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REVIEW
Establishment of Self-sufficient Concentrate by an Ear Corn Silage Production System through Cooperation between Arable and Livestock Farming

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Abstract
We have developed an ear corn silage production system in which only nutritious ears of corn are harvested from whole plants by a self-propelled forage harvester equipped with a corn snapping header and a kernel processing unit, followed by using a roll baler for chopped material combined with a bale wrapper to prepare silage. The harvesting capacity was 2.1 ha/h with a harvesting loss of 1.1%. The ensiling capacity was 1.2 ha/h with a product loss ranging from 0.5% to 1.7% after improvements were made to the roll baler for chopped material, combined with a bale wrapper and its program for packing control. Ear corn silage (ECS) contained 48.1% starch and 28.9% NDF. The fermentation quality of the silage after approximately one year in storage was also good: a pH of 4.0, the presence of lactic and acetic acids, and less than 10% of VBN/TN. These results demonstrated the practical use of the ECS mechanical system. ECS residue (i.e. stalks and leaves) was considered to be effective in improving the physical properties of soil, but with no observable effect on crop yield. In the demonstration field, the ECS yield was 8.9 t/ha and the production cost was ¥31.9/kg at 71% dry matter. Assuming that they harvested at 60% dry matter and the loss at ensiling was effectively controlled, the yield of ECS could have been 18.6 t/ha. This is higher than the 16.7 t/ha of yield necessary to sell at the asking price of a dairy farmer. The results above suggest that it is possible for arable farmers to profit by continuing the production of ECS.

Discipline: Agricultural machinery
Additional key words: crop rotation, feed composition, fermentation quality, roll baler for chopped material combined with bale wrapper, snapping header

Introduction

Cereal feed has been imported since the 1950s to support the growth of livestock farming in Japan (Noguchi 2011), resulting in a low self-sufficiency rate for feed in Japan, especially the 14% rate for concentrated feed (MAFF 2015), and is one of the reasons for Japan's low food self-sufficiency rate. Recent sharp fluctuations in the prices of cereals (including corn) caused by global climate change and an unstable international situation have had serious impacts on the Japanese livestock industry. To realize sustainable livestock farming, the productive capability of self-supplied concentrated feed must be enhanced. Corn has high land productivity and a higher grain yield compared to rice and wheat, as well as fine palatability for livestock animals. Silage made from ear corn harvested exclusively from whole corn plants (i.e. ear corn silage, hereinafter ECS) offers potential use as self-supplied concentrated feed. However, livestock farmers generally lack the land for roughage production as they feed a growing number of animals, and in Hokkaido, meadow field per large livestock is on the decline (MAFF 2015). Conversely, farmers in large-scale arable farming areas of Hokkaido face their own difficulties in keeping crop rotation systems due to a labor shortage caused by forced scale expansion (Hiraishi 2013). Introducing corn into the crop rotation is expected to reduce the labor in large-scale arable farming, which is urgently needed as a measure against labor shortages and thus for the maintenance of arable farming areas.

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This study was intended to establish, for the first time in Japan, a practical mechanized system for producing ECS to meet the growing demand for self-supplied concentrated feed, and also to establish a cooperative arable and livestock farming production system through demonstration tests for ECS production introduced into arable farming areas.

Establishment of an ECS harvesting and preparation system

We developed and examined a system of harvesting only nutritious ears of corn from their tops by using a self-propelled forage harvester equipped with a kernel processing unit plus a snapping header (Fig. 1) . The harvested corn is ensiled using a roll baler for chopped material combined with a bale wrapper to prepare silage (Fig. 2). The fieldwork efficiency for harvesting was 2.1 ha/h, and ear corn could be harvested with a head loss rate of 1.1%. The fieldwork efficiency for preparing

Fig. 1. Snapping header.

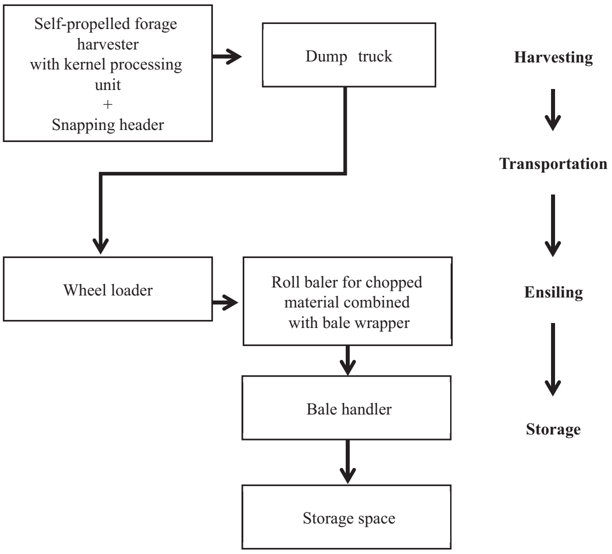

Fig. 2. Workflow of the ECS production system

Table 1. Feed composition of ear corn parts and machine harvested ECS ingredients.

	Ear corn parts[1] (N=5)			ECS	Silage	
	Husk	Cob	Kernel	ingredients[2] (N=20)	ECS[3] (N=9)	(Reference) WPCS[4]
DM[5](%)	43.9	38.6	63.5	56.7	57.8	40.0
Feed composition (%DM)						
CP[6] (%)	3.6	3.1	8.1	7.1	7.6	3.2
NDF[7] (%)	83.7	83.5	8.7	32.6	28.9	20.1
ADF[8] (%)	43.1	44.5	5.2	17.9	13.7	12.4
ADL[9] (%)	4.2	7.7	0.4	2.6	2.0	-
Starch (%)	1.8	2.1	71.1	48.0	48.1	-
Weight component ratio (%)	7	11	82	-	-	-

[1] Sampled and split by hand. One unit consisted of ten consecutive ears of corn.
[2] Harvested by machine.
[3] Silage after six months of storage.
[4] Whole crop corn silage (Standard table of feed composition in Japan (2001)), maturity, Japan
[5] Dry matter
[6] Crude protein
[7] Neutral detergent fiber
[8] Acid detergent fiber
[9] Acid detergent lignin

silage was 1.2 ha/h with a preparation loss rate of 2.3%, although the reentry of spilled ear corn material was necessary. As a general practice now being employed, corn is harvested and processed as a portion of whole plant corn silage (WPCS), for which a self-propelled forage harvester and a wheel loader are used for harvesting and ensiling in a bunker silo, respectively. The harvesting work efficiency and preparation work efficiency of this process are 2.1 ha/h and of 0.7 ha/h, respectively (Hokkaido Department of Agriculture 2005). Compared with WPCS, the levels of work efficiency of ECS are almost the same for harvesting and higher for preparation.

Sealed roll bales had an air-dry matter rate of 58%, average weight of 488 kg, average diameter of 102 cm, average height of 98 cm, and average dry matter density of 355 kg/m^3. The roll bales were made at 30 rolls per ha. Starch content in the ECS was estimated 58.7% according to the weight ratio and starch content of each ear corn part, although the measured starch content of the ECS ingredients was 48.0% (Table 1). Visual observation of the ECS suggests that this condition is mainly due to the mixing of stalks and leaves during machine harvesting. The weight ratio of stalks and leaves in the ECS ingredients was estimated to be 17.6% from the starch content of 48.0%, under the assumption of a constant weight ratio and starch content for each ear corn part. As ECS is expected to be used as a concentrated feed, the degree and causes of contamination in ear husks, stalks and leaves in ECS must be identified in order to increase the total digestible nutrients (TDN) content by securing a starch content of 50% or higher. Table 2 lists the fermentation qualities of the ECS. Fine ECS quality after one year of storage was confirmed by the presence of lactic acid and acetic acid, constant levels of pH at 4.0 or lower, and 10% or lower values of volatile basic nitrogen/ total nitrogen (VBN/TN).

Table 2. Fermentaion qualities of the ECS.

Storage length	6 months	11 months
DM (%)	57.8	57.2
pH	4.1	4.0
Organic acid composition (%FM[1])		
Lactic acid	0.81	1.16
Acetic acid	0.19	0.27
Propionic acid	0	0.03
Isobutyric acid	0.11	0.13
VBN/TN[2](%)	2.3	5.6
V-score	91	88

[1]Fresh matter
[2]Volatile basic nitrogen/total nitrogen

Harvesting/preparation efficiency and silage quality of ECS

Loss at the ensiling stage must be reduced in order to achieve practical use of the mechanized harvesting and preparation system for ECS. This loss was caused by spills from the front part of the forming chamber and the wrapper (Fig. 3). Spills from the front part of the forming chamber were associated with the air-dry matter rate of ECS: the lowest value of loss was at an air-dry matter rate of around 55.5% (Fig. 4). Spills from the wrapper were caused by short cut lengths of the ingredients, so that there were fewer total spills at a cut length of 10 mm or longer (Table 3). However, the shorter cut length

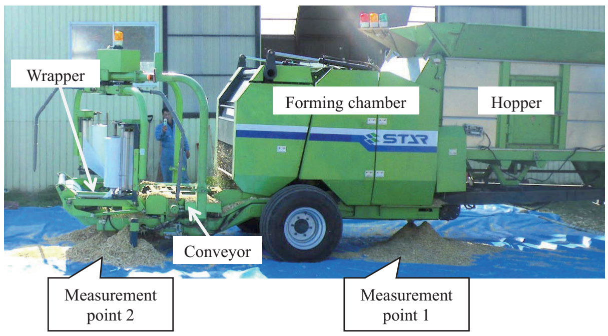

Fig. 3. The roll baler for chopped material combined with bale wrapper, and two measurement points for losses.

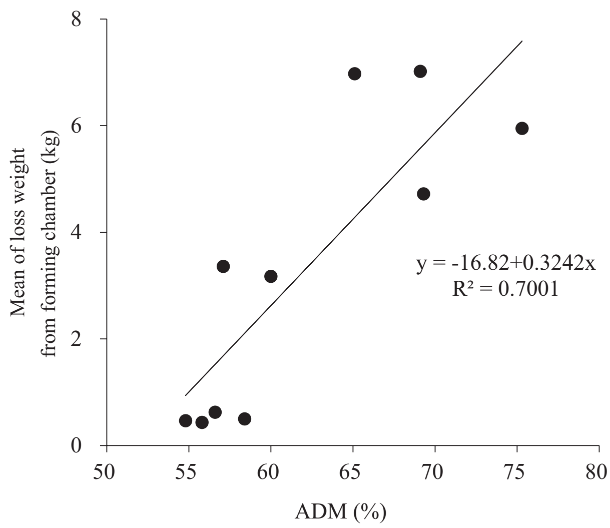

Fig. 4. Relationship between air-dry matter (ADM) and the mean of loss weight from the forming chamber.

is known to improve the fermentation quality of WPCS (Messer and Hawkins 1977). Okamoto et al. (1979) and Ohshita (2006) recommended a cut length of 10 mm or shorter, which would neither shorten the rumination time nor reduce feeding for dairy cattle. This effect of cut length on fermentation quality was thought to be same in the case of ECS because both ingredients are similar. Therefore, we improved the settings of the roll baler for chopped material combined with a bale wrapper to reduce loss under the condition of a cut length of 10 mm or shorter. Lowering the level of the wrapper diminished the gap of the level between the wrapper and the conveyor. As a result, the drop impact that occurs when moving a roll bale from the conveyor part to the wrapper was reduced. We also improved the packing control program to continue supplying materials during the binding of a roll bale with a net in the forming chamber. These changes reduced loss from the wrapper, thereby lowering the preparation loss rate to 0.5%-1.7% per roll bale, which is comparable to rates normally observed for WPCS. In this case, the air-dry matter of ECS ranged from 55% to 65%. ECS prepared using this improved method has high fermentation quality (V-score = 96 or higher) (Table 4), suggesting that it was possible to prepare ECS in a practical way by using the chopping-type baler.

ECS is known to have a high starch content, but our results indicated that the contamination of ear husks, stalks and leaves in ear corn would lower the value, so we investigated the effects of harvesting conditions (i.e. cutting height, operating speed) and corn variety on the composition of ECS. Significant effects of cutting height were found in dry matter (DM), organic matter (OM) and adenosine digestible fiber (ADF). Given the significant interaction between cutting height and variety with crude protein (CP) and starch (Table 5), only the simple main effect was evaluated. The effect of cutting height on CP was only significant in variety '39B29' and the effect of cutting height on starch was only found in variety '39M48'. These results were attributed to inter-varietal differences in the kernel-cob ratio and plant type of ear corn as listed in Table 6. Further investigation is needed to identify the characteristics of varieties involved in these effects. Regarding operating speed, only small effects on feed composition were found at 4-6 km/h.

Table 3. Loss weight and percentage, and setting cut length.

Setting cut length (mm)	Loss weight (kg)		Loss percentage (%)
	Forming chamber	Wrapper	
5	5.9[a]	14.0[a]	3.7[a]
10	4.1[a]	6.3[b]	2.0[b]
16	3.8[a]	5.4[b]	2.0[b]

Values in the columns followed by the same letter are not significantly different at $P < 0.05$.

Table 4. Fermentation qualities of ECS and the packing control program.

	Packing control program		P value
	Before improvement	After improvement	
N (Bale)	3	8	
DM (%)	61.4	60.5	0.479
pH	3.9	4.1	0.167
Organic acid composition (%FM)			
Lactic acid	0.91	1.09	0.137
Acetic acid	0.21	0.25	0.236
Propionic acid	0.00	0.00	N.S.
Isobutyric acid	0.39	0.39	0.970
VBN/TN (%)	4.5	6.9	0.106
V-score	99	96	0.064

Table 5. Effect of harvesting and corn variety conditions on feed composition of ECS.

Corn Variety	Operation speed (kmh-1)	Cutting height	DM (%)	Feed composition (%DM) OM[1]	CP	NDF	ADF	Starch
39B29	4	Normal	64.1	98.1	7.2	37	17.5	49.1
		High	63.9	98.1	7.4	34.4	16.1	45.5
	6	Normal	67	97.9	6.9	35	16.1	52.7
		High	64.7	98.1	7.7	36.1	16.3	51.1
39M48	4	Normal	59.9	97.5	7	34.6	17.7	41.1
		High	56.6	98	6.7	30.1	14.6	57.6
	6	Normal	60.9	97.7	7	30	14.9	47.9
		High	56.5	97.9	6.9	30	14.2	51.6
Mean of hybrid	39B29		65	98	7.3	35.7	16.5	50
	39M48		58.2	97.8	6.9	31	15.2	49.8
Mean of cutting height	Normal		63.5	97.8	7	34.5	16.6	48.3
	High		60.4	98	7.2	32.7	15.3	51.4
Three-way layout ANOVA	Variety		***	***	***	**	*	n.s.
	Operation speed		n.s.	n.s.	n.s.	n.s.	*	n.s.
	Cutting height		***	**	n.s.	n.s.	*	n.s.
	Operation speed x Variety		n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
	Cutting height x Variety		n.s.	n.s.	**	n.s.	n.s.	*
	Operation speed x Cutting height		n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
	Variety x Operation speed x Cutting height		n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

*: P < 0.05, **: P < 0.01, ***: P < 0.001, n.s.: no significant difference.

[1]Organic matter

Table 6. Plant type and ADM1 at harvesting.

Hybrid	39B29	39M48	t.test
Plant type (cm)			
Plant height	336 ± 17.5	346 ± 12.6	n.s.
Ear height	152 ± 9.7	171 ± 9.2	***
Stalk diameter	1.35 ± 1.19	1.49 ± 0.54	**
ADM (%)			
Ear corn			
Kernel	72.1 ± 4.0	70.1 ± 2.4	n.s.
Cob	43.0 ± 4.1	38.3 ± 2.3	**
Husk	51.2 ± 7.5	58.5 ±11.5	n.s.
Stalk and leaf	30.2 ± 4.5	31.0 ± 5.2	n.s.
Ear corn yield ($kgha^{-1}$)	13691 ± 361	15938 ± 285	**

**: P < 0.01, ***: P < 0.001, n.s.: no significant difference.
[1] Air-dry matter

Investigation of introducing ECS corn into the crop rotation system

Arable farmers considering whether to produce ECS corn must consider how to use harvest residues and determine the cost of ECS production. To solve these problems, we conducted two types of experiments. Because we considered it appropriate to plow harvest residues back into the soil, we investigated the physical and chemical properties of the soil plowed with said residues, and then studied the productivity of succeeding crops. WPCS residue was used in the control group. In the soil in which ECS residue was harrowed, the C/N ratio increased under higher temperature in soybean fields, but that tendency was not clear in wheat fields (Fig. 5). Improvements in the physical properties of soil were confirmed by the increased gas phase of the crop season following the year of plowing (Fig. 6). As succeeding crops, spring wheat and soybean showed significant and slight increases in yield, respectively, though the values were not significant (Table 7). In an experiment where sweet corn residue was plowed into the soil as a substitute for feed corn, sugar beets were not influenced by a higher C/N ratio caused by ECS residue, and their root weight was increased by 1.2 times due to the improved physical properties of the soil. The results of our experiments show that sugar beet is most appropriate as a succeeding crop of ECS. Okumura et al. (1997) found that the growth of potato is strongly affected by preceding crops, that is, the yield of potato succeeding sugar beet is higher than that of succeeding winter wheat or kidney beans. And in the crop rotation employed in Hokkaido, early maturing potato varieties are chosen as the preceding crop of winter wheat, as the proceeding crop should be harvested before the beginning of September—the time limit for making preparations for sowing winter wheat. Furthermore, to avoid the repeated cultivation of gramineous crops, soybean-corn rotation has been widely practiced in the Corn Belt region of the United States since the latter half of the 20th century. From these facts, the cultivation of soybean after winter wheat and before corn can be interpreted as a valid rotation. In conclusion, we suggest the best crop rotation system as follows: ECS → Sugar beet → Potato → Winter wheat → Soybean → ECS.

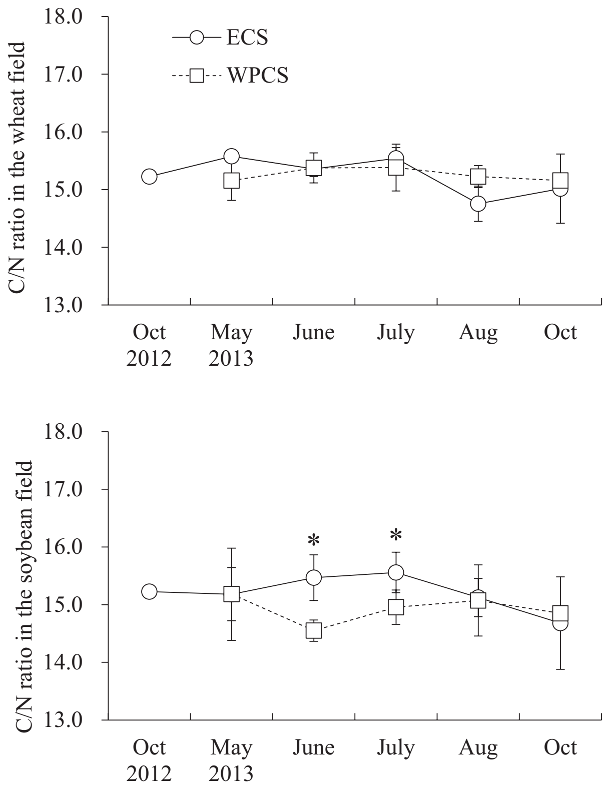

Fig. 5. Change of C/N ratio in field soil under higher temperature during summer.
Error bars show standard deviation.
***: P < 0.05**

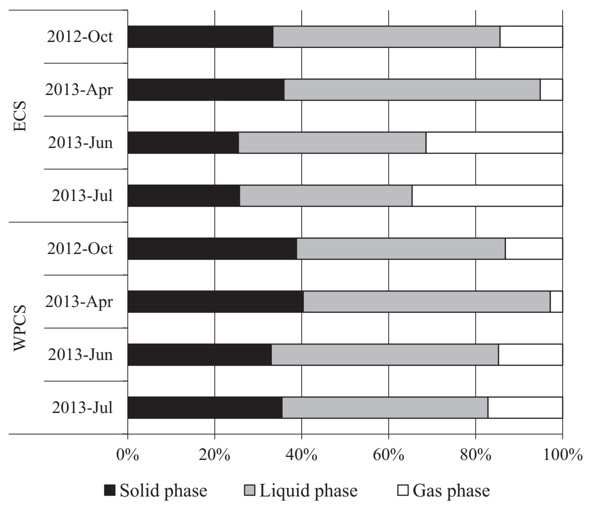

Fig. 6. Changes in the three phases of soil after plowing. (Measurement depth: 12.5 cm)

Besides plowing, we considered the possibility of using ECS residue as bedding material for livestock barns and investigated methods of collecting the residue. When ECS residue was collected as roll bales, the collection rate ranged from 22% to 26% and the average water content was 59%. ECS residue must be sufficiently dried for use as bedding material. However, such drying is difficult to do in the climate of Hokkaido. In addition, there is little possibility of the residue collected being used as roughage due to soil contamination. Consequently, we concluded that it is appropriate to return ECS residue to the soil.

In order to demonstrate the economic viability of the ECS self-supplying system in arable farming and contribute to the establishment of an ECS production system based on cooperation between farmers engaged in arable farming and those engaged in livestock farming, the ECS production cost in arable farming was estimated using accrual cases in the Central Hokkaido region. In this case study, arable farmers conducted the farm operations that

Table 7. Yields of soybean and wheat as succeeding crops of ECS.

Residue	ECS (kg 10a-1)	WPCS (kg 10a-1)	t.test
Soybean	436	388	n.s.
Wheat	444	349	*

*: P < 0.05, n.s.: no significant difference.
*, significant at 5% level. n.s., not significant.

included use of a harrow, seeding work, and applying herbicide, while harvesting and silage preparation were outsourced to contractors, which cost ¥31.9/kg (with an air-dry matter rate of 71%). Arable farmers require more than ¥200,000/ha to continue the production of ECS. On the other hand, dairy farmers quoted that the upper limit price of ECS was ¥35/kg. In this case study, the actual ECS yield of arable farmers was 8.9 t/ha, corresponding to gross income of ¥27,754/ha with an ECS price of ¥35/kg, and lower than the preferable gross income of ¥200,000/ha (Fig. 7). The corresponding ECS yield to the preferable gross income with an ECS price of ¥35/kg was estimated as 14.1 t/ha (Fig. 7).

Since the estimated yield of ECS by sampling just before harvesting was 16.1 t/ ha, a large loss (of approximately 45%) was presumed at ensiling. As described previously, the loss of ensiling increased mainly in line with the air-dry matter rate of ECS. In this case study, the air-dry matter rate at harvesting was 71%, and much higher than that at the proper timing of harvesting which corresponded to 60% (Ohshita 2013). In this experiment, the roll baler for chopped material combined with a bale wrapper was used to ensile with the packing control program adjusted to the proper air-dry matter rate of 55% to 65%. If the air-dry matter rate at harvesting was approximately 60%, it would be possible to reduce the loss of ensiling below 1.7% instead of 45%. In this case study, we estimated that the yield of ECS from 60% air-dry matter was 18.6 t/ha, thereby exceeding 16.7 t/ha, for which the air-dry matter rate was converted from 71% to 60% of 14.1 t/ha that corresponded to the preferable gross income with an ECS price of ¥35/kg. Therefore, we concluded that ECS production through cooperation between arable farming and livestock farming was economically viable.

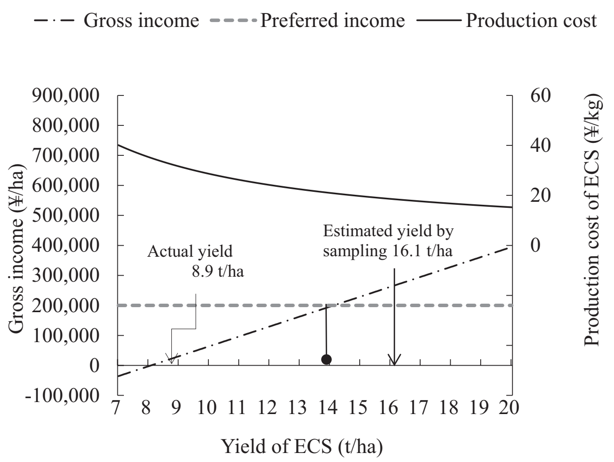

Fig. 7. Estimated gross income to the yield of ECS. (Assumed price of ECS = ¥35/kg; air-dry matter rate of ECS = 71%)

Conclusion

We established a mechanized system for harvesting and ensiling ECS, and then demonstrated the practicality of the system by showing its operating efficiency and performance, which were comparable to those for WPCS, and its high fermentation quality of ECS after one year of storage. Moreover, we showed that ECS residue does not reduce the productivity of succeeding crops, and that our newly proposed crop rotation system has high feasibility. The crop rotation including corn for ECS is an unprecedented cropping system. While ECS has been produced in large-scale bunker silos and other facilities in Western countries, little has been reported on the quality of ECS ensiled as wrapped roll bales, and our new production system is the first of its kind in the world. This system will allow the wide-area distribution of ECS. In 2015, ECS produced by arable farmers in Central Hokkaido on their farms, each with an area of approximately 10 ha, was fed to livestock in Eastern Hokkaido.

References

Hiraishi, M. (2013) Rural trend prediction using the Census of Agriculture and Forestry. *Miscellaneous publication of Hokkaido Research Organization Agricultural Experiment Stations*, **40**, 1-19 [In Japanese].

Hokkaido Agriculture Department (2005) *Agricultural production system of Hokkaido*. Hokkaido Agricultural Extension Association, Sapporo, Japan, pp521 [In Japanese].

MAFF: Affairs of Feedstuff. http://www.maff.go.jp/j/chikusan/sinko/lin/l_siryo/pdf/11_meguji_illust.pdf

Messer, H. J. M. and Hawkins, J. C. (1977) The influence of the properties of grass silage on bulk density and horizontal pressure. *J. JAE*, **22**, 55-64.

Noguchi, T. (2011) The present conditions and problems of agricultural cooperatives for the feed grain from the United States and the formula feed supply in Japan. Nouson Kenkyu, **113**, 39-52 [In Japanese].

Ohshita, T. (2006) Considerations on the corn silage ensiling, consider from relations between harvest time and nutrient loss rate. *Bokuso to Engei*, **54**(1), 7-10 [In Japanese].

Ohshita, T. (2013) Manual of the ear corn silage production and utilization. Dairy farming division, HARC, NARO, 1-9 [In Japanese].

Okamoto, Z., Deoka, K. and Bando, K. (1979) Influence of cut length of corn silage on rumination behaviors of dairy cow. *Bulletin of the Hokkaido Prefectural Shintoku Animal Husbandry Experiment Station*, **10**, 33-36 [In Japanese].

Okumura, M., Yamagami, M. and Higashida, S. (1997) The crop rotation maturities and combination for the effective soil management. *Soil Science and Plant Nutrition*, **68**(3), 331-335 [In Japanese].