Effects of the introduction of robot tractors onto dairy farms in Hokkaido, Japan

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Abstract

Long working hours are a serious issue in dairy farming in Japan. Labor-saving is a particularly important issue in dairy farming in Hokkaido, where dairy farms are larger in scale than in other regions of Japan, with larger areas of grassland under their management. To address demand for labor-saving, Japanese agricultural machinery manufacturers are developing robot tractors for harvesting hay. We accordingly conducted experiments on the use of robot tractors in hay harvesting in Hokkaido and analyzed their effectiveness in reducing hay harvesting man-hours and the economic feasibility of using them in dairy farming.

Introduction of a robot tractor with additional mower and tedder enabled a 45.4% reduction in hay harvesting man-hours. Our management model simulation indicated that in the case of a single farm management model, use of a robot tractor would alleviate peak workloads, but net income would decrease. However, our simulation of a model in which 2 dairy farms share the use of a robot tractor indicated that in addition to easing peak workloads, using a robot tractor would increase net income.

Keywords

Robot tractor, Hay harvesting, Man-hours, Linear programming method, Dairy farm management model

Introduction

Long working hours are a serious issue in dairy farming in Japan. On average, dairy farmers work 2237 hours per year, which is longer than their counterparts in other livestock farming, dry field farming, and paddy farming (Fig.1.). Labor-saving is a particularly important issue in dairy farming in Hokkaido, where dairy farms are larger in scale than in other regions of Japan, with larger areas of grassland under their management. And bigger dairy farms have longer working hours (Fig.2.).

An increasing number of dairy farms are using robot milkers as a means of expanding their dairy herds without increasing working hours (Hokkaido Government 2021) (Fig. 3.). More and more dairy farmers are also outsourcing feed production to contractors or total mixed ration (TMR) centers to reduce working hours (Kubota 2019) (Fig.4. and 5.). However, feed production contractors have also been facing labor shortages in recent years that are forcing them to adopt more labor-saving methods (MAFF 2016) (Fig.6. and 7.).

Purpose of this study

To address demand for labor-saving, Japanese agricultural machinery manufacturers are developing robot tractors for harvesting hay. They are currently conducting experiments in Hokkaido with the aim of reducing hay harvesting man-hours by enabling a single operator to simultaneously operate a robot tractor in tandem with a manned tractor. However, there is as yet no clear data on the extent to which robot tractors can reduce hay harvesting man-hours and on the economic feasibility of using robot tractors in dairy farming.

We accordingly conducted experiments on the use of robot tractors in hay harvesting in Hokkaido and analyzed their effectiveness in reducing hay harvesting man-hours and the economic feasibility of using them in dairy farming.

Research method

We first conducted experiments to investigate the number of man-hours involved in using a robot tractor to harvest hay. There are 4 steps in the process of hay harvesting: mowing, tedding, raking, and baling. The grass is first mown with a mower, and then tedded (turned over) with a tedder to aid drying. Once the hay is dry, a rake attachment is used to gather it into rows for baling into round bales using a round baler. Tedding is carried out 6 times over the space of 3 days. Since robot tractors can be used only for mowing, tedding, and raking, we investigated the number of man-hours involved in these 3 steps. In 2019 when we conducted our investigations, the first hay crop was harvested in June and the second in September as is done every year. Yield was much the same for both crops, with the first crop producing 41 rolls, and the second 44 rolls.

We considered two harvesting procedures that differed according to the way the robot tractor was used (Table.1.). In Case 1, a robot tractor carried out tedding at the same time as a manned tractor mowed the hay. Later, tedding was carried out by both robot and manned tractors, and in the final stage, the robot tractor raked the hay while the manned tractor baled it. In Case 2, both robot and manned tractors first mowed the hay simultaneously, after which the Case 1 procedure was followed. The number of man-hours involved in these 2 procedures was compared with that of the conventional procedure in which the hay is harvested without using a robot tractor.

We ran the experiment using rectangular fields of approximately 5 ha (273 m × 182 m) and compared man-hours per hectare. The hay was mown in a spiral path from field perimeter to center, after which tedding, raking, and baling were carried out while moving up and down the long axis of the field.

Secondly, we considered the economic feasibility of using robot tractors in dairy farming. We used linear programming to construct a dairy farm management model that we then used to estimate how man-hours and net income changed when making hay with the help of a robot tractor in place of the conventional hay harvesting system. Our model was premised on a Hokkaido dairy farm of average size with 70 dairy cattle managed by a married couple. Milk yield per cow was set at 8500 kg and the price of milk at 100 yen per kilogram. Expenses other than family labor costs were 577,000 yen per cow (Table.2.). The model's applicable period was September when the 2nd crop of hay was harvested. Of the farm's workforce of 2, 1 person was assigned exclusively to milking and other herd management tasks and could work 6 hours per day. The other person was assigned to hay harvesting as well as herd management tasks and could work 8 hours per day (Table.3.).

For our analysis, in addition to a single dairy farm model, we also used a model in which 2 dairy farms share a single robot tractor. Because investing in a robot tractor would also entail investment in an additional mower and tedder, pushing up depreciation expenses, there was a risk in the case of a single dairy farm that introducing a robot tractor would result in a drop in net income even if it helped to reduce man-hours.

This prompted us to construct a second 2-farm model to estimate the benefits of shared use of a robot tractor. This model assumes that because there are 2 tractors available from the start, no additional tractor is needed. Also, assuming that hay harvesting is carried out by just one person at any time, there is no need for 2 rake attachments and roll balers, which means that net income can be expected to rise as a result of lower depreciation expenses. However, whether a single person can harvest the amount of hay required by 2 dairy farms within a given period of time is questionable.

Hay harvesting requires 3 consecutive days without rain. On the first day, the grass must be mown and tedded once during the morning, and then tedded again in the afternoon. On the second day, it is tedded a further 2 times, once in the morning and once in the afternoon. On the third day, the hay is again tedded in the morning and afternoon before being baled. This 3-day hay harvesting operation was taken to comprise 1 set.

Looking at meteorological data for the study site for the 5 years from 2017 to 2021, the number of days in September with precipitation of 5 mm or more was 5.2 days. We accordingly set the number of rainy days at 5. If these 5 days were concentrated in the first 5 days of the month, there would be 23 days available for harvesting hay. If, however, the 5 rainy days were scattered with at least 2 days between them, the fewest number of days required to harvest the hay would be 13 days. We accordingly set an upper limit of 13 days for the number of days required for hay harvesting. In other words, the maximum number of 3-day harvesting sets was 13 sets. Also, depending on how the rainy days are scattered, harvesting in a maximum of 11 out of 13 sets overlapped with tedding and other operations in 2 other harvesting sets. For example, Set 1 3rd day operations are carried out on the same day as Set 2 2nd day operations and Set 3 1st day operations. On such days, harvesting requires the maximum number of man-hours. We accordingly used such a day to set limits on working hours.

Key findings

Firstly, use of a robot tractor reduced the time required for hay harvesting by 36.4% for Case 1, and by 45.4% for Case 2 (Fig.8.).

Secondly, our simulation of robot tractor introduction using our dairy farming management model showed that use of the robot tractor based on Case 1 would result in a 6.9% reduction in man-hours at the peak of harvesting operations in September. However, net income would fall by 4.5% owing to the increase in depreciation expenses accruing to the robot tractor and additional tedder. Using a robot tractor with Case 2 would result in an 8.6% reduction in man-hours, but net income would fall by 7.5% owing to the increase in depreciation expenses accruing to the additional mower. With the 2-farm management model, on the other hand, shared use of the robot tractor would result in the same reduction in man-hours in September when the second crop of hay is harvested, but with Case 1, net income would rise by 3.6% owing to depreciation expenses saved by not needing to invest in an additional mower, rake attachment, and roll baler. Similarly, using the Case 2 procedure, net income would increase by 2.1% owing to depreciation expenses saved by not needing to invest in an additional rake attachment and roll baler (Table.4.).

In the above simulation, we set an upper limit of 70 dairy cows, but since there was some margin in man-hours, we performed another simulation for use of a robot tractor in a single farm setting premised on the ability to accommodate more dairy cows. In this simulation, the number of dairy cows could be raised to 73 with conventional hay harvesting, and to 79 with Case 1 robot tractor use, resulting in an increase in net income of 3.9% compared with conventional hay harvesting. Case 2 robot tractor use enabled the number of dairy cows to be increased to 81, resulting in an increase in net income of 3.8%.

Conclusion and discussion

Introduction of a robot tractor with additional mower and tedder enabled a 45.4% reduction in hay harvesting man-hours. Our management model simulation indicated that in the case of a single farm management model, use of a robot tractor would alleviate peak workloads, but net income would decrease. However, our simulation of a model in which 2 dairy farms share the use of a robot tractor indicated that in addition to easing peak workloads, using a robot tractor would increase net income. Our simulations also indicated that use of a robot tractor could result in an increase in net income even in a single farm management setting in which there is scope to increase the number of dairy cows, since the reduction in hay harvesting man-hours would enable the dairy herd to be expanded.

If the farm’s cowshed had sufficient room to accommodate an additional 10 cows, introduction of a robot tractor would enable net income to increase even in a single farm setting. If the farm’s cowshed lacked the room to accommodate additional cattle, sharing the use of a robot tractor with another dairy farm would enable both farms to increase net income.

Acknowledgement

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Reference

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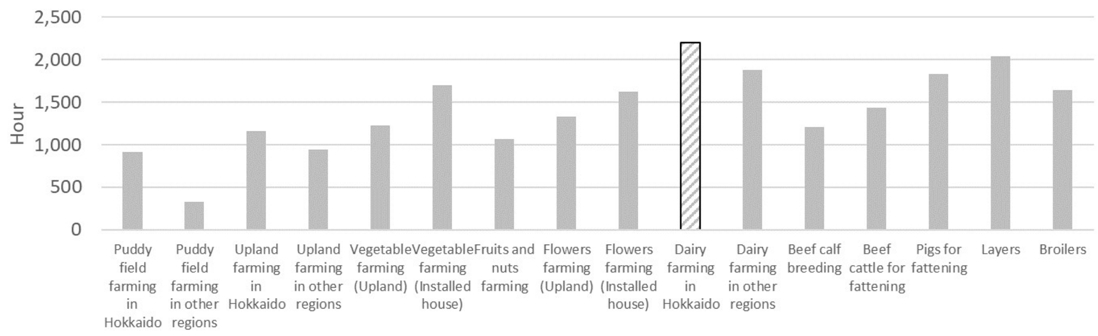
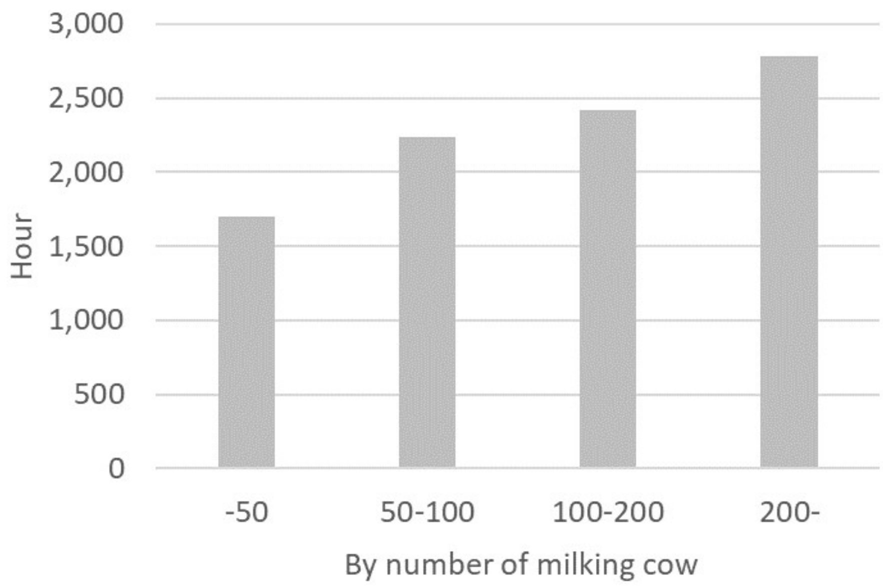
Fig. 1 Working hours per family member (2019)



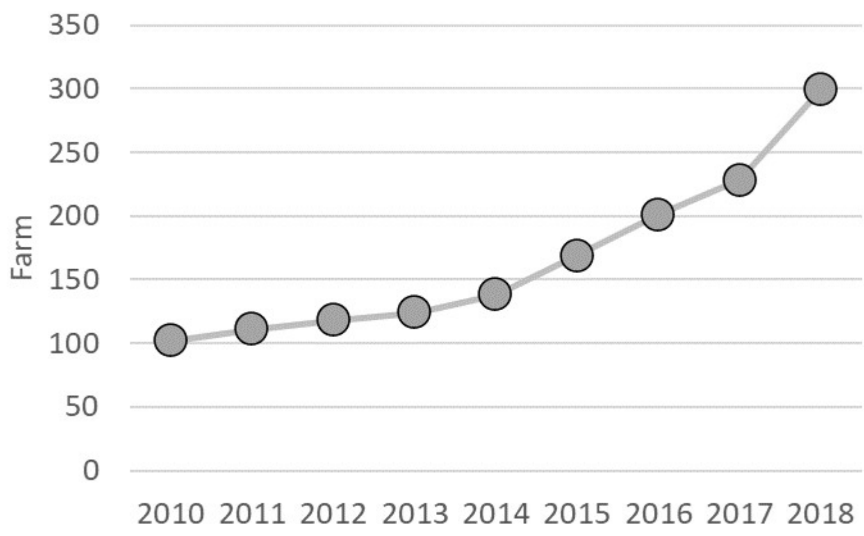
Source: The statistical yearbook of MAFF (Ministry of agriculture, forestry, and Fisheries)

Fig.2 Working hours per family member on dairy farm in Hokkaido (2019)



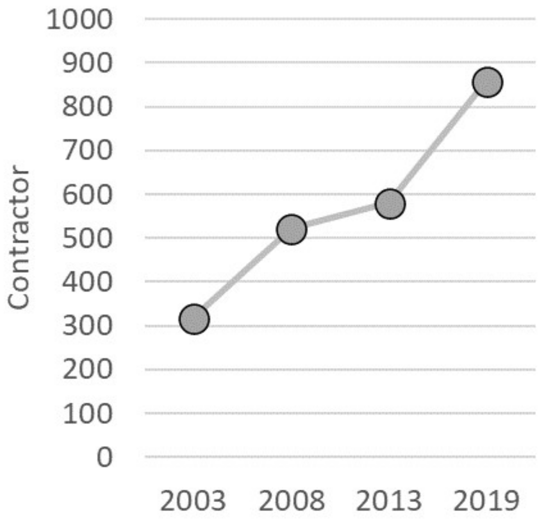
Source: The statistical yearbook of MAFF (Ministry of agriculture, forestry, and Fisheries)

Fig.3 Number of dairy farms introducing robot milker in Hokkaido



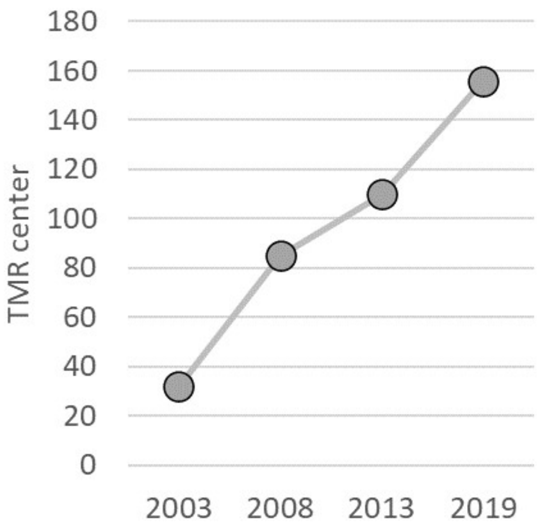
Source: Hokkaido government

Fig.4 Number of contractors in Japan



Source: Ministry of agriculture, forestry, and fisheries

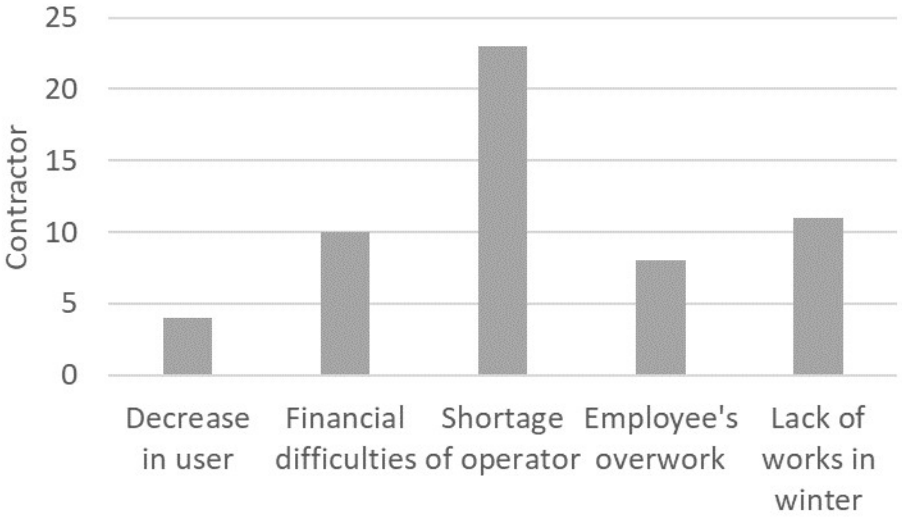
Fig.5 Number of TMR center in japan



Source: Ministry of agriculture, forestry, and fisheries

Fig.6 Current issues in contractor in Hokkaido (2013)

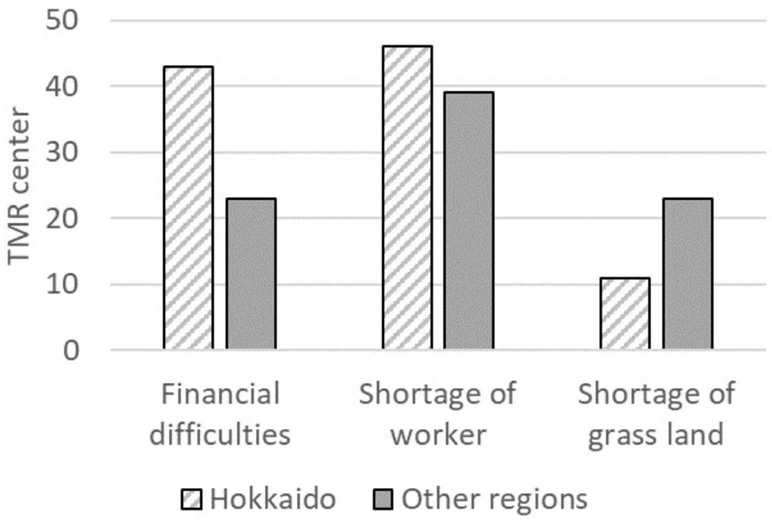
(Multiple answers allowed)



Source: Agriculture & Livestock Industries Corporation: Results of questionnaires that were distributed to 70 contractors and replied from 32 in Hokkaido. The collection rate was 46%.

Fig.7 Issues for the future in TMR center (2016)

(Multiple answers allowed)



Source: Ministry of agriculture, forestry, and fisheries: Results of questionnaires that were replied from 28 in Hokkaido and 31 in other regions.

Table.1 Three harvesting procedures of hay

<table>
<tr><th rowspan="3"></th><th colspan="6">Making hay needs continual three days without rain.</th></tr>
<tr><th colspan="2">First day</th><th colspan="2">Second day</th><th colspan="2">Third day</th></tr>
<tr><th>A.M.</th><th>P.M.</th><th>A.M.</th><th>P.M.</th><th>A.M.</th><th>P.M.</th></tr>
<tr><td>Convention</td><td>Human Mowe
&
Human Tedder</td><td>Human Tedder</td><td>Human Tedder</td><td>Human Tedder</td><td>Human Tedder</td><td>Human Tedder
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<tr><td>Case 1</td><td>Robot Mower +
Human Tedder</td><td>Robot Tedder +
Human Tedder</td><td>Robot Tedder +
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Human Tedder</td><td>Robot Tedder +
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<tr><td>Case 2</td><td>Robot Mower +
Human Mower
&
Robot Tedder +
Human Tedder</td><td>Robot Tedder +
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</table>

Table.2 The outline of the farming model - an average size in Hokkaido -

Number of workers	Number of milking cows	Milk yields per head a 305 days	Milk price per kg	Milking cost per head	The amount of investment Case 1	The amount of investment Case 2	Cow's demand for hay a year
2	70	8500kg	\$0.88	\$5,099	\$7,599	\$12,636	0.1942(10a)
Only one person operate making hay.	Adult heads are around 80. Fixed		One dollar equals 113.17 yen				

Table.3 Simplex table for simulations

	Convention	Case 1	Case 2	Investments 1	Investments 2	Convention selection	C 1 selection	C 2 selection	Labor 1 milking	Labor 2 milking	Milking costs	Milk yields	Milk price	Land balance	Total usage		Starting inventory
Profit/Unit (dollar)	0	0	0	-7599	-12636	0	0	0	0	0	-5099	0	0.88	0			
Heads constraint (heads)											1				70	<=	70
Lands (10a)	1	1	1												14	<=	1000
Lobor 1 (hours)	0.181	0.116	0.1						0.152						7.246	<=	8
Labor 2 (hours)										0.152					5.928	<=	6
Cost of heads (heads)									-1	-1	1				0	=	0
Grass needs (10a)	-1	-1	-1								0.1942				-0.406	<=	0
Selection convention	1					-1000									-986	=<=	0
Selection c1		1					-1000								0	<=	0
Selection c2			1					-1000							0	=<=	0
Selection constraint						1	1	1							1	=<=	1
Convention constraint	1														14	<=	1000
C 1 Constraint		1													0	<=	1000
C 2 Constraint			1												0	<=	1000
C 1 Investments		1		-1000											0	<=	0
C 2 Investments			1		-1000										0	=<=	0
Cost constraint											-1	1			0	=<=	0
Milk sale (kg/head)												-8500	1		0	=<=	0
Land balance constraint (10a)														1	1	=<=	1
Grass balance constraint (10a)	1	1	1								-0.1942			-1	-0.594	<=	

Fig.8 Labor saving time by using robot tractor

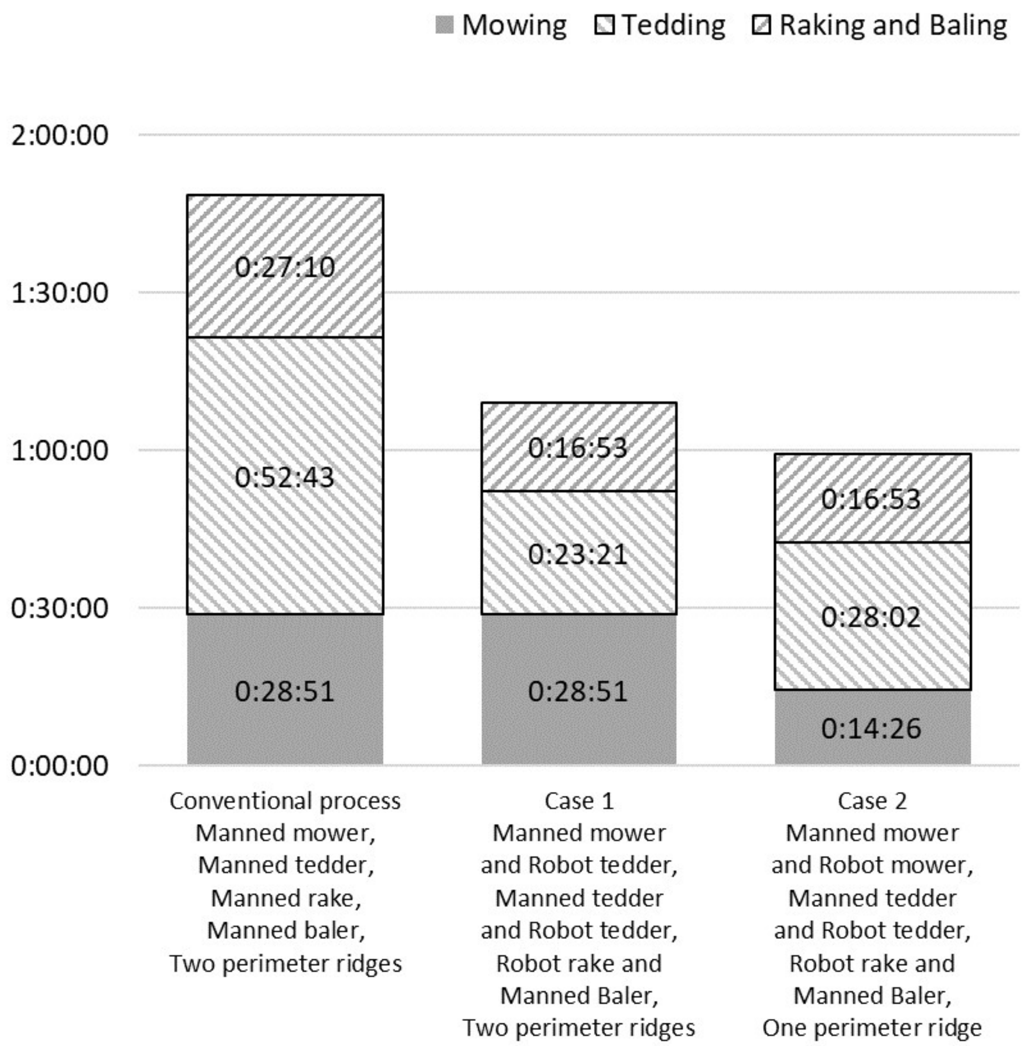

Table.4 Simulation results

Scenarios	States	Number of introducing machines			Number of dairy farms	Hay making process	Number of milking cows	Working hours rate	Income rate
		Robot Tractor	Mower	Tedder					
1	Convention				1	Manned mower Manned tedder Manned rake Manned baler	70	100	100
2	Case 1	1		1	1	Manned mower and robot tedder Manned tedder and robot tedder Robot rake and Manned baler	70	93.1	95.5
3	Case 2	1	1	1	1	Manned mower and robot mower Manned tedder and robot tedder Robot rake and Manned baler	70	91.4	92.5
4	Convention				2	Manned mower each of them Manned tedder each of them Manned rake each of them Manned baler each of them	140	100	100
5	Case 1	1		1	2	Manned mower and robot tedder Manned tedder and robot tedder Robot rake and Manned baler	140	93.1	103.6
6	Case 2	1	1	1	2	Manned mower and robot mower Manned tedder and robot tedder Robot rake and Manned baler	140	91.4	102.1