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REVIEW

Forage Cropping System of Natural-Reseeded Barnyardgrass (*Echinochloa crus-galli*) for Abandoned Paddy Fields and Its Feasibility in Mountainous Area

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Abstract

A field experiment was carried out from October 1999 to September 2001 to establish a cropping system with Italian ryegrass (*Lolium multiflorum*) and natural-reseeded barnyardgrass (*Echinochloa crus-galli*) in an abandoned paddy field. Ryegrass was sown in October 1999 and 2000, and barnyardgrass was sown only in October 1999. A split-split plot arrangement was applied with the ryegrass varieties (an early-maturing type (EM) and a mid- to late-maturing type (LM)) as the main plot factors. The subplot factor was barnyardgrass at various sowing rates (100, 200, and 300 g/a). EM and LM were harvested twice and once, respectively, the following spring, and barnyardgrass was harvested twice: once in the summer and once in the autumn in both the EM and LM plots. In both years, the ryegrass yields depended significantly on the variety: the yield of EM was greater than that of LM. The first crop yields of barnyardgrass were affected by the preceding ryegrass varieties: greater yields of barnyardgrass were obtained when EM was the preceding crop than when LM was. The barnyardgrass sowing rate had no significant effect on either the first or the second crop yields. A sufficient number of seeds were produced to naturally establish a sward of barnyardgrass the following year in both the EM and LM plots. To verify the feasibility of this cropping system with ryegrass and barnyardgrass, we applied the system to a small field owned by a cattle farmer. The productivity cost of using this cropping system for grass production, excluding the cost depreciation for farm equipment, was comparable to the price of imported hay.

Discipline: Grassland
Additional key words: early-maturing ryegrass, mid- to late-maturing ryegrass, productivity cost, subsidy

Introduction

In the last few decades, the rice production quota has increased the number of abandoned paddy fields in a mountainous area of San-in District, on the main island of Japan, Honshu. Although the Japanese government has taken a number of steps to promote the use of these abandoned paddy fields for forage production, the fields remain unplanted because the soil is too moist to grow forage crops well. The annual forage cropping system in the San-in District used to be dominated by sorghum (*Sorghum bicolor*) and Italian ryegrass (*Lolium multiflorum*), and large machines were not used for small-scale cattle production in small fields. These days, however, this sort of cropping system is rare, owing to the focus on sorghum production. As a corollary, the area devoted to forage production has rapidly decreased.

Echinochloa species, serious annual weeds affecting summer crops in almost all countries in temperate

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zone countries, produce a lot of seeds from early summer to late autumn. New plants emerge late the next spring, growing vigorously and with a high production mass[4]. They are also adapted to a wide range of soil moisture conditions[6]. Moreover, high nutritive value and palatability of barnyardgrass (*E. crus-galli*), one of the major weeds in Japan, are well known[1]. These characteristics of barnyardgrass as both weed and feed suggest that the species has the potential to be a quality forage that can establish itself without sowing in small abandoned paddy fields[3].

When natural-reseeded barnyardgrass is used as a substitution crop for sorghum, an annual cropping system of wild grass and Italian ryegrass could be adopted. This system requires a walking-type rotary mower and round baler, both of which are already possessed by many cattle production farmers. Although the cropping system is expected to be useful, the feasibility of the system for cattle production farmers is unknown.

The objectives of the study are: (1) to establish an annual cropping system with barnyardgrass and Italian ryegrass for abandoned paddy fields and (2) to verify the feasibility of the cropping system in small fields for small-scale cattle production.

Materials and methods

1. Annual Cropping System

The field experiment was conducted from October 1999 to September 2001 in an abandoned paddy field in Oda City in Shimane Prefecture. The field had been left unplanted for four years. Vegetation growing naturally there had been cut twice a year, and the cuttings had not been removed. Ryegrass and barnyardgrass were sown on October 15, 1999. To determine how barnyardgrass yield was affected by the relationship between the ryegrass maturity and the sowing rate of barnyardgrass, the plots were arranged in a split-split plot design with ryegrass variety as the main plot factor and barnyardgrass sowing rate as the subplot factor with three replications. Each sub-plot was 6- × 5 m. The ryegrass variety treatments consisted of an early-maturing type Tachiwase (hereafter referred to as EM) and a mid- to late-maturing type Mammoth B (hereafter referred to as LM). These were sown at a rate of 300 g/a. The barnyardgrass sowing rates were 100, 200 and 300 g/a. The barnyardgrass seeds were collected from a meadow in Oda prior to the experiment; percentage ripening of those seeds was 12% through soft X-ray measurement. In the EM plots, the first and second ryegrass crops were harvested on May 1 and June 6, 2000, respectively. In the LM plots, ryegrass was harvested on May 25, 2000. The first and second barnyard crops were respectively harvested at the heading stage (on 9 August 2000) and after seed setting (on 3 October 2000) in both the EM and LM plots (Fig. 1). After the second crops of barnyardgrass were harvested, the plots were fertilized and plowed.

On October 20, 2000, the same ryegrass varieties were sown on the same plots used in the experiment the previous year. Barnyardgrass was not sown, since the species was expected to regenerate through natural reseeding the following year. The ryegrass harvesting dates were 6 May and 7 June 2001 in EM and 22 May 2001 in LM. The barnyardgrass harvesting dates were 8 August and 28 September 2001, both the EM and LM plots. To determine the number of barnyardgrass seeds scattered in the plots, soils within three 25-×25 cm quadrates were sampled at a 3 cm depth in 2000 and at 0–5 cm and 5–10 cm depths in 2001 in each sub-plot. Prior to the sowing, the plots were improved with cattle manure com-

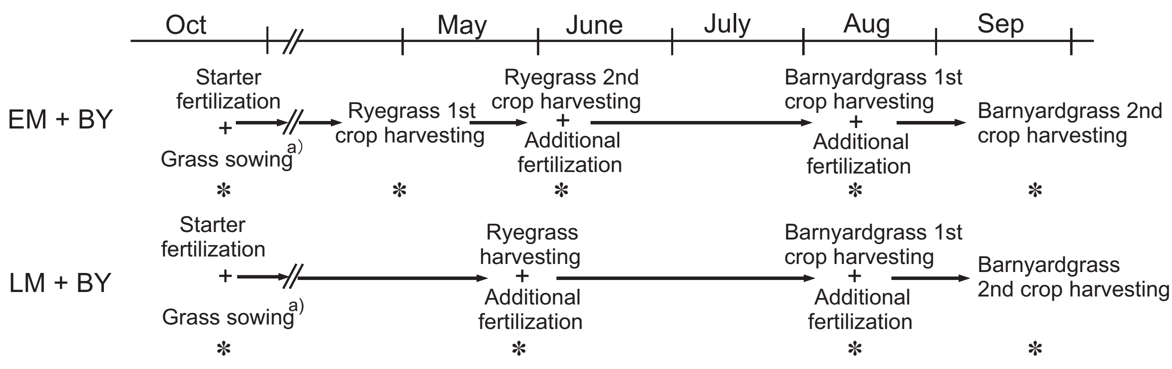

Fig. 1. Cultivation schedule details of ryegrass and barnyardgrass production

EM: Early maturing variety of ryegrass, Tachiwase. LM: Mid- to late-maturing variety of ryegrass, Mammoth B.
BY: Barnyardgrass. *: Date of fertilization, sowing and/or harvesting.
a): Ryegrass and barnyardgrass were sown the first autumn and only ryegrass was sown the following year.

post at 200 kg/a and with calcium carbonate at 10 kg/a, and then fertilized. Fertilization included starter fertilizer at a rate of N-P_2O_5-K_2O =1.0-1.0-1.0 kg/a before the sowings. Additional fertilizer was applied after the second ryegrass crops and the first barnyardgrass crops were harvested at the same rate of N-P_2O_5-K_2O, respectively (Fig. 1). Data for both years were analyzed and subjected to analysis of variance.

2. Feasibility of the cropping system for the cattle farmer

In autumn of 1998, the annual cropping system with ryegrass and barnyardgrass (hereafter referred to as R + B) was applied to the small scale cattle farmer to verify the feasibility of the cropping system. The farmer had four cows for calf production and breeding, and had 0.21 ha of meadow and 1.0 ha of pasture, and scale of the farmer in the experiment was prevalent in mountainous areas of the San-in District. In that experiment, EM (Tachiwase) was the only ryegrass variety used. The productivity cost of the R + B cropping system was investigated from October 1999 to September 2000. The farmer in the study already owned a walking-type mower and round baler appropriate for use in this cropping system. Data for this system were compared with data for a ryegrass and sorghum cropping system (hereafter referred to as R + S) adopted by the cattle farmer mentioned above.

Results

1. Annual cropping system

The statistical analysis found no significant differences among barnyardgrass sowing rates nor ryegrass variety × the sowing rates interactions in terms of grass yield, grass growth parameters, or weed dry weight in any of the harvestings. Therefore, data are presented as the average of the three sowing rates.

(1) Ryegrass yields and weeds

Ryegrass yields depended significantly on the variety in both years. The total yields of EM harvested twice conventionally were greater than those of LM harvested once (Fig. 2).

Regardless of the ryegrass variety, the whole dry

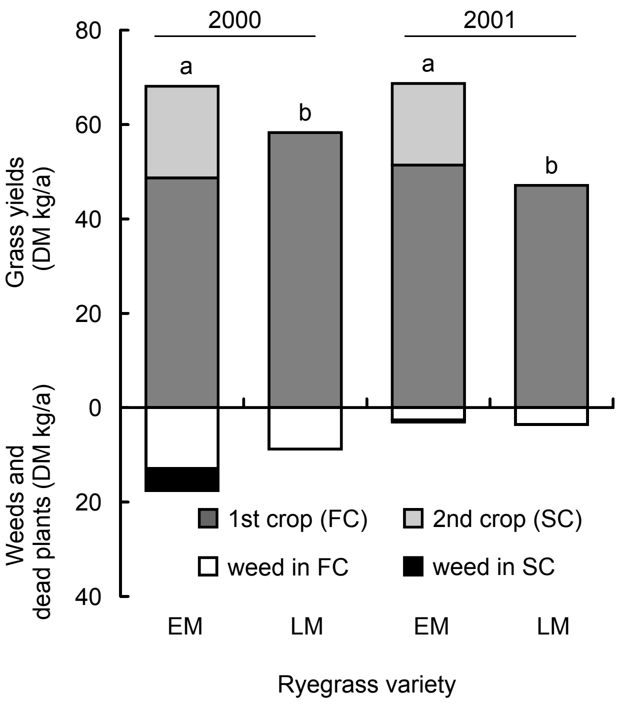

Fig. 2. Yields of ryegrass and weights of weeds and dead plants

Data were averaged across the three different sowing rates of barnyardgrass.
EM: Early maturing variety of ryegrass, Tachiwase.
LM: Mid- to late-maturing variety of ryegrass, Mammoth B.
Total yield values assigned the same letters on the bars in each year are not significant ($P<0.05$).

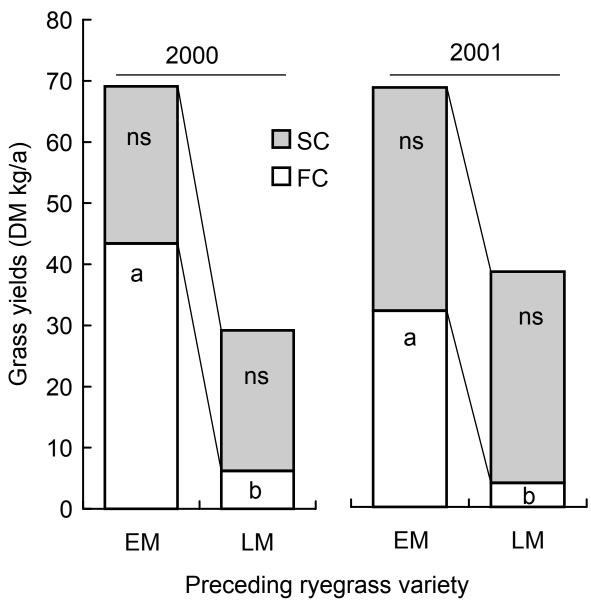

Fig. 3. Yields of barnyardgrass followed by different ryegrass varieties

Data were averaged across the three different sowing rates of barnyardgrass.
FC and SC mean the first crop and second crop of barnyardgrass.
EM: Early maturing variety of ryegrass, Tachiwase.
LM: Mid- to late-maturing variety of ryegrass, Mammoth B.
ns: Not significant ($P<0.05$). Values assigned the same letters on the bars in each year are not significant ($P<0.05$).

Table 1. Growth characteristics of barnyardgrass at harvest time[a)]

Treatment and statistics		2000				2001			
		First Crop		Second Crop		First Crop		Second Crop	
		PH[b)]	TN[b)]	PH	TN	PH	TN	PH	TN
	(g/a)	(cm)		(/m^2)		(cm)		(/m^2)	
Early-maturing ryegrass variety (EM) (V)[c)]									
Barnyardgrass sowing rate (R)[d)]	100	118	237	102	409	103	321	99	290
	200	112	195	104	350	101	486	99	294
	300	107	240	95	229	112	226	107	297
Mid- to late-maturing ryegrass variety (LM) (V)[c)]									
Barnyardgrass sowing rate (R)[d)]	100	73	165	93	185	51	112	102	153
	200	75	141	105	227	53	124	101	261
	300	64	168	103	245	61	202	106	243
ANOVA significance									
Variety (V)[c)]		**	NS	NS	NS	*	**	NS	NS
Sowing rate (R)[d)]		NS	NS	NS	NS	NS	NS	NS	NS
V × R		NS	NS	NS	NS	NS	NS	NS	NS

a): Experimental plots were arranged by a split-split design with ryegrass variety as the main plot factor and barnyardgrass sowing rate as the subplot factor.
* and ** show significance levels of $P<0.05$ and $P<0.01$, respectively, and NS means not significant ($P<0.05$).
b): PH and TN mean plant height and tiller number of barnyardgrass.
c): EM and LM are Tachiwase and Mammoth B, respectively.
d): Barnyardgrass was sown at the ryegrass sowing date in autumn 1999 and was not sown the following year.

Table 2. Seed production of barnyardgrass in second crop[a)]

Treatment and statistics		2000	2001		
		0–5 cm	0–5 cm	6–10 cm	Total
	(g/a)	(/m^2)	(/m^2)		
Early-maturing ryegrass variety (EM) (V)[b)]					
Barnyardgrass sowing rate (R)[c)]	100	6,827	6,321	540	6,861
	200	5,824	9,638	687	10,325
	300	4,058	5,784	583	6,367
Mid- to late-maturing ryegrass variety (LM) (V)[b)]					
Barnyardgrass sowing rate (R)[c)]	100	1,974	3,729	464	4,193
	200	2,395	3,865	418	4,283
	300	2,759	2,121	651	2,772
ANOVA significance					
Variety (V)		*	*	NS	*
Sowing rate (R)		NS	NS	NS	NS
V × R		NS	NS	NS	NS

a): Experimental plots were arranged by a split-split design with ryegrass variety as the main plot factor and barnyardgrass sowing rate as the subplot factor.
* shows a significance level of $P<0.05$, and NS means not significant ($P<0.05$).
b): Ryegrass preceded barnyardgrass. EM and LM are Tachiwase and Mammoth B, respectively.
c): Barnyardgrass was sown only in autumn 1999 and was not sown the following year. Barnyardgrass in 2000 was from the sowing in 1999, and the plants growing in 2001 were regeneration through reseeding.

weights of weeds in 2001 were less than those in 2000, and those in the second crops were less than those in the first. In EM, *Alopecurus aequalis* Sobol. var. *amurensis* (Komar.) Ohwi and *Poa annua* L. were the main weed species detected in the first crops, and *Trifolium repens* was the main weed detected in the second crops in 2000. However, all those species declined the following year. In LM, *Poa annua* L. was the main weed species in the first crop in 2000. However, the species declined the following year.

(2) Barnyardgrass performance and weeds

Barnyardgrass yields: In both years, there were significant differences in the first crop yields between the preceding ryegrass varieties, with much lower yields in LM plots than in EM plots (Fig. 3). Growth parameters of barnyardgrass reflected these yields differences in the first crops in both years. The parameters in barnyardgrass after LM were smaller than those after EM, although there was no significant difference in the tiller number of barnyardgrass between preceding ryegrass varieties in 2000 (Table 1).

The second crop yields of barnyardgrass were not affected by the preceding ryegrass varieties, and in both years the yields after EM were almost the same as those after LM. There was no significant difference among barnyardgrass sowing rates or between preceding ryegrass varieties and no significant interactions were found in sowing rates × ryegrass variety (Table 1).

Seed production of barnyardgrass: The seeds scattered in the plots were from only the second crops, since the first crops were harvested before seeds had set. There were significant differences in seed production between the preceding ryegrass varieties; in both years EM plots had more seeds per unit area than in LM plots. In seed production, there were no differences among the sowing rates of barnyardgrass or in the interaction of ryegrass varieties × sowing rate of barnyardgrass (Table 2).

Weeds in barnyardgrass: The whole dry weights of the weeds contained in the barnyardgrass were greater in 2000 than in 2001. This decrease resulted from deceases in *Digitaria cilliaris* and *Cyperus* spp., which were the most dominant weeds in both the first and second crops after both EM and LM. However after LM, *Cyperus* species in the first crop decreased to an amount less than that of *D. ciliaris*. Moreover, the *Cyperus* supplanted the Gramineae species despite cropping in 2001 (Fig. 4).

2. Feasibility of the cropping system for the cattle farmer

In the R + B system, the grasses were harvested four times and were made into hay (Fig. 1), while in the R + S system, ryegrass and sorghum were each harvested twice; the ryegrass was made into hay and the sorghum was ensilaged. Table 3 presents the labor hours, labor cost, material cost, productivity cost, and yield per unit area. Both labor hours and labor cost per unit area were lower in R + B than in the R + S, because the cost of barnyardgrass production was lower compared with sorghum

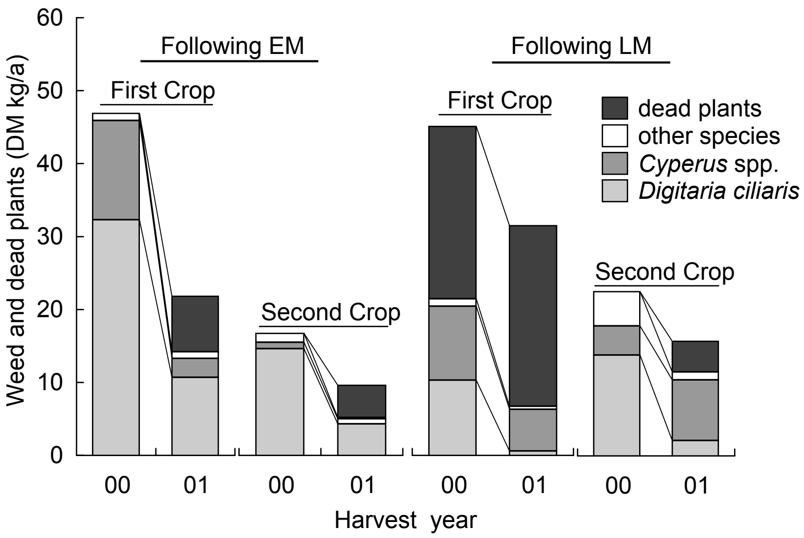

Fig. 4. Dry weight of weeds and dead plants in barnyardgrass

Data were averaged across the three different sowing rates of barnyardgrass.
EM: Early maturing variety of ryegrass, Tachiwase.
LM: Mid- to late-maturing variety of ryegrass, Mammoth B.
Main species of dead plants were Italian ryegrass in first and barnyardgrass in second crop.

production. The productivity cost per unit weight was much lower in R + B than in R + S, although the total annual yield was less in the R + B than in R + S because barnyardgrass yield in the former was less than sorghum yield in the latter (Table 3).

Discussion

The study elucidated the useful performance of barnyardgrass combined with Italian ryegrass in an annual cropping system for forage production. The first crop yield of barnyardgrass was affected by the maturity of the preceding ryegrass variety; that first yield was significantly lower when it followed the LM ryegrass. It is considered that the lower plant heights and fewer tillers of the barnyardgrass after the LM ryegrass were caused by the competition between the regrowing ryegrass and barnyardgrass. The LM ryegrass regrew after the harvest in early summer, and these regrowing plants impeded the growth of barnyardgrass seedlings. The yield of EM ryegrass, harvested twice, was significantly larger than that of the LM ryegrass, with the corollary that total grass yield in the annual crop rotation was larger when the early-maturing ryegrass was used, achieving 140 kg/a, than when the mid- to late-maturing variety was used.

Labeled sowing rate of barnyard millet (*Echinochloa frumentacea*), which is a forage crop having higher germination percentage than barnyardgrass, is around 600 seeds/m^2. Through the consideration of percentage ripening and seed weight, the calculated numbers of ripening barnyardgrass seeds sown at the start of the cropping system were 140, 280, and 420 seeds per/m^2 at the 100, 200 and 300 g/a sowing rates, respectively. These sowing rates were not enough to establish a barnyardgrass sward in 2000 through the comparison of germination percentage of the two *Echinochloa* species. Nevertheless, barnyardgrass yields in 2000 equaled those in 2001, which were established from enormous seeds produced in autumn 2000 (1,974–6,827 seeds/m^2). The compensative production of barnyardgrass was associated with the seed bank of the grass that prevailed in abandoned paddy fields in Japan[2], although few barnyardgrass plants had been found in the field before the experiment. The seedlings emergent from seeds near the soil surface by plowing at the beginning of the experiment contributed to the high production of barnyardgrass. The amount of seeds in the soil must be considered at the beginning of the adaptation of the cropping system. The significant higher production of seeds from the second barnyardgrass crop shows that early-maturing ryegrass might be better to ensure the establishment of a barnyardgrass sward the following year without sowing.

Smaller amounts of weeds included in the grasses were found in 2001 than in 2000. This might be associated with the greater growth potential of the crops than those of the weed species. This means that the amount of weeds in grass swards could decrease after the cropping system is adopted. However, the dry weights of *Cyperus* weeds were exceptionally higher in the second crop of early-maturing ryegrass and in both crops of barnyardgrass in 2001. It is well known that perennial weeds increase in a pasture because they are less subject to disturbance by cultivation. Since the sward is plowed only once a year at the time of ryegrass sowing, perennial *Cyperus* species might have the potential to prevail over the field shortly after the cropping system is adopted[5]. Damage by *Cyperus* species might be the restricting factor in the adaptation of this cropping system, since the species are specific to wet and semi-wet soils, including

Table 3. Required cost for grass production in the annual cropping system

Item	Ryegrass + barnyardgrass		Ryegrass + sorghum	
	Input or productive amount	Input cost (yen)	Input or productive amount	Input cost (yen)
Labor cost (/a)[a)] (A)	5.37 h	4,027.5	11.3 h	8,475.0
Material cost (/a)[b)] (B)		2,178.5		3,885.7
Total production cost (yen/a) (C = A + B)		6,206.0		12,360.7
Dry matter yield (D)	158.1 kg		254.3 kg	
Production cost (yen/DM kg) (C/D)	39.3		48.6	

a): Values were derived from input amount (labor hour) × unit cost (750 yen/h).
b): Material cost included those of seeds, fertilizer, soil amendment, fuel, light, heat and power. Cost of self-sufficient compost was not included. Cost depreciation was not included.

paddy fields, and are thought to be recalcitrant weeds in Japan.

Labor hour and material costs in the R + B are lower than that in the R + S although the yield in the former is less than that in the latter, which has a high cost input for high yield. Additionally, the R + B could alleviate the burden of labor in summer, not requiring processes such as ensilaging required for R + S. Thus, the R + B cropping system is expected to be feasible for promoting land utilization in mountainous areas. The farmer in this experiment was already equipped with the implements needed for the R + B system, and has been using them for 15 years. Hence, the production cost of hay was calculated except cost depreciation, and was 39 yen/DM kg in this cropping system, which was adapted to an area of only 10 a (Table 4). This production cost is greatly lower than the price of purchased hay for calf raising (50 yen/DM kg). However, the productivity cost of the R + B system would be increased by the cost depreciation when farmers purchase the implements to start this system, especially when this cropping system is adapted to a relatively small planted area (Table 4 and Fig. 5). Hence, it is beneficial that the existing agricultural subsidies in the rice quota are applied to the purchase of the implements

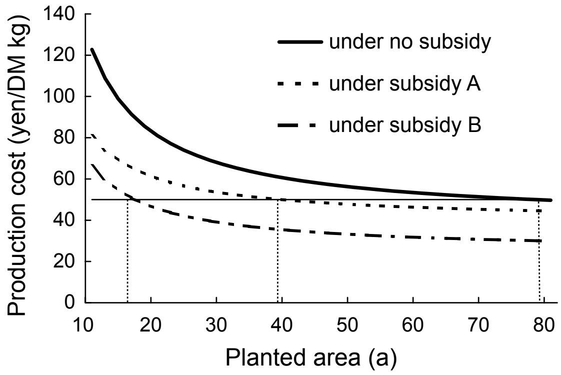

Fig. 5. Change in production cost associated with planted area in the annual cropping system with ryegrass and barnyardgrass

Data were calculated from labor cost, material cost and cost depreciation shown in Table 4.
Subsidy A: Half the sum of machinery equipments is financially supported.
Subsidy B: In addition to the subsidy A, forage production itself is supported at a rate of 2,300 yen/a.
The horizontal solid line indicates the price of imported hay. The vertical dotted lines indicate the minimum planted areas in which production costs are comparable to the price of imported hay (50 yen/DM kg).

Table 4. Required cost for grass production in the annual cropping system (/a/year)

Item	Input or productive amount	Input cost (yen)
Labor cost[a)]	5.37 h	4,027.5
Except for harvest	1.14 h	855.0
For harvest	4.23 h	3,172.5
Material cost		2,178.5
Seed	0.3 kg	240.0
Compost[b)]	200 kg	0
Fertilizer	13.3 kg	1,064.0
Soil amendment	10 kg	300.0
Miscellaneous[c)]		574.5
Cost depreciation[d)]		13,200.0
Mower		3,300.0
Round baler		9,900.0
Total (A: including cost depreciation)		19,406.0
Total (B: except cost depreciation)		6,206.0
Yield (DM kg) (C)	158.1 kg	
Production cost (yen/ DM kg) (A/C)		122.7
Production cost (yen/ DM kg) (B/C)		39.3

a): Values were derived from unit cost of 750 yen/h.
b): Self-sufficient.
c): Fuel, light, heat and power.
d): Agricultural implements of 1,320,000 yen were supposed to depreciate over 10 years.

for starting such a cropping system and to forage production itself. Farmers have two recommended subsidies; one provides half the sum of the cost of the implements (A) and another supports forage production itself at a rate of 2,300 yen/a in a converted paddy field (B). Subsidies A and B can be applied simultaneously to the same farmed area (A + B). Grass hay could be produced at prices comparable to that of imported hay by planting more than 80 a under no subsidy, and more than 40 a under subsidy A, which provides half the sum of the cost of the implements for the cropping system, and more than 17 a under subsidy B, which supports forage production at a rate of 2,300 yen/a, in addition to subsidy A (Fig. 5).

Conclusion

Our experiment indicated that an annual cropping system with early-maturing ryegrass and natural-reseeded barnyardgrass would enable farmers to produce forage at a low cost, relative to that of imported hay, and that this system would be favorable for farmers equipped with a walking-type mower and round baler. Moreover, it is necessary to improve the productivity cost for farmers by agricultural subsidies in hilly and mountainous areas.

References

1. Agriculture, Forestry and Fisheries Research Council Secretariat, MAFF (1995) Standard table of feed composition in Japan, 1995. Central Association of Livestock Industry, Tokyo, pp.60.
2. Anzai, T. (1988) Emergence of weeds and changes in soil properties in fallow paddy fields. *Chiba nougyou-shikenjou kenkyu hokoku* (*Bull. Chiba Agric. Exp. Stn.*), **29**, 93–104 [In Japanese with English summary].
3. Higashi, M. et al. (1999) Establishment of techniques for activation of the will to produce self-supplied feed by utilization of wild grass –The appearance of wild grass by rotary-tilling or plowing–. *Miyazakiken chikusan-shikenjou shiken-kenkyu hokoku* (*Bull. Miyazaki Lives. Exp. Stn.*), **12**, 128–138 [In Japanese].
4. Nishi, K. (1981) Studies on the dry matter production in the populations of rice plant (*Oryza sativa* L.) and barnyardgrass (*Echinochloa crus-galli* Beauv. var. *formosensis* Ohwi) in paddy field. I. Comparison of the dry matter production of two plant species in single planting. *Zassou kenkyu* (*Weed Res. Jpn.*), **26**, 281–285 [In Japanese with English summary].
5. Noguchi, K. (1992) Changes of the weed flora caused by changes of cultivation techniques –Paddy-upland rotation–. *Zassou kenkyu* (*Weed Res. Jpn.*), **37**(1), 1–7 [In Japanese].
6. Yamasue, Y. (1992) Physiological adaptation of *Echinochloa* weeds with a special reference to seed germination and flooding tolerance of the seedlings. *Zassou kenkyu* (*Weed Res. Jpn.*), **37**(2), 83–91 [In Japanese].