Comparison of the Economic Performance of Robotic Milking System and Conventional Milking System

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Abstract: Usage of robotic milking systems is increasing more and more to decrease labor input and to enhance the life quality of dairy farmers. Over 30,000 milking robots are operational on dairy farms around the world today, heading by West Europe, United States of America, Canada and Australia. According to a study in 2016, there are 54 milking robots in 21 farms in Turkey. Its adaptation rate in Turkey is slow because usage of robotic milking systems (RMS) is new and there is not enough information about the economic performance of robotic milking systems against conventional milking systems (CMS). In this paper, literature about the economics of robotic milking was reviewed to compare with conventional milking systems. Data of investment cost, labor input, energy consumption, feed cost, milking frequency, milk yield and net income criteria's from 33 studies on 13 different countries between 1998-2017 were compiled as a table. According to the table, a comparison was done for each criterion by years and recommendations for future were done.

Keywords: *Comparison, economic performance, robotic milking systems;*

Robotik ve Geleneksel Sağım Sisteminin Ekonomik Performansının Karşılaştırılması

Özet: Süt sağım robotlarının; süt çiftliklerinde iş gücü ihtiyacını azaltmak ve çiftçilerin yaşam kalitesini arttırmak amacıyla başta batı Avrupa, Amerika Birleşik Devletleri, Kanada ve Avustralya olmak üzere kullanımı her geçen gün artmaktadır. Bugün dünya genelinde 30,000'nin üzerinde süt sağım robotu kullanıldığı tahmin edilmektedir. 2016 yılında gerçekleştirilen bir çalışmada Türkiye'de 21 çiftlikte kurulu toplam 54 adet süt sağım robotu kullanıldığı tespit edilmiştir. Bu teknolojinin kullanımının yeni olması; süt sağım robotlarının, diğer otomatik sağım sistemlerine göre ekonomik performansının işletmeciler tarafından tam olarak bilinmemesi nedeniyle süt sağım robotları yavaş benimsenmektedir. Bu çalışmada, robotik süt sağım sisteminin ekonomik performansı ile mevcutta kullanılan geleneksel sağım sistemlerinin karşılaştırılması amacıyla; bu konuda gerçekleştirilen yerli ve yabancı literatür taranmıştır. Tarama sonucunda 13 farklı ülkede, 1998-2017 yılları arasında gerçekleştirilen, 33 adet çalışmada yer alan süt sağım robotları kullanılan çiftliklerin yatırım maliyeti, işgücü ihtiyacı, enerji tüketimi, yem tüketim miktarı, sağım sıklığı, ineklerin verimliliği ve işletme geliri verileri bir tabloda derlenmiştir. Derlenen bu bilgiler yardımıyla robotik süt sağım sistemi kullanan işletmeler ile kullanmayan işletmelerin ekonomik performansı yıllar itibariyle ve yukarıda sayılan kriterler çerçevesinde karşılaştırılmış ve ileriye yönelik öneriler sunulmuştur.

Anahtar sözcükler*: Karşılaştırma, ekonomik performans, robot süt sağım sistemleri;*

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INTRODUCTION

The most remarkable technological innovation in the dairy sector in recent years is undoubtedly robotic milking systems (RMS). In 1992, the Dutch company Lely introduced the first milking robot (Schewe and Stuart, 2015). After the introduction of the first RMS, the adoption of the new technological innovation proceeded slowly and in 1996 only about 45 installations were used on commercial farms with the majority in the Netherlands. By the end of 2009, RMS was estimated to be deployed on more than 8,000 dairy farms in over 25 countries worldwide and the number rose to 10,000 by 2010. Today, the number has risen to 30,000 (Jiang et al., 2017). Still, the major number of the robotic milking stations is located in Western and Northern Europe but numbers are continuously growing in other countries over the globe. The highest proportion (30 %) of robotically harvested milk in a country was reached by Iceland in 2012 (Sandgren et al., 2015). It is currently not possible to classify establishments that using RMS or conventional milking systems (CMS) on the basis of country and to give the RMS numbers on a country-by-country basis. This is due to the fact that there is no international organization currently collecting information regarding the use of RMS. In addition, a literature related to this statistics could not be reached in the literature research.

RMS is a system that allows cows to be milked voluntarily with little or no human intervention. The main aim of the RMS is to take the drudgery out of milking and to allow the farmer to concentrate on management and stockmanship. Human health issues, unusual work hours, and strenuous working conditions have made obtaining reliable milking labor a major concern of dairy producers. One of the principle attractions of RMS is that they may provide an opportunity to break the labor barriers to expansion (Fisher et. al., 2003). But besides reducing needed labor force, RMS's economic performance is an important issue.

Dairy farmers are interesting RMS but they have not enough information about the economic performance of RMS against CMS. For this purpose, RMS and CMS were compared in this study according to investment cost, labor input, energy consumption, feed cost, milking frequency, milk yield and net income criteria's. As a result of the study, economic and social effects on the farm were assessed and recommendations for future were done. Compiling the results of previous studies on the economic performance of RMS can be beneficial for the dairy farmer to decide having this technology and for researchers to guide their future studies.

MATERIALS and METHODS

During this study, literature about economic compression of RMS and CMS was reviewed and the data presented in this paper was collected from 33 studies carried out in 13 different countries from 1998 to 2017. These countries were given in Table 1. In the table, the total number of references is higher than 33. Because two of the studies were carried out in two or more countries.

Table 1. Number of references by country

Country	Number of References
Belgium	1
Canada	5
Denmark	3
Finland	3
Germany	2
Holland	8
Ireland	2
Japan	1
Norway	1
Poland	1
Spain	1
Turkey	1
USA	8
Total	37

As a result of the literature research, the economic performance criteria and values used in each of the 33 studies were prepared as a detailed table. When the table was completed, it was determined that a total number of 7 criteria were used in 33 studies on the comparison of RMS and CMS. These criteria were; investment cost, labor input, energy consumption, feed cost, milking frequency, milk yield and net income. Considering that in preferring RMS by dairy farmers, main factors that farmers take in account, were a decrease in labor force requirement and increase in milk yield and net income; it was considered that these 7 criteria are sufficient to reveal the positive and negative aspects of RMS according to CMS.

To interpret data's, percentage changes were calculated. The percentage change or percent change is defined as a way of expressing any change in a given variable. It denotes the change in the old value and the new one. In mathematics, the concept of percent change is used to describe the relationship between the old value of a variable and the new value of the same variable. Positive values indicate a percentage increase whereas negative values indicate percentage decrease. After data's were compiled, percentage changes between RMS and CMS were calculated by following formula (V_1: Value of RMS; V_2: Value of CMS);

$$\text{The percentage change} = (V_1-V_2) / V_2*100$$

The percentage change was not calculated by using the base year; it was calculated by using the value of CMS as the base. Calculations were done separately by using RMS and CMS values for each reference independent from the year. For example, energy consumption factor was calculated in 5 studies. For each of these 5 studies, by using energy consumption value of RMS (V1) and energy

consumption value of CMS (V2), percent change was calculated separately and the results were presented as a table.

After calculating percentage change values, the mean and standard deviation were calculated by using calculated percentage changes. Normal distribution function calculated, normal distribution curve drawn and values out of normal distribution defined by using z-score. To define normal distribution range, the z-score value in the probability of 40% (0.3997) was used which is 1.28 in the z-score table. By using following formula, positive and negative range values defined (z: z-score (Standard Score), x: the value to be standardized; μ: the mean; σ: the standard deviation).

$$z= (x - \mu) / \sigma$$

RESULTS and DISCUSSION

Milk Yield

In 15 of the 33 studies, which have been carried out between 2003 and 2015, results of milk yield for both RMS and CMS were presented. Milk yield percentage change was calculated and presented in Table 2. When Table 2 was examined, in only one of these studies milk yield percentage showed a decrease and in only one of them, no difference was observed. In other 13 studies, it has been determined that the milk yield is higher in dairy farms using RMS than in dairy farms using CMS.

When the average of all results is taken, it is seen that the dairy farms using RMS obtained 14.66% higher milk yield than dairy farms using CMS. As it is seen in Table 2, an increase of 98% in the study carried out in 2010. By calculating the mean and standard deviation, it can be regarded as an exception because it is out of the normal distribution (Figure 1). If we exclude this exceptional value, we can say that using RMS in dairy farms increased milk yield by an average of 8.66% when compared with CMS.

Table 2. The percentage change of milk yield

Reference No	Year	Country	Milk Yield Change (%)
9	2003	Canada	0,00
8	2003	Canada	2,00
30	2003	USA	5,00
41	2004	Holland	2,00
14	2004	Holland	6,95
24	2005	Denmark	17,71
12	2007	Finland	24,10
28	2008	Canada	4,00
13	2010	Finland	98,57
27	2011	USA	23,47
39	2012	Ireland	- 5,00
37	2013	USA	10,00
40	2014	Norway	9,46
3	2014	Poland	12,28
32	2015	USA	9,31
		Mean	14,66

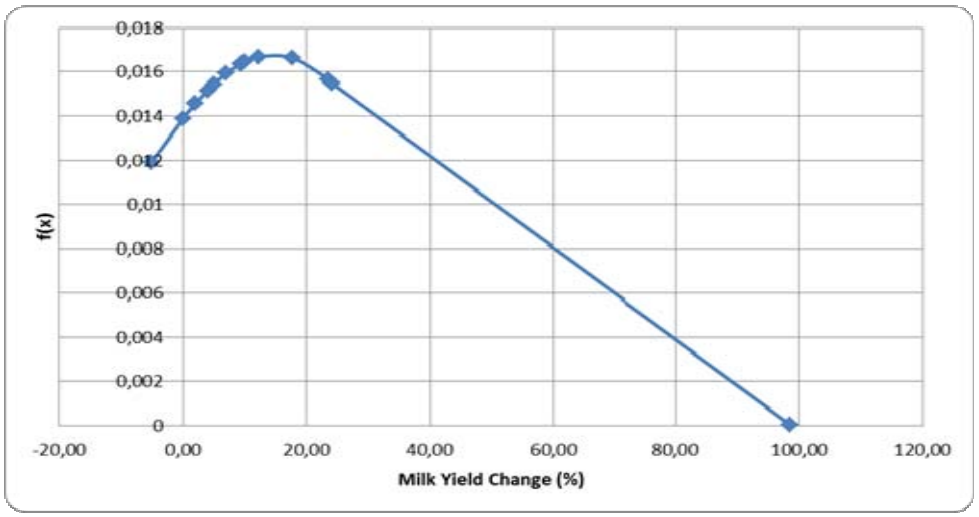

Figure 1. Normal distribution curve of milk yield

Investment costs

In 9 of the 33 studies, which have been carried out between 1998 and 2015, results of investment costs for both RMS and CMS were presented. Investment cost percentage change was calculated and presented in Table 3. All

percentage change values are positive in Table 3. This means that RMS investment cost is higher than CMS investment cost.

Table 3. The percentage change of investment costs

Reference No	Year	Country	Investment Costs Change (%)
25	1998	USA	83,88
8	2003	Canada	66,67
41	2004	Holland	150,33
20	2005	Finland	309,68
28	2008	Canada	8,70
35	2010	Holland	25,85
29	2011	Canada	76,00
40	2014	Norway	35,21
23	2015	Ireland	21,06
		Mean	86,38

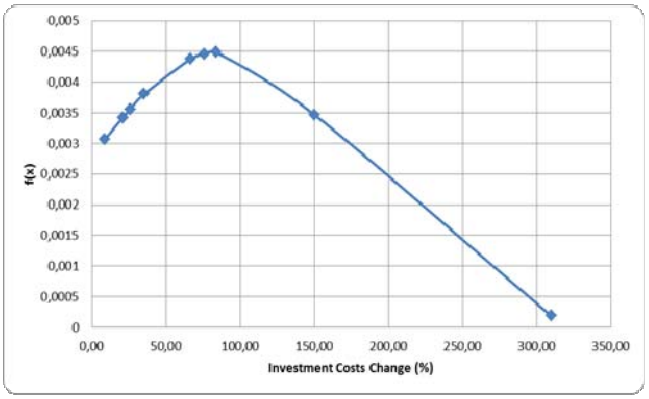

Figure 2. Normal distribution curve of investment costs

When the average of all results is taken, it is seen that the dairy farms using RMS have 86.38% higher investment costs than dairy farms using CMS. As it is seen in Table 3, an increase of 309% in the study carried out in 2005. By calculating the mean and standard deviation, it can be regarded as an exception because it is out of the normal distribution (Figure 2). If we exclude this exceptional value, we can

say that investing RMS in dairy farms costs higher by an average of 58.46% when compared with CMS.

Labor input

In 16 of the 33 studies, which have been carried out between 2002 and 2015, results of labor input for both RMS and CMS were presented. Labor input percentage change was calculated and presented in Table 4. When Table 4 was examined, in only one of these studies observed an increase. In other 15 studies, it has been determined that the labor cost is lower in dairy farms using RMS than in dairy farms using CMS.

Table 4. The percentage change of labor input

Reference No	Year	Country	Labor Input Change (%)
21	2002	Belgium, Denmark, Germany, Holland	-29,00
9	2003	Canada	-68,91
41	2004	Holland	-23,83
24	2005	Denmark	-43,40
20	2005	Finland	-37,61
12	2007	Finland	-30,00
28	2008	Canada	-40,00
19	2010	Holland	-25,00
35	2010	Holland	-3,92
29	2011	Canada	-30,00
27	2011	USA	-23,97
5	2012	Spain	29,26
37	2013	USA	-66,67
40	2014	Norway	-9,35
23	2015	Ireland	-36,80
32	2015	USA	-29,00
		Mean	-29,26

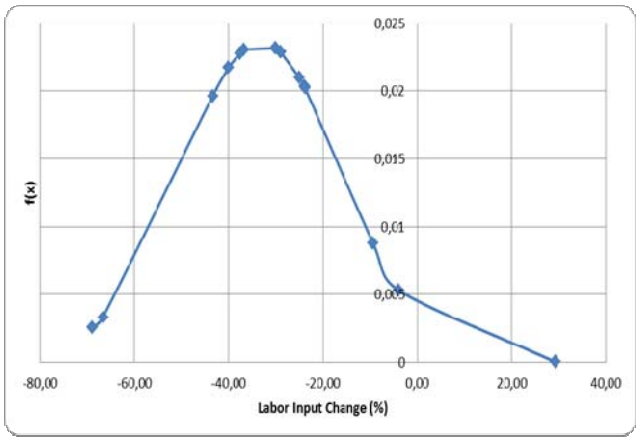

Figure 3. Normal distribution curve of labor input

When the average of all results is taken, it is seen that the dairy farms using RMS have 21.72% lower labor costs than dairy farms using CMS. By calculating the mean and standard deviation, the values -68.91%, -66.67% and 29.26% can be regarded as an exception because they are out of the normal distribution (Figure 3). If we exclude these exceptional values, we can say that labor input for RMS in dairy farms costs lower by an average of 27.84% when compared with CMS.

Energy consumption

In 5 of the 33 studies, which have been carried out between 2004 and 2015, results of energy consumption for both RMS and CMS were presented. Energy consumption percentage change was calculated and presented in Table 5. When Table 5 was examined, energy consumption percentage change was observed positive in all studies. It has been determined that the energy consumption is higher in dairy farms using RMS than in dairy farms using CMS.

Table 5. The percentage change of energy consumption

Reference No	Year	Country	Energy Consumption Change (%)
4	2004	Holland	42,00
35	2010	Holland	30,00
39	2012	Ireland	37,98
11	2015	USA	10,95
23	2015	Ireland	72,35
		Mean	38,66

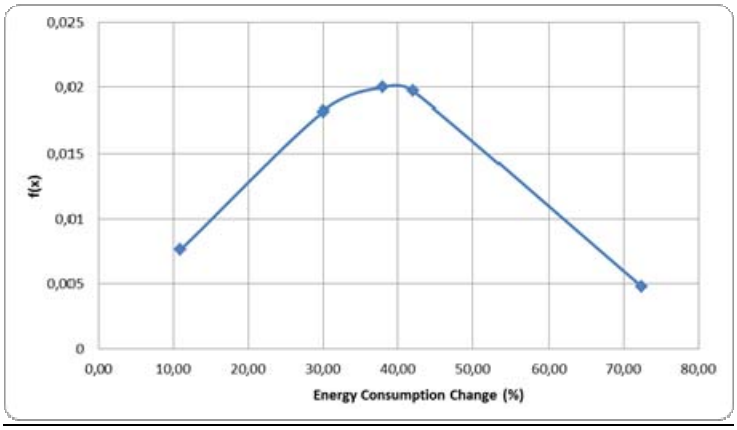

Figure 4. Normal distribution curve of energy consumption

When the average of all results is taken, it is seen that the dairy farms using RMS have 38.66% higher energy consumption than dairy farms using CMS. By calculating the mean and standard deviation, the values 10.95% and 72.35% can be regarded as an exception because they are out of the normal distribution (Figure 4). If we exclude these exceptional values, we can say that energy consumption RMS in dairy farms is higher by an average of 36.66% when compared with CMS.

Feed cost

In 5 of the 33 studies, which have been carried out between 2003 and 2015, results of feed cost for both RMS and CMS were presented. Feed cost percentage change was calculated and presented in Table 6. When Table 6 was examined, in all studies feed cost percentage change is not greater than %6.

Table 6. The percentage change of feed cost

Reference No	Year	Country	Feed Cost Change (%)
2	2003	Holland	-5,11
30	2003	USA	3,00
35	2010	Holland	0,00
31	2012	USA	0,28
32	2015	USA	2,04
		Mean	0,04

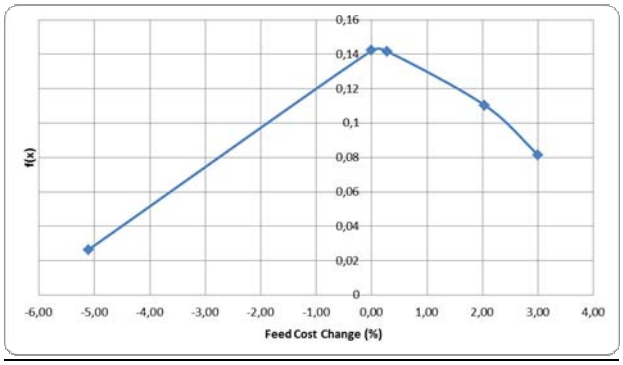

Figure 5. Normal distribution curve of feed cost

When the average of all results is taken, it is seen that dairy farms using RMS have 0.04% higher feed cost than dairy farms using CMS. By calculating the mean and standard deviation, the value -5.11% can be regarded as an exception because it is out of the normal distribution (Figure 5). If we exclude this exceptional value, we can say that the feed cost of dairy farms using RMS is higher by an average of 1.33% when compared with CMS. This value of percentage change is so small to say there is a difference. So we can say that the feed cost of dairy farms using RMS is similar to feed cost of dairy farms using CMS

Milking Frequency

In 13 of the 33 studies, which have been carried out between 2000 and 2016, results of milking frequency for both RMS and CMS were presented. Milking frequency for CMS was assumed 2 times in all studies. Milking frequency percentage change was calculated and presented in Table 7. When Table 7 was examined, in only one of these studies milking frequency percentage change showed a decrease. In other 12 studies, it has been determined that the milking frequency is higher in dairy farms using RMS than in dairy farms using CMS.

Table 7. The percentage change of milking frequency

Reference No	Year	Country	Milking Frequency Change (%)
1	2000	Germany	41,00
7	2001	Holland	15,00
26	2004	USA, Canada	30,00
36	2004	Japan	35,00
24	2005	Denmark	27,50
28	2008	Canada	32,50
19	2010	Holland	37,50
39	2012	Ireland	- 6,50
5	2012	Spain	34,50
31	2012	USA	40,00
11	2015	USA	40,00
32	2015	USA	40,00
10	2016	Turkey	30,00
		Mean	30,50

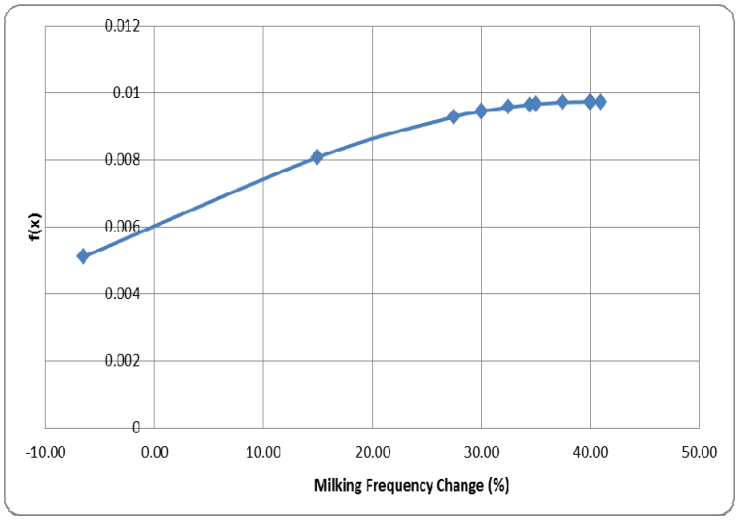

Figure 6. Normal distribution curve of milking frequency

When the average of all results is taken, it is seen that the dairy farms using RMS have 30.50% higher milking frequency than dairy farms using CMS. Milking frequency is an average of 2.61 in dairy farms using RMS. By calculating the mean and standard deviation, the value -6.50% can be regarded as an exception because it is out of the normal distribution (Figure 6). If we exclude this exceptional value, we can say that the milking frequency of RMS in dairy farms is higher by an average of 33.58% and milking frequency is an average of 2.67 when compared with CMS.

Net income

In 7 of the 33 studies, which have been carried out between 2005 and 2015, results of net income for both RMS and CMS were presented. Net income percentage change was calculated and presented in Table 8. When Table 8 was examined, in only one of these studies showed an increase and in only one of them, no difference was observed. In other 5 studies, it has been determined that net income is lower in dairy farms using RMS than in dairy farms using CMS.

Table 8. The percentage change of net income

Reference No	Year	Country	Net Income Change (%)	
2	2003	Holland	-	9,30
41	2004	Holland		0,08
24	2005	Denmark		30,90
35	2010	Holland	-	2,26
40	2014	Norway	-	22,08
23	2015	Ireland	-	30,18
32	2015	USA	-	19,57
		Mean	-	7,49

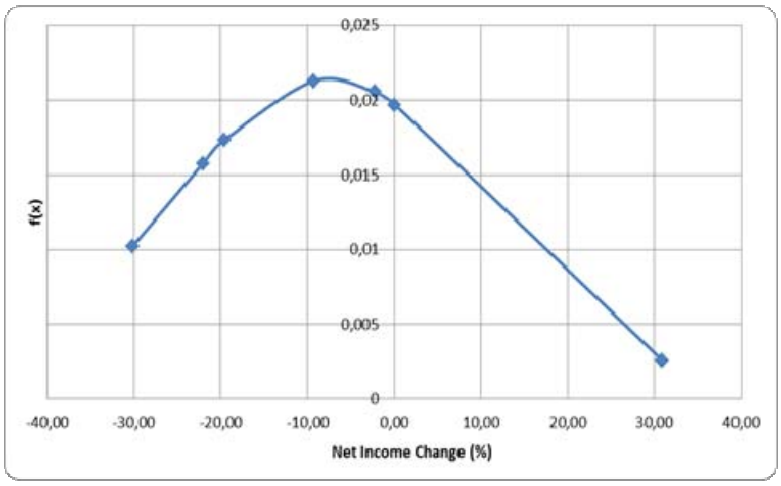

Figure 7. Normal distribution curve of net income

When the average of all results is taken, it is seen that the dairy farms using RMS have 7.49% lower net income than dairy farms using CMS. By calculating the mean and standard deviation, the value 30.90% can be regarded as an exception because it is out of the normal distribution (Figure 7). If we exclude this exceptional value, we can say that the net income of RMS in dairy farms is lower by an average of 13.89% when compared with CMS.

CONCLUSION

As a result of the study, it was determined that the milking frequency in dairy farms that using RMS was average of 33.58% (with an average of 2.67 milking) higher than CMS-using ones. The average rate of increase in milk yield in enterprises using RMS was 8.66%. The labor input requirement of RMS was 27.84% less. However, despite these advantages, RMS had an investment cost of 58.46% more than those using CMS. The energy requirement of RMS was 36.66% higher. In addition, the net income of RMS-using dairy farms was 13.89% lower than those using CMS. And there is no significant difference determined in feed cost between RMS and CMS.

In summary, considering the 7 criteria evaluated within the scope of the study; it can be said that dairy farms using RMS have advantage of milk yield (8.66%), labor input (-27.84%) and milking frequency (33.58%), while having disadvantage of investment costs (58.46%), energy consumption (36.66%) and net income (-13.89%). There is no significant difference determined in feed cost between RMS and CMS.

Despite disadvantages in net income, investment cost and energy consumption, the use of RMS in the world are increasing day by day. The most important reason for this is the decrease in the labor input requirement and therefore the improvement of the farmer's social life. By decreasing the labor input requirement, RMS's benefits for farmers social life are: raising the quality of life by

spending more time with the family and freeing up time for other activities; less physical work for farmers who are old or have health problems; raising the opportunity to attract and protect skillful staff; a choice for innovators who want to try new ideas; possibility to enlargement of herd (more efficient use of the existing workforce) without having to get a new employee.

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