)$$

Where, Lj stands for timeliness cost for product j (kg ha^{-1} per day), P_j for price of each product (Rials kg^{-1}), and Aj for cultivated area (ha).

Machinery timeliness cost S (in Rials) was calculated using the following formula for each crop j handled with the machine:

$$S = \Sigma_{i=1}^{m}(\frac{n_i-1}{2})k_ip_in_i \quad (4)$$

Where, m is the number of crops grown, n_j is the average number of days available to perform the operation on crop j, P_j is the price of each product (Rials kg^{-1}), and k_j is the average area in hectare of crop i harvested per day.

The parameter n_i was calculated by the following formula:

$$n_i = \frac{A_i}{B\times P\times C} \quad (5)$$

Where B is the number of work hours per day. P is the workday probability (%) and C is the capacity of machine (horsepower per hectare)

Since only two farmers owned wheat combine, farmers were classified into six groups based on farm size and tractor ownership. Mechanical operation included tillage, furrow, seeding, chemical fertilize spreading, and harvesting. Farmers decide on the extent of mechanical operation based on the nature of the product and their financial ability.

To determine the optimum crop mixture, linear programming for income maximization was used. Products produced by farmers in the region were wheat, rice, barley, corn, sugar beet, and Canola.

Needed data were collected from selected farms in Marvdasht Township in Fars Province of Iran, and a major wheat producer region in the country. The region is dominated by small to medium farms and crop production is relatively mechanized. There are a number of contractors in the area who own machinery and rent them to farmers. A sample of 80 farms was selected by stratified sampling method and interviewed. First, on the basis of degree of mechanization, a sample of ten villages was selected, in which the farms were divided into three homogeneous groups based on their size for determination of optimum cropping pattern and with respect to the minimum timeliness cost, farms were divided into six categories and in each group representative farms were selected.

RESULTS AND DISCUSSION

Findings of the study showed that 23 percent of farmers owned tractor and 77 percent rented tractor for farm operations. Only two farmers owned wheat combine. In terms of farm size, 36 percent of farmers had less than five hectares of land, 38 percent 5-10 ha, and 26 percent had more than 10 ha. Table 1 shows average cultivated areas for the major crops in various groups. As Table 1 illustrates, wheat with cultivated area of 39.7 hectares stands in the first place and rice stands in the second place and is produced in all groups, except in the third one. Canola, which is rather a newly introduced crop, is produced only in the fifth and sixth groups, which did not own tractor.

Ownership or renting of tractor might have considerable effect on timeliness cost. Table 2 shows that only 23 percent of the farmers owned tractor and the rest of them rented machinery through contractors.

Since the majority of farmers used to rent machinery for farm operations, the probability of facing with timeliness cost was high. Table 3 shows timeliness costs for various products in each group of farmers. As Table 3 shows timeliness cost for wheat was higher compare to the other crops. This was due to the fact that wheat was the only crop that all activities from cultivating to harvesting were mechanized and as a result the timeliness cost of it was more than other crops

To determine the optimum point for buying machinery to minimize timeliness cost for each group of farms, liner programming model was applied. Table 4 shows total costs of using machinery under present and optimum conditions.

As Table 4 shows, in the first group with

Table 1. Average cultivated area under the major crops in various groups (ha).

Crop	Group					
	1	2	3	4	5	6
Wheat	3.7	4.2	11.1	2.2	5.7	12.8
Barley	0.4	-	1.1	-	0.6	2.1
Rice	2.1	3.1	-	2.2	1.9	3.1
Corn	0.3	0.6	3.3	-	1.1	2.1
Sugar beet	0.2	-	0.5	-	0.6	0.5
Canola	-	-	-	-	0.5	0.5

Table 2. Distribution of farmers based on ownership and renting tractor.

Farm size	Ownership		Renting	
	No	%	No	%
< 5	3	4	26	32
5-10	7	9	23	29
>10	8	10	13	16

Table 3. Average timeliness cost for machinery per day hectare for various farms and products (000, Rials).

Crop	Farm size (ha)					
	<5		5-10		>10	
	Cultivating	Harvesting	Cultivating	Harvesting	Cultivating	Harvesting
Wheat	532.8	343.2	664.8	686.4	1.9205	895.2
Rice	1334.4	444.0	2.044	-	-	-
Barley	984.0	984.0	1.468	-	784.8	674.44
Sugar beet	-	499.2	-	-	-	-
Colza	-	-	-	-	-	2861.7

Table 4. Comparison of total costs of using machinery in present and alternative conditions in three groups of farms (000, Rials).

Total costs	1-5 ha	5-10 a	>10 ha
Present	6326.4	8676.0	11595.8
Alternative	6597.6	8488.8	11626.1

farms less than five hectares, present machinery cost was less than alternative condition. At present, most of the farmers in this group rented tractor and combine harvester. The result in alternative condition indicated that buying machinery in this group was not economically justified. In the second group, machinery cost under present condition was more than alternative condition, which implied that it was less costly for the farmers to buy tractor and rent combine harvester. At present, a small number of farmers in this group own tractor and the majority of farmers rent machinery. In the third group, with farms over 10 hectares, the best alternative was buying tractor and renting the combine. In this group, the cost difference between present and alternative condition was considerable because most of the farmers rented machinery and, as a result, timeliness cost was considerable. On the whole, in spite of timeliness cost in the first group due to small farm size and high cost of buying machinery, it was less costly to rent machinery, while in the second and third groups, due to larger farm size, buying tractor was advisable.

To determine the optimum crop pattern to maximize revenue with respect to timeliness cost, farms were divided into six homogenous groups in terms of cultivated area and owning or renting tractor. Table 5 shows the cultivated areas for various crops under present and optimum conditions.

Table 5 shows that in all groups the cultivated areas for wheat and rice were close to optimum condition. Land allocated

Table5 . Cultivated areas allocated to crops under present and optimum conditions in various groups of farms (ha).

Crop	Wheat		Rice		Barley		Corn		Sugar Beet		Canola	
Groups	P [a]	O [b]	P	O	P	O	P	O	P	O	P	O
1	3.75	2.0	0.3	1.0	2.0	0.0	2.75	2.0	0.1	0.0	0.0	2.25
2	4.0	7.2	0.0	1.0	3.2	0.0	0.7	4.8	0.0	0.0	0.0	0.0
3	11.2	7.0	1.0	1.0	0.0	0.0	3.25	4.8	0.4	0.0	0.0	0.85
4	2.0	2.0	0.0	1.0	2.2	0.0	0.0	2.2	0.0	0.0	0.0	1.0
5	5.5	6.0	0.6	1.0	2.0	0.0	1.0	0.4	0.5	0.0	0.5	1.7
6	12.7	7.0	0.2	0.1	3.0	0.0	2.0	0.0	0.5	3.38	0.5	0.75

[a] Present, [b] Optimum.

Table 6. Gross margin in present and optimum cropping patterns for various groups (million Rials).

Group	1	2	3	4	5	6
Optimum	192.04	426.24	664.32	139.2	196.8	330.2
Present	159.12	386.15	442.08	102.24	132.0	323.8

to corn in three groups was relatively higher in optimum condition. Canola was added to crop pattern in all groups, except the second one. Sugar beet was included in the optimum condition only in the sixth group of farms which had over 10 hectares of land. Cultivated areas in all groups increased in the optimum cropping pattern, mostly, in groups which owned tractor and had more than five hectares of land. Cultivated areas in the second and fourth groups with lands between 5-10 hectares increased, but in the other groups decreased in the optimum cropping pattern mainly due to considerable cost timeliness in the these groups. Another major change in optimum cropping pattern condition was addition of Canola in most of the groups. In the existing condition, canola was produced only in the fifth and sixth groups. Table 6 illustrates the gross margin under present and optimum cropping patterns for various groups.

As Table 6 shows, gross margin is higher in optimum compared to existing cropping patterns. The highest increase in gross margin was related to those farmers with more cultivated areas who presumably owned tractor and did not incur timeliness cost.

Findings of the study indicated that timeliness cost was an important item in operation costs of farms through its effect on quantity of production. Also, there was an inverse relation between timeliness cost and farm size. Since most of small farmers had to hire machinery, they could not obtain the needed machinery at proper time and this affected their products value. On the other hand, it was costly to buy machinery for small farms due to investment and depreciation cost. The findings of the study also suggested that minimizing timeliness cost could paved the way for more efficient utilization of available resources through optimization of cropping pattern. On the basis of findings, ways to decrease timeliness cost could lead to increase in revenue, productivity, and competitiveness both in domestic and international markets.

Based on findings of the study, the following recommendations are made:

With respect to considerable timeliness cost for farmers who rent machinery for farm operations, formation of machinery cooperatives for joint use of machinery is recommended.

In cases where formation of machinery cooperatives is difficult, neighboring farmers could form a group to buy machinery for joint use.

With respect to increasing revenue in optimum cropping patterns, training extension workers to help farmers to use improved techniques for optimization of resources to produce more valuable crops is recommended.

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بهینه سازی کاربرد ماشین در مزارع با تاکید بر هزینه تاخیر زمانی

ب. نجفی، و س. ترابی دستگردویی

چکیده

با توجه به اهمیت هزینه های تاخیر زمانی در کاربرد ماشین آلات در مزرعه هدف این مقاله تعیین این هزینه و اثر آن بر درآمد کشاورزان می باشد. افزون براین با فرض حذف هزینه تاخیر زمانی ترکیب بهینه محصولات تعیین و با الگوی موجود مقایسه شده است. در راستای اهداف مطالعه روش های برنامه ریزی خطی و برنامه ریزی عددی مختلط مود استفاده قرار گرفته است. برای انجام بررسی شهرستان مرودشت در استان فارس در جنوب ایران انتخاب و اطلاعات مورد نیاز از نمونه تصادفی ۸۰ نفری مدیران مزرعه از طریق مصاحبه و تکمیل پرسشنامه جمع آوری شده است.نمونه منتخب بر مبنای اندازه مزرعه و مالکیت و یا اجاره ماشین آلات به شش گروه تقسیم و در هر گروه یک مزرعه نماینده انتخاب گردید. نتایج مطالعه نشان داد که ۱۹ درصد کشاورزان دارای تراکتور و ۸۱ درصد از تراکتور اجارهای استفاده کرده و در نتیجه هزینه تاخیر زمانی برای گروه اخیر قابل ملاحظه بوده است.نتایج همچنین نشان داد که برای کشاورزان با بیش از ده هکتار زمین خرید تراکتور دارای توجیه اقتصادی می باشد. نتایج همچنین نشان داد که میان الگوی کشت موجود و بهینه با توجه به هزینه تاخیر زمانی تفاوت وجود داردو در صورت انجام بموقع عملیات بازده برنامه ای برای همه گروهها افزایش یافته و این افزایش برای گروههای با اندازه مزرعه بیش از پنج هکتار بیشتر بوده است. بمنظور کاهش هزینه تاخیر زمانی مالکیت مشترک ماشین ها توسط صاحبان مزارع مجاور توصیه شده است.