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REVIEW

Planning Large-scale Feed Production for Japanese Cattle Farming under the Condition of Cropland Dispersion

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Abstract

With increases in the scale of feed-crop production in farm management, croplands are dispersed into larger areas and feed-crop production become more expensive. Here I examine how to increase feed production economically through livestock farm management under the condition of cropland dispersion. I constructed farming models reflecting cropland dispersion based on farm surveys and simulated optimized feed production by using the integer programming method. In the first study, I analyzed the effect of dispersion of feed-cropping fields on the management entities of breeding cattle for beef in the Kyushu District of Japan. The simulation results suggested that large-scale beef calf-raising farms would need to use feed-cropping fields ≦1 km from the cattle sheds to achieve increased feed self-sufficiency. Moreover, if a farm has a total of 14 ha of fields at 0.4 ha per field ≦3 km from the cattle shed, it would cover expenses even if calf prices declined to the support price. My second study revealed that feed crop-production costs could be decreased by optimizing feed-crop allocation (grasses and corn) to the fields around the total mixed ration (TMR) center run by Hokkaido dairy farmers. This could be achieved depending on the state of activities of the center that contracts out the harvesting and bunkering operations and on harvesting conditions.

Discipline: Farm economics
Additional key words: farming model simulation, integer programming method, distance from sheds to feed-cropping fields, feed-crop allocation to the fields, TMR center

Introduction

After World War II, there was remarkable development of farm management entities raising commercial livestock in Japan, and this improved the Japanese diet. The development of these entities, however, has relied on imported feed (Japan Livestock Industry Association, 1999). For this reason, Japanese stockbreeding suffered heavy damage from the surge in the price of imported feed in autumn 2008 (Ministry of Agriculture, Forestry and Fisheries 2015b), leading to a realization that feed self-sufficiency is important in Japan.

Researchers in the field of agricultural economics state that feed self-sufficiency is important because of the need for food self-sufficiency, food security, environmental protection, feed-safety, and the effective use of land (Syogenji 2000). Despite these needs, it is not yet clear how feed production in Japan can be increased economically. Especially, it is unclear how large-scale feed-crop production can be planned under the condition of cropland dispersion. Here, therefore, I attempted to determine the measures that could be used to increase feed production.

In the first study, I analyzed the effect of cropland dispersion coinciding with the expansion of domestic feed production on the cost of feed to farm management entities breeding beef cattle in the Kyushu district (Kubota 2012). In the second study, my research group examined the optimized allocation of feed crops, such as grass and corn, to the fields belonging to a total mixed ration (TMR) center run by dairy farmers, which produces and delivers TMR to dairy farms in Hokkaido (Kubota & Fujita 2011). In these two studies, I have conducted farm surveys, constructed farming models based on the surveys, and simulated optimized farming state by using the integer programming method.

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Effect of land dispersion on cost of feed production (Kubota 2012)

1. Objective of analysis

As production lands become dispersed over a large area, feed production becomes more costly because the distance from cattle sheds to the croplands becomes long. This is likely to weaken the cost advantage of local feed production over imported feed. Accordingly, the maximum cattle-shed-to-field-distance that retained an advantage in feed-production costs over imported feed needs to be calculated. First, I investigated large-scale beef cattle breeding farms to gather information on feed-production costs and the state of field dispersion. Second, I constructed a farming model based on the survey results and then simulated optimum farming state aiming at a maximum farming income.

2. Survey results

I investigated five managed farms in Kagoshima Prefecture and three in Nagasaki Prefecture. Kagoshima Prefecture contained vast upland farming areas, whereas the farms in Nagasaki Prefecture were hilly or mountainous. All the farms investigated had >100 breeding beef cattle and produced feed over areas with a range of 7-10 ha.

The average distance from the cattle sheds to the feed-cropping field on each farm was 1-4 km, except for one farm which has a field 40 km away. The average greatest distance to a field on each farm was 6 km. One farm had feed-cropping fields <1 km away from the sheds. Feed-cropping fields on the farms in Kagoshima Prefecture had an average area of 0.4 ha; the number of fields per farm was 15-41, and the fields were grouped in three to six blocks, each of which has three to eight fields. The feed-cropping fields on the farms in Nagasaki Prefecture had an average area of 0.2 ha; the number of fields per farm was 48-64, and the fields were grouped in three to seven blocks, each of which has eight to 21 fields.

3. Farming model

My farming model was that of a beef cattle breeding farm. It is aimed to maximize farming income by calf selling for fattening cattle with feed production and feed purchase. The model has four family workers, one cattle shed which accommodates 150 heads of cattle, and one block of fields around the shed and three or four or five distant blocks of fields.

Figure 1 shows a pattern diagram of the farming model constructed by the integer programming method. The figure indicates that the model consists of fixed cost processes, feeding cattle process, feed-crop production processes, feed supply processes to cattle, including the purchasing feeds and feed nutrition adjustment processes to proper proportion. The model has 220 processes and 305 constraints.

In the model, beef calf price is set up to 410,000 yen which is the average price of beef cattle in the Wagyu calf auction market from fiscal year of 1999 to 2008 in Japan.

Feed production processes represent grass harvest

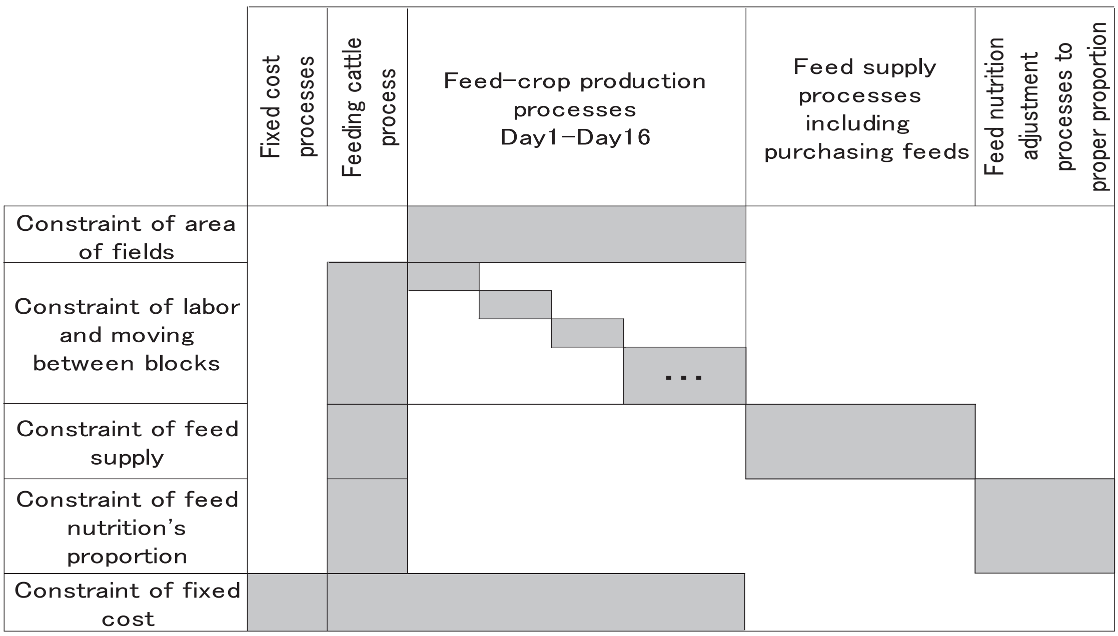

Fig. 1. Pattern diagram of farming model 1

Main technical coefficients are written in the gray parts.

work in April because of the busiest farming season. Feed production processes naturally are given an annual cost of feed production. According to the weather data, there are sixteen days to conduct farming except for rainy days in April.

Feed-production process is set up as the integer process in every field. Working time to raise beef calves raising and feed production is limited to within 8 hours every day.

In producing feed crops, the model initially uses a block of fields around the shed. After finishing use of the block around the shed, the model begins to use block of fields that are farther way to produce feed crops. Usually, one block of fields is around the shed and the remaining three to five blocks are away from the shed. The field blocks were numbered as follows: one is the block around the shed; distant blocks are assigned numbers two, three, four, etc. In producing feed crops, model uses blocks in ascending order.

I then conducted a simulation of distance from sheds to fields. The total number of combinations in the simulation model was 540. There were three different numbers for feed-cropping blocks per farm (four, five, and six); three different numbers for fields per block (four, six, and eight); two acreages of fields (0.2 and 0.4 ha); 10 different distances to each block (from 10 km to 1 km in steps of 1 km); and three different distances between fields in the same block (0, 50, and 100 m).

4. Round trip and one-way trip from the shed to blocks to conduct feed-crop production in the model

Tables 1 and 2 show the simplex table of the component of feed production. When the model uses distant blocks to feed-crop production, round-trip processes from the shed to distant block work simultaneously. For instance, in Tables 1 and 2, when the "Decision of last block number at the second day" process that is established in ninth file works for one, the "Not going to the distant block and back at the second day" process that is established in 10th file which does not influence the result of simulation works by the constraint set up in the 13th line because block one is not a distant block. The process established in 10th file works before the 11th process works because the 11th process has a minus coefficient of profit. The 10th process works for only one because of the limit by 14th line's constraint. Therefore, when the ninth file's process works over two, the 11th file's process works for one, which influences the result of simulation on a cost and work time of round trip from shed to field.

When the farming model uses more than two distant blocks, one-way processes also work. By round-trip and one-way process, the farming model can reflect the effects of land dispersion in terms of cost and working time for feed-crop production. For example, when ninth file's process works for two, in other words, farming model finishes working for feed-crop production at block two at the second day, and process of 13th file, "Decision of starting block number at the second day," works for one, that is, when the farming model starts working for feed-crop production at block one, or the block around the shed, the 14th file's process, "Moving for another block of field at the second day," works for one according to 19th line's constraint. However, moving from block one to block two is not one-way trip but is a round-trip, because one-way is moving process between distant blocks, and round-trip process already has been reflected into simulation by 11th file's process. Then, a process, "Denial of moving at the second day," set up in 15th file, works for one by 20th line's constraint, which contradicts the influence of one-way moving process set up in 14th file.

In addition, when ninth file's process works for three, in other words, farming model finishes working for feed-crop production at block three, and 13th file's process works for one, 14th file's process works for two. In this case, as mentioned above, moving from block one to block two is not a one-way process but a round-trip, and moving from block two to block three is just a one-way process. After all, 14th file's process works extra. Accordingly, 15th file's process works for one by 20th line's constraint, contradicting one of the influences of one-way moving process that is set up in 14th file, similar to the above.

In the case where 13th file's and ninth file's processes work for one each or in the case of both zero, because feed-crop production has not been done, moving between distant blocks process is contradicted by 14th, 15th and 16th file's process.

5. Simulation results

When each field covers an acreage of 0.4 ha, feed-crop production is conducted within 6.4-12.8 ha in the case of distances of 1 km from sheds to field. In the case of distances of 2 km, feed-crop production is also conducted within 7.2-8.0 ha, except for the case of four blocks and four fields per block. In the case of distances of 3 km, feed-crop production is conducted within 8.0 ha only in the case of eight fields per block and adjacent fields in the same block (Table.3).

If the case of an increase in the price of calves from 410,000 to 530,000 yen, no farming model allowed the farms to produce feed crop. By contrast, with a fall in the price of calves to 310,000 yen–the security price set by Japanese government for farms–all the farming models

Table 1. Simplex table for simulation of economically advantageous distance to field on livestock farm (1) (an extract)

	Unit	Max or min amount	Relation	1 Feeding cattle	2 Feed production in the number one block around the shed at the first day	3 Feed production in the distant field at the first day	4 Going to distant field and back at the first day	5 Moving for another block at the first day	6 Feed production in the number one block around the shed at the second day	7 Permission of moving for distant block at the second day	8 Feed production in the distant block at the second day	9 Decision of last block number at the second day	10 Not-going to the distant block and back at the second day	11 Going to distant block and back at the second day	12 Permission for the opening of work at the second day
A coefficient of profit	1000 yen			333	−85	−123	−8	−3	−85		−123			−8	
1 Constraint of near field numbers		8	≧		1				1						
2 Constraint of distant field numbers		40	≧			1					1				
3 Hours of labor at the first day	minute	480	≧	2	67	101	29	11							
4 Operated near field numbers at the first day			≧		−1		8								
5 Constraint of moving to distant block of field at th first day			≧			1	−8	−8							
6 Constraint of moving between distant block of field at the first day			≧				−7	1							
7 Hours of labor at the second day	minute	480	≧	2					67		101			29	
8 Constraint of field numbers at the second day			≧		−1	−1			1		1				
9 Operated near field numbers for two days			≧		−1				−1	8					
10 Constraint of moving to distant block of field at the second day			≧							−40	1				
11 End block of field number at the second day			≧		1	1			1		1	−8			
12 Decision of end block of field numbers at the second day		7	≧		−1	−1			−1		−1	8			
13 Constraint of going to distant field and back (1) at the second day			≧									1	−1	−8	
14 Constraint of going to distant field and back (2) at the second day		1	≧										1		
15 Beginning block of field number at the second day			≧		1	1									1
16 Decision of beginning block of field numbers at the second day		7	≧		−1	−1									−1
17 Constraint of operation beginning at the second day		1	≧												1
18 Operation beginning at the second day			≧						1		1				−48
19 Moving for another block of field at the second day			=									−1			
20 Arrangement of moving at the second day		6	≧												
21 Priority of not-moving and constraint of denial at the second day			≧									−1			
22 Constraint of moving arrangement control at the second day		1	=												
23 Constraint of not-moving at the second day		1	≧												
24 Hours of labor at the third day	minute	480	≧	2											
25 Constraint of field numbers at the third day			≧		−1	−1									
26 Constraint of operation at the third day			≧						−100		−100				
27 Operated near field numbers for three days			≧		−1				−1						
28 Constraint of moving to distant block of field at the third day			≧												
29 End block of field number at the third day			≧		1	1			1		1				
30 Decision of end block of field numbers at the third day		7	≧		−1	−1			−1		−1				
31 Constraint of going to distant field and back (1) at the third day			≧												
32 Constraint of going to distant field and back (2) at the third day		1	≧												
33 Beginning block of field number at the third day			≧		1	1			1		1				
34 Decision of beginning block of field numbers at the third day		7	≧		−1	−1			−1		−1				
35 Constraint of operation beginning at the third day		1	≧												
36 Operation beginning at the third day			≧												
37 Moving for another block of field at the third day			=												
38 Arrangement of moving at the third day		6	≧												
39 Priority of not-moving and constraint of denial at the third day			≧												
40 Constraint of moving arrangement control at the third day		1	=												
41 Constraint of not-moving at the third day		1	≧												

This simplex table shows the case of 0.4 hectare per field.

Table 2. Simplex table for simulation of economically advantageous distance to field on livestock farm (2) (an extract)

13 Decision of starting block number at the second day	14 Moving for another block at the second day	15 Denial of moving for another block at the second day	16 Cancellation of denial of moving for another block at the second day	17 Not-moving for another block at the secod day	18 Control of arrangement of moving for another block at the second day	19 Feed production in the block around the shed at the third day	20 Permission of moving for distant block at the third day	21 Feed production in the distant block at the third day	22 Decision of last block number at the third day	23 Not-going to the distant block and back at the third day	24 Going to distant block and back at the third day	25 Permission for the opening of work at the third day	26 Decision of starting block number at the third day	27 Moving for another block at the third day	28 Denial of moving for another block at the third day	29 Cancellation of denial of moving for another block at the third day	30 Not-moving for another block at the third day	31 Control of arrangement of moving for another block at the third day
	−3	3	−3			−85		−123			−8			−3	3	−3		
						1												
								1										
	11	−11	11															
−8																		
8																		
1	1																	
1		5																
			−2	−5	7													
					1													
				1														
						67		101			29			11	−11	11		
						1		1										
						1		1										
						−1	8											
							−40	1										
						1		1	−8									
						−1		−1	8									
									1	−1	−8							
										1								
												1	−8					
												−1	8					
												1						
						1		1				−48						
									−1				1	1				
													1		5			
									−1							−2	−5	7
																		1
																	1	

enable feed-crop production.

With a fall in the price of calves to 310,000 yen, distance of 3 km to the fields gave a farm income of 4,370,000 yen under the best conditions of field dispersion, namely a field area of 0.4 ha, six blocks, with eight fields per block and adjacent fields in the same block. In 2008, beef calf-raising farms in the Kyusyu District were each estimated to need 4,050,000 yen to cover their expenses. Therefore, if the distance from the cattle sheds to feed-cropping fields was within 3 km, beef calf-raising farms could get by on a farming income even if the price of calves were to fall to 310,000 yen. Under this scenario, a farm would have 104 heads of breeding cattle, 14.4 ha of feed-production fields, and 92.4% feed self-sufficiency.

6. Conclusion

The simulation results suggest that large-scale beef calf-raising farms need to have their feed-cropping fields within the distance of 1 km from the cattle sheds to increase the rate of feed self-sufficiency. Moreover, it is important for farms to produce feed crop to secure the farm against fall in calf price, even if it is impossible to have fields within 1 km of the cattle shed. If a farm has a total of 14 ha of fields at 0.4 ha per field, within 3 km of the cattle shed, it would be able to cover expenses, even if the price of calves were to decline heavily.

Optimized allocation of feed-crop production around a TMR center (Kubota & Fujita 2011)

1. Objective of analysis

The feed-cropping fields of a TMR center are likely to be dispersed over an area larger than that of the fields for farming. However, just as on farms, harvested feed crops are collected at one storage point of the TMR center. Therefore, distance from the storage site at the TMR center to the feed-cropping fields can become very great, leading to a high cost of feed production.

I showed here that, when feed crops such as grasses and corn are arranged appropriately according to distance to fields and working systems, the cost of feed-crop production could be decreased. First, I conducted a survey of the TMR center to gather data on distance to fields and cost of feed-crop production. Second, I constructed a farming model and used the model to simulate the allocation of feed crops to minimize the cost of feed production.

2. Survey results

The TMR center surveyed by us is run by six dairy farms with 440 heads of milking cows. It has 300 ha of feed-cropping fields, and it uses 200 ha of those fields for grass production and 100 ha for corn. In terms of the distance from the TMR center to the fields, 100 ha was 1 km away, 75 ha was 1-3 km away, 90 ha was 3-5km away, and 35 ha was 5-7 km away.

The TMR center contracts a local construction firm to operate the harvesting machinery, transport the harvested feed crops in about three to five dump trucks (each with a carrying capacity of 10 t), and pack the feed crops into a bunker silo.

3. Farming model

The farming model represents the TMR center producing feed crops. Figure 2 shows a pattern diagram of whole farming model and Tables 4 and 5 show an extracted simplex table constructed by an integer programming

Table 3. Acreage of feed production by simulation

Field acreage	Distance to the field	Distance between fields in the same block	Acreage								
			Six blocks			Five blocks			Four blocks		
			Eight fields (ha)	Six fields (ha)	Four fields (ha)	Eight fields (ha)	Six fields (ha)	Four fields (ha)	Eight fields (ha)	Six fields (ha)	Four fields (ha)
0.4ha	1km	0m	12.8	12.8	9.6	12.8	12.0	6.4	12.8	9.6	6.4
		50m	12.8	12.8	9.6	12.8	12.0	6.4	12.8	9.6	6.4
		100m	12.8	12.8	9.6	12.8	12.0	6.4	12.8	9.6	6.4
	2km	0m	8.0	7.6	7.2	8.0	7.6	7.2	8.0	7.6	–
		50m	8.0	7.6	7.2	8.0	7.6	7.2	8.0	7.6	–
		100m	8.0	7.6	7.2	8.0	7.6	7.2	8.0	7.6	–
	3km	0m	8.0	–	–	8.0	–	–	8.0	–	–
		50m	–	–	–	–	–	–	–	–	–
		100m	–	–	–	–	–	–	–	–	–

The price of calf has been assumed to be equal to 410,000 yen.

method. The farming model consists of processes such as feed-crop-harvesting processes arranged according to the distance of blocks, number of trucks, truck number selection processes, and operating cost processes. Table 6 shows the conditions and the limitations of simulation by the farming model that aimed to minimize the cost of harvesting feed crops by allocating feed crops to each field under the necessary field area conditions and limitations on the operating conditions.

4. Simulation results

The results of simulations are provided in Table 7. Under the first set of conditions, corn is allocated into fields located 1, 3, and 5 km from the storage site at the TMR center. In fact, because the corn-producing fields at the TMR center are located at the same distances from the center, the model simulations reproduced the allocation of corn well.

When the maximum number of trucks is increased to five, corn was allocated to fields that are farther away than the first set conditions and grasses were allocated to nearby fields. Next, under conditions in which the cropping terms of corn harvest are shortened from 7 to 6 days, the modeled locations of some of the corn are changed to fields 3 km away so that the corn-harvesting operations would end within 6 days.

If the TMR center does not contract out the harvesting and bunkering operation to the local construction firm, the hourly cost of harvesting the crops falls. Thus, costs could be decreased even when the number of trucks is decreased and if the harvesting time is extended. Under this scenario, the feed-crop allocations are again changed. Corn is allocated to nearby fields (3 and 5 km from the center) because it is necessary to finish harvesting corn within 6 days with a lower number of trucks.

5. Conclusion

As mentioned above, depending on whether the TMR center contracted out the harvesting and bunkering operations and on harvesting conditions, the center could decrease the cost of feed-crop production by arranging the allocations of feed crops and changing the number of dump trucks. The analysis covered a comparatively small-scale TMR center. With a large-scale center the cost of harvesting feed crops would likely fall further with such adjustments. It is thus important for TMR centers to consider the allocation of feed crops when planning their feed-crop production.

Future studies

These two studies have revealed how to use the dispersing feed-cropping fields to enable farms to produce feed crops efficiently. As domestic feed production has developed in Japan, livestock management seems to avoid heavy economic damage from a surge in imported feed prices. However, feed-crop harvest can be poor. Some TMR centers that produce TMR cheaply use the residues from the production of juice or tofu. Another future need is to determine the conditions under which these residues can be used with maximum efficiency by the TMR center.

According to Japan’s Ministry of Agriculture,

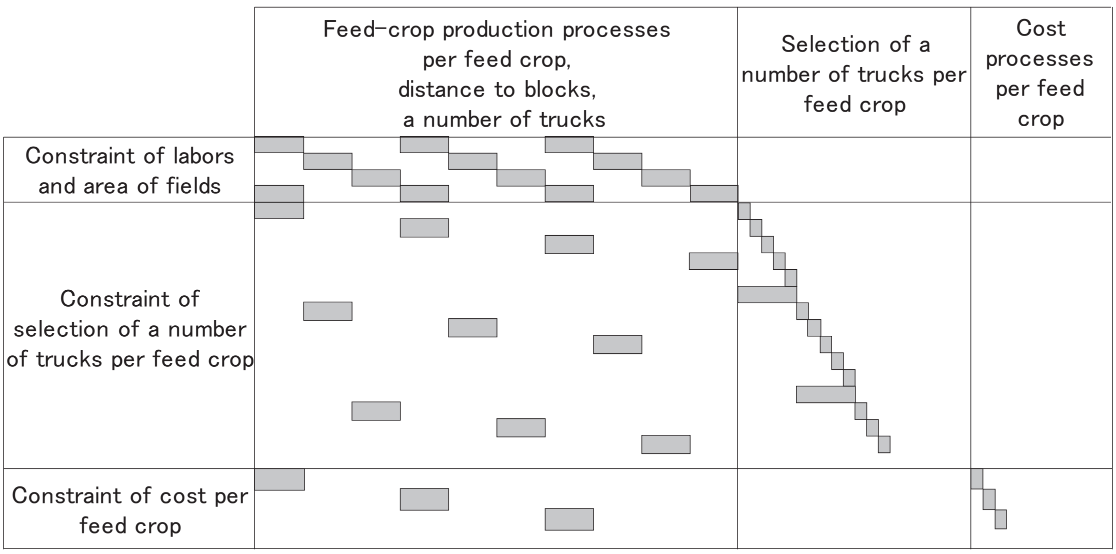

Fig. 2. Pattern diagram of farming model 2
Main technical coefficients are written in the gray parts.

Table 4. Simplex table for simulation of the allocation of feed crops based on cost (1) (an extract)

		Unit	Max or min amount	Relation	1 First crop of grass,one truck, distance of 1km	2 First crop of grass,one truck, distance of 3km	3 First crop of grass,one truck, distance of 5km	4 First crop of grass,one truck, distance of 7km	5 First crop of grass,two trucks, distance of 1km	6 First crop of grass,two trucks, distance of 3km	7 First crop of grass,two trucks, distance of 5km	8 First crop of grass,two trucks, distance of 7km	9 First crop of grass,three trucks, distance of 1km	10 First crop of grass,three trucks, distance of 3km	11 First crop of grass,three trucks, distance of 5km	12 First crop of grass,three trucks, distance of 7km
	A coefficient of cost	1000 yen														
1	Constraint of labor: First crop of grass	minute	5040	≧	221	393	566	738	113	198	284	369	94	136	194	251
2	Constraint of labor: Second crop of grass		4200	≧												
3	Constraint of labor: Corn		2880	≧												
4	Constraint of acre: Grass	ha	200	≦	5	5	5	5	5	5	5	5	5	5	5	5
5	Constraint of acre: Corn		100	≦												
6	Constraint of acre: Distant block of fields: 1km	ha	100	≧	5				5				5			
7	Constraint of acre: Distant block of fields: 3km		75	≧		5				5				5		
8	Constraint of acre: Distant block of fields: 5km		90	≧			5				5				5	
9	Constraint of acre: Distant block of fields: 7km		35	≧				5				5				5
10	Constraint of acre: One truck			≧	5	5	5	5								
11	Constraint of acre: Two trucks			≧					5	5	5	5				
12	Constraint of acre: Three trucks			≧									5	5	5	5
13	Constraint of acre: Four trucks			≧												
14	Constraint of acre: Five trucks			≧												
15	Selection of a number of trucks		1	≧												
16	Cost of the case: One truck			≧	221	393	566	738								
17	Cost of the case: Two trucks			≧					113	198	284	369				
18	Cost of the case: Three trucks			≧									94	136	194	251
19	Cost of the case: Four trucks			≧												
20	Cost of the case: Five trucks			≧												

Table 5. Simplex table for simulation of the allocation of feed crops based on cost (2) (an extract)

13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
First crop of grass,four trucks distance of 1km	First crop of grass,four trucks distance of 3km	First crop of grass,four trucks distance of 5km	First crop of grass,four trucks distance of 7km	First crop of grass,five trucks distance of 1km	First crop of grass,five trucks distance of 3km	First crop of grass,five trucks distance of 5km	First crop of grass,five trucks distance of 7km	Selection of one truck	Selection of two trucks	Selection of three trucks	Selection of four trucks	Selection of five trucks	Account of cost, one truck	Account of cost, two trucks	Account of cost, three trucks	Account of cost, four trucks	Account of cost, five trucks
													5.5	11	16.5	22	27.5
81	112	149	192	81	94	121	156										
5	5	5	5	5	5	5	5										
5				5													
	5				5												
		5				5											
			5				5										
								-200									
									-200								
										-200							
5	5	5	5								-200						
				5	5	5	5					-200					
								1	1	1	1	1					
													-60				
														-60			
															-60		
81	112	149	192													-60	
				81	94	121	156										-60

Table 6. Conditions of simulation

Conditions	Number of trucks	Cropping terms of corn: Days	Outsourcing of crop harvesting	Outsourcing of bunkering
First conditions based on survey	3–4	7	Outsourcing	Outsourcing
Increase in the maximum number of trucks	5	7	Outsourcing	Outsourcing
Reduction of cropping terms of corn	5	6	Outsourcing	Outsourcing
Stop outsourcing except for truck work	5	6	Stop outsourcing	Stop outsourcing

Table 7. Allocation of feed crops to fields by simulation

	1km block 100ha		3km block 75ha		5km block 90ha		7km block 35ha	
	grass (ha)	corn (ha)	grass (ha)	corn (ha)	grass (ha)	corn (ha)	grass (ha)	corn (ha)
First condition	95	5	0	75	70	20	35	0
Increase in the number of trucks	100	0	75	0	25	65	0	35
Reduction of cropping terms of corn	100	0	25	50	75	15	0	35
Stop outsourcing on harvesting and bunkering	100	0	15	60	50	40	35	0

Acreage of each field is 5 hectares.

Forestry, and Fisheries, food related industries produce about 20 million tons of waste; about 15 million tons of this is reused, mostly as feed. The amount of food waste from Japanese households is estimated at about 11 million tons; only about 0.5 million tons of this is reused. Therefore, about 15 million tons of waste is burned or buried (The Ministry of Agriculture, Forestry and Fisheries 2015a). It is important to determine how this food waste can be reused as feed.

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