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Dry Matter Productivity of High Biomass Sugarcane in Upland and Paddy Fields in the Kanto Region of Japan

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Abstract

Eight high biomass sugarcane clones and two commercial sugarcane cultivars were planted in upland and paddy fields in Tsukuba in 2003-2005 to identify a new crop suitable for abandoned paddy fields in the Kanto region of Japan. The paddy field was flood irrigated until harvest in 2003 and 2004. In 2005, the paddy field was flood irrigated for one month after transplantation and then the water was drained to above ground level to maintain an ill-drained condition. The highest dry matter (DM) yield of the high biomass clones was over 40 Mg/ha in the upland field, and even in the ill-drained paddy field, all high biomass clones achieved almost 30 Mg/ha. Because DM yield of feed-use rice cultivars is reported to be around 20 Mg/ha, DM yield of high biomass clones grown in ill-drained conditions would exceed that of feed-use cultivars grown in a flooded condition. Average DM yield, stalk number and plant length of the high biomass clones grown in the ill-drained paddy field were better than those grown in the flood-irrigated condition. Although the average DM yield in the paddy field was lower than the upland field every year ($P < 0.01$), the average proportion (paddy/upland) of DM yield in 2005 when the paddy field was in the ill-drained condition was 0.79, whereas it was 0.59 in 2003 and 0.54 in 2004 when the paddy field was flood irrigated. The results suggest that sugarcane and high biomass clones can be grown in ill-drained paddy fields with good yields; however, cultivars with improved initial growth rates and winter survivability are necessary for the Kanto region.

Discipline: Crop production
Additional key words: *Erianthus* spp., sorghum

Introduction

A large number of agricultural fields have been abandoned in Japan. In 2005, 385,791 ha of paddy fields were found to be abandoned[8], which is 10.1% of the entire arable area. The reasons for abandoning fields include aging of farmers, inconvenient location and poor drainage. Therefore, new crops suitable for abandoned fields are required.

High biomass sugarcane clones have been bred at National Agricultural Research Center for Kyushu Okinawa Region (KONARC) and some show high biomass production[13, 16], which is a suitable characteristic for feed and biomass crops. Recently, the first high biomass sugarcane cultivar for feed use in Japan, ‘KRFo93-1’ was released by KONARC[11]. However, sugarcane cultivation

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areas for sugar manufacturing in Japan are mostly in Okinawa and other Nansei Islands in subtropical regions, whereas most of the abandoned agricultural fields are located in temperate regions.

In a field experiment with flooding treatment, Deren et al. observed 20.1 t/ha of aboveground dry matter (DM) yield for a plant crop and 60.1 t/ha for a ratoon crop with the 'US72-1288' hybrid line of sugarcane. Another hybrid line, 'US84-1009', showed 11.3 t/ha for a plant crop and 59.4 t/ha for a ratoon crop, indicating that they could be productive even under flooded conditions[2]. If high biomass clones can grow well in the Kanto region and in ill-drained paddy fields, they can be suitable candidates for growth as feed- and/or biomass-use crops in abandoned agricultural fields. We conducted upland and paddy field experiments in 2003-2005 to evaluate the yield potential of high biomass clones.

Materials and methods

1. Plant materials

Plant materials examined in the field experiments are shown in Table 1. 'NiF8' and 'NCo310' are commercial sugarcane cultivars. 'NiF8' is the current leading cultivar in Japan, and 'NCo310' is the previous leading cultivar which has been used as the main standard cultivar in breeding programs for characteristics such as germination rate, tillering, leaf retention, and disease resistance[15]. Eight high biomass clones between sugarcane cultivar (*Saccharum* spp. hybrid) and wild species of sugarcane (*S. spontaneum*), sorghum (*Sorghum bicolor*) and *Erianthus* spp. were also examined. Among the high biomass clones, the possibility of self-pollination cannot be excluded except for hybrid line 'KRSp93-19', which has been evaluated with molecular markers (Terajima et al. unpublished data). Both the sorghum cultivar 'Tentaka' and the rice (Oryza sativa) cultivar 'Kusahonami' have high biomass production and are cultivated for feed use.

2. Cultivation method

Experiments were conducted in 2003, 2004 and 2005 at the National Institute of Crop Science, National Agriculture and Food Research Organization in Tsukuba, Ibaraki, Japan (36°01'N, 140°06'E). The upland field soil was a low-humic andosol and the paddy field soil was alluvial. Sugarcane cultivars and high biomass clones were cut to 5 cm lengths with 1 node and an axillary bud, raised for 1 month in greenhouse-maintained cell trays, and transplanted to upland and paddy fields on the days listed in Table 2. Sugarcane cultivars and high biomass clones in 2004 and 2005 were newly planted and not ratoons. Nursery rice was also raised for 4 weeks prior to transplanting, whereas sorghum was direct seeded to the upland field. The transplanting and seeding date for rice and sorghum was the same as that for sugarcane. The paddy field was flood irrigated until the rice was harvested in 2003 and 2004. In 2005, the paddy field was flood irrigated for 1 month after transplanting and then the water was drained to above ground level. Following this, the underground drain valve was closed, such that the paddy field remained in an ill-drained condition. Oat was sown in mid December and applied as green manure to the upland field in late April, and compost was applied to

Table 1. Cultivars and clones provided for field experiments

Cultivar/Clone	Note	Female parent	Male parent
95GA-18	High biomass sugarcane clone	SK-13, F1 between sugarcane and sorghum	Sumac, Sorghum cultivar
97S-107	High biomass sugarcane clone	F146, Sugarcane cultivar	IJ76-349, Erianthus spp.
97S-27	High biomass sugarcane clone	G30, F1 between sugarcane and sorghum	US56-15-2, Wild species of sugarcane
97S-51	High biomass sugarcane clone	G38, F1 between sugarcane and sorghum	US56-15-2, Wild species of sugarcane
KRSp93-19	High biomass sugarcane clone	NCo310, Sugarcane cultivar	Glagah Kloet, Wild species of sugarcane
KRSp93-30	High biomass sugarcane clone	Ni6, Sugarcane cultivar	Glagah Kloet, Wild species of sugarcane
S3-27	High biomass sugarcane clone	IRK67-1, Sugarcane cultivar	Glagah Kloet, Wild species of sugarcane
S5-16	High biomass sugarcane clone	NCo310, Sugarcane cultivar	Glagah Kloet, Wild species of sugarcane
NCo310	Sugarcane cultivar	Co421, Sugarcane cultivar	Co312, Sugarcane cultivar
NiF8	Sugarcane cultivar	CP57-614, Sugarcane cultivar	F160, Sugarcane cultivar
Kusahonami	Rice cultivar for feed		
Tentaka	Sorghum cultivar for feed		

Table 2. Details of cultivation method in 2003, 2004 and 2005

Year	Upland field		Paddy field	
	Sugarcane cultivars and hybrid sugarcane lines	Sorghum	Sugarcane cultivars and hybrid sugarcane lines	Rice
2003				
Inter-row spacing (cm)	80	25	80	25
Intra-row spacing (cm)	20	20	20	20
Density of planting (m^{-2})	6.25	20	6.25	20
Plot area (m^2)	12	12	12	12
Number of plots	3	3	3	3
Harvesting area (m^2)	3.36	3	3.36	3
Day of transplanting	21-May	21-May	22-May	22-May
Base fertilizer: N-P-K (kg/ha)	60-150-150	60-150-150	60-150-150	60-150-150
First additional fertilizer: N-P-K (kg/ha)	90-0-0	90-0-0	90-0-0	90-0-0
Second additional fertilizer: N-P-K (kg/ha)	–	–	–	–
Total fertilizer: N-P-K (kg/ha)	150-150-150	150-150-150	150-150-150	150-150-150
2004				
Inter-row spacing (cm)	120	60	120	30
Intra-row spacing (cm)	20	10	20	16
Density of planting (m^{-2})	3.12	16.6	3.12	21
Plot area (m^2)	10.8	10.8	10.8	10.8
Number of plots	2	2	2	2
Harvesting area (m^2)	5.76	2.4	5.76	0.54
Day of transplanting	19-May	19-May	20-May	20-May
Base fertilizer: N-P-K (kg/ha)	60-150-150	60-150-150	60-150-150	60-150-150
First additional fertilizer: N-P-K (kg/ha)	45-0-0	45-0-0	45-0-0	45-0-0
Second additional fertilizer: N-P-K (kg/ha)	45-0-0	45-0-0	45-0-0	45-0-0
Total fertilizer: N-P-K (kg/ha)	150-150-150	150-150-150	150-150-150	150-150-150
2005				
Inter-row spacing (cm)	120	60	120	60
Intra-row spacing (cm)	20	10	20	10
Density of planting (m^{-2})	3.12	16.6	3.12	16.6
Plot area (m^2)	12	12	12	12
Number of plots	3	3	3	3
Harvesting area (m^2)	5.76	2.88	5.76	2.88
Day of transplanting	18-May	18-May	20-May	20-May
Base fertilizer: N-P-K (kg/ha)	60-150-150	60-150-150	60-150-150	60-150-150
First additional fertilizer: N-P-K (kg/ha)	45-0-0	45-0-0	45-0-0	45-0-0
Second additional fertilizer: N-P-K (kg/ha)	–	–	–	–
Total fertilizer: N-P-K (kg/ha)	105-150-150	105-150-150	105-150-150	105-150-150

the paddy field at approximately 10 t/ha in late February. Base fertilizer was applied to the top 25 cm of the top soil 1 week before transplanting. Fertilization was added by top-dressing close to the plants 1 month after transplanting. Only in 2004, additional fertilizer was applied once again 1 month later. Details of the cultivation methods, such as inter-row and intra-row spacing, plot and harvesting areas, number of plots, and amount of fertilizers are shown in Table 2. Intertillage and earthing-up were carried out only for the upland field every year, 1 month after transplanting. Weeds were controlled with a spray herbicide and a cultivator for inter-row spaces and manually for intra-row spaces.

3. Measuring method

Above-ground plant material was harvested by sickle and chain saw from late November to early December after the termination of plant growth. The fresh weight of the entire sample and sub samples were weighed at the field. Sub samples were weighed again after drying at 80°C in a circulation drier for a few days until the weights stopped decreasing. The number of stalks that had at least one open leaf and plant lengths were measured at harvest.

4. Statistical analysis

Results were analyzed by ANOVA using the SPSS statistical program[12]. A *P*-value of < 0.05 was considered significant.

5. Meteorological data

Average, maximum and minimum air temperatures as well as the amount of precipitation at the experimental field were obtained from the Weather Data Acquisition System of the National Institute of Agro-Environmental Sciences (NIAES) in Tsukuba. Corresponding data for Tanegashima Island were obtained from the website of the Japan Meteorological Agency[6].

Results

1. Meteorological data

Meteorological data are shown in Fig. 1. In the Kanto region of Tsukuba, there was still the possibility of frost in April, whereas the risk of frost was very low in May. In winter, there was frost in November every year and the plant growth stopped after frost. The maximum temperatures from June to September were higher than 30°C every year. The average amount of precipitation for 1 year was 1,277 mm from 2003 to 2005, and 949 mm for the growing period (May to November).

Compared with Tanegashima Island, which is the northern limit of commercial sugarcane production in Japan, Fig. 1 shows the following four characteristics. (1) The average temperature in Tsukuba was lower than that in Tanegashima almost every month, especially in winter. (2) The maximum temperature in Tsukuba was slightly higher than that in Tanegashima in summer, whereas it was slightly lower in winter. (3) The minimum temperature in Tsukuba was slightly lower than that in Tanegashima in summer and much lower in winter. (4) There was less precipitation in Tsukuba than in Tanegashima in summer and similar precipitation in winter.

2. DM production

Table 3 shows DM yield in the upland and paddy fields. Among all of the crops examined, the sorghum cultivar 'Tentaka' had the highest DM yield every year in the upland field ($P < 0.05$). In 2003, 'Tentaka' was planted in the paddy field, but there was poor growth and DM yield was 4.5 Mg/ha. Therefore, it was not planted in the paddy field in 2004 and 2005. Among all cultivars and clones examined in the paddy field that was flood irrigated, only the high biomass clone '97S-107' in 2003 earned a higher DM yield than the rice cultivar 'Kusahonami' ($P < 0.05$), but the difference was not significant in 2004. All high biomass clones achieved a greater yield than 'Kusahonami' in the ill-drained paddy field in 2005 ($P < 0.05$). Compared to the commercial sugarcane cultivars, four high biomass clones achieved a greater yield in the upland field in 2005 ($P < 0.05$). In the paddy field, seven high biomass clones in 2003 and three high biomass clones in 2005

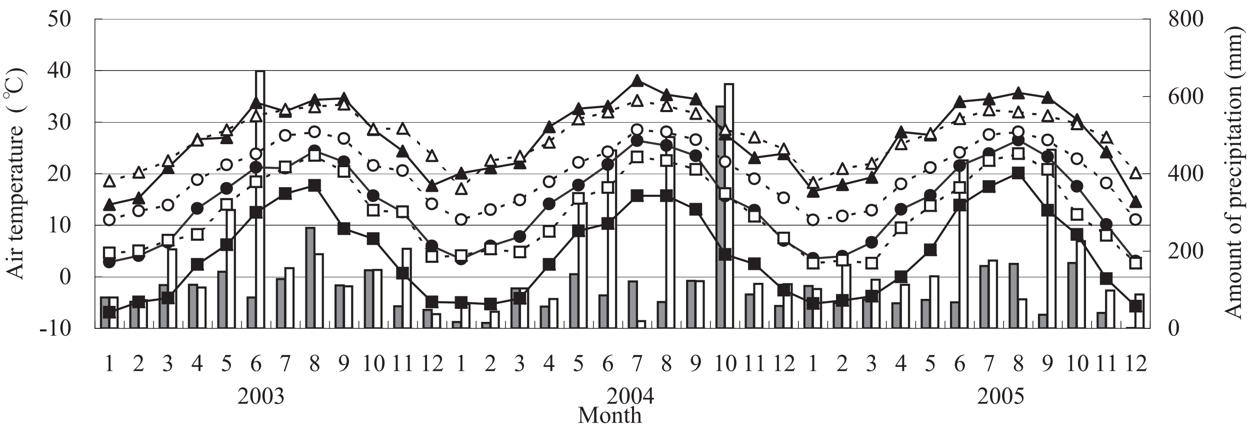

Fig. 1. Meteorological data for Tsukuba and Tanegashima

●: Average temperature in Tsukuba, ▲: Maximum temperature in Tsukuba, ■: Minimum temperature in Tsukuba, ○: Average temperature in Tanegashima, △: Maximum temperature in Tanegashima, □: Minimum temperature in Tanegashima. Gray bars represent monthly precipitation in Tsukuba. White bars represent monthly precipitation in Tanegashima.

Table 3. Dry matter yield (Mg/ha) of upland and paddy field in 2003, 2004 and 2005

Upland field

Cultivar/Clone	2003		2004		2005	
95GA-18	35.7 ± 7.0[a)]	a	31.0 ± 1.0	abc	33.4 ± 0.7	bc
97S-107	40.7 ± 10.3	a	34.6 ± 4.3	ab	36.4 ± 2.5	b
97S-27	28.5 ± 5.8	a	34.9 ± 2.3	ab	33.8 ± 1.7	bc
97S-51	40.1 ± 4.6	a	36.1 ± 2.7	ab	36.3 ± 2.2	b
KRSp93-19	33.4 ± 4.0	a	34.1 ± 2.6	abc	40.3 ± 2.5	b
KRSP93-30	30.1 ± 1.8	a	32.3 ± 2.8	abc	37.1 ± 1.0	b
S3-27	18.9 ± 3.6	a	20.1 ± 2.7	c	32.4 ± 0.8	bc
S5-16	30.6 ± 1.5	a	33.7 ± 2.4	abc	33.7 ± 3.7	bc
NCo310	20.0 ± 0.8	a	25.2 ± 1.5	bc	26.2 ± 1.2	c
NiF8	27.4 ± 5.7	a	28.0 ± 2.0	abc	27.9 ± 1.8	c
Tentaka	42.7 ± 5.0	a	41.5 ± 1.3	a	50.6 ± 1.0	a

Paddy field

Cultivar/Clone	2003		2004		2005[b)]	
95GA-18	19.1 ± 1.3	b	14.6 ± 2.7	a	28.2 ± 1.4	ab
97S-107	27.3 ± 3.0	a	17.0 ± 1.7	a	29.7 ± 0.6	a
97S-27	19.7 ± 1.5	b	20.9 ± 1.9	a	29.4 ± 2.8	a
97S-51	18.9 ± 1.8	b	17.5 ± 3.5	a	29.0 ± 2.5	a
KRSp93-19	18.6 ± 1.4	b	17.2 ± 1.0	a	26.2 ± 2.5	abc
KRSP93-30	18.2 ± 1.1	b	16.6 ± 0.8	a	27.4 ± 2.0	abc
S3-27	14.1 ± 1.5	bc	18.4 ± 1.5	a	26.4 ± 0.7	abc
S5-16	20.6 ± 1.4	ab	17.2 ± 2.1	a	27.0 ± 0.2	abc
NCo310	11.2 ± 1.3	c	14.4 ± 4.1	a	21.6 ± 1.6	bc
NiF8	11.1 ± 0.9	c	8.3 ± 1.5	a	20.4 ± 2.3	c
Kusahonami	19.1 ± 0.0	b	19.3 ± 0.1	a	13.2 ± 0.7	d

a): Means ± standard error followed by the same letter are not significantly different according to QREGW test at P = 0.05.

b): Paddy field was flood irrigated in 2003 and 2004. In 2005, paddy field was flood irrigated at first for one month after transplanting and then water was drained above ground level.

produced more yield than both commercial sugarcane cultivars ($P < 0.05$).

Table 4 shows average growth traits in the upland and paddy fields and average proportions (paddy/upland) of growth traits. Each value in Table 4 includes sugarcane cultivars and high biomass clones. The average yields in the paddy field were lower than the upland field every year ($P < 0.01$). The average stalk number in the paddy field was lower than the upland field in 2004 ($P < 0.01$), but those in 2003 and 2005 were not significantly different ($P > 0.05$). The average plant lengths were shorter in the paddy field than in the upland field every year ($P = 0.01$ in 2003 and $P < 0.01$ in 2004 and 2005). The average proportions of growth traits indicate the extent to which the growth traits were suppressed in the paddy field compared to the upland field. The average proportion of DM yields, stalk numbers and plant lengths in 2005 were higher than in 2003 and 2004 ($P < 0.05$).

Discussion

The highest DM yield of the high biomass clones was over 40 Mg/ha in the upland field, and even in the ill-drained paddy field, all high biomass clones achieved almost 30 Mg/ha, although the high biomass clones and

Table 4. Average growth traits of upland and paddy field and average proportions (paddy/upland) of growth traits including sugarcane cultivars and high biomass sugarcane clones

	Yield (Mg/ha)			Stalk number (m^{-2})			Plant length (cm)		
Field	2003	2004	2005	2003	2004	2005	2003	2004	2005
Upland	30.5±2.3 [a)]	31.0±1.6	33.7±1.3	23.5±2.7	25.6±1.8	23.3±1.7	351±20	348±7	357±6
Paddy	17.9±1.5	16.2±1.0	26.5±1.0	18.9±3.9	16.8±1.8	23.7±1.7	258±13	266±5	309±6
P [b)]	<0.01	<0.01	<0.01	0.36	<0.01	0.85	0.01	<0.01	<0.01
Proportion	0.59±0.03 b	0.54±0.05 b	0.79±0.02 a	0.78±0.13 b	0.64±0.04 b	1.02±0.03 a	0.74±0.03 b	0.77±0.01 b	0.87±0.01 a

a): Means ± standard error followed by the same letter are not significantly different according to QREGW test at P = 0.05. Each value includes sugarcane cultivars and high biomass sugarcane clones.

b): *P* value of the field effect.

commercial sugarcane cultivars were grown for 1 month before transplanting (Table 3). None of the high biomass clones exceeded the sorghum cultivar 'Tentaka' in DM yield in the upland field, and none of the high biomass clones exceeded the rice cultivar 'Kusahonami' in DM yield in the paddy field except '97S-107' in 2003 ($P < 0.05$, Table 3). However under the ill-drained conditions in 2005, DM yield of all high biomass clones and sugarcane cultivars were higher than that of 'Kusahonami' (Table 3). In 2005, the comparatively dry condition for paddy rice and severe light interception by sugarcane cultivars and high biomass clones, which grew taller than in 2003 and 2004 (Table 4), were likely responsible for the low DM yield of rice. DM yields for feed-use rice cultivars are around 20 Mg/ha[5, 9, 10], therefore, DM yield of high biomass clones grown in ill-drained condition would have exceeded that of the feed-use rice grown in the flooded condition.

The DM yield of the high biomass clones obtained in this experiment was similar to that usually observed in Tanegashima. The DM yield of the hybrid line 'KRSp93-30' in the Tanegashima region was 30.2 Mg/ha and 58.5 Mg/ha for plant and ratoon crops, respectively[14]. Sugimoto et al. (2001) also mentioned that high biomass clones had higher productivities than sugarcane cultivars for ratoon crops, whereas productivities of plant crops were similar to those of sugarcane cultivars[13]. Another hybrid line for feed use, 'KRFo93-1' was harvested three times in 2 years from newly planted seedlings, and the total DM yield was 50 Mg/ha/year, whereas the total DM yield of a commercial sugarcane cultivar 'NCo310' was one third of this value[11].

The meteorological data suggested that the summer air temperature in Tsukuba was suitable for growing. Maximum air temperature in summer was slightly higher in Tsukuba than Tanegashima, and though minimum air temperature in summer was lower in Tsukuba than Tanegashima, it was high enough for continued growth. However, in other seasons, it seemed to be too cold for the growth of sugarcane. Hence, the period of active growth was limited to summer, and frost damage also shortened the entire growing period. A slower growth during the early stage of sugarcane compared with sweet sorghum has been reported[17]. Low temperature in spring may additionally suppress the growth during the early stage, but the 949 mm of average precipitation from May to November seemed to be enough to keep the plants growing during the growth period (Fig. 1).

Average growth traits of the sugarcane cultivars and high biomass clones were better in the ill-drained paddy field (2005) than in the flood-irrigated condition (2003 and 2004). Although the average DM yield in the paddy field was lower than in the upland field every year (Table 4, $P < 0.01$), the average proportion (paddy/upland) of DM yields in 2005 (0.79) was higher than those in 2003 and 2004 (0.59 and 0.54 respectively) (Table 4, $P < 0.05$). These results suggest that the ill-drained paddy field was better than the flood-irrigated condition for increasing DM yield, even though the yields in the paddy field were lower than that in the upland field every year. The average stalk number in the paddy field in 2004 was significantly lower than in the upland field (Table 4, $P < 0.01$), and those in 2003 and 2005 were not significantly different (Table 4, $P > 0.05$), which may have been the result of higher density planting in 2003 (6.25 plants/m^2) than in 2004 and 2005 (3.12 plants/m^2). The average proportion of stalk numbers in 2005 was higher than in 2003 and 2004 (Table 4, $P < 0.05$). These findings suggest that the stalk number of sugarcane cultivars and high biomass clones in the ill-drained paddy field were not suppressed, whereas those in the flooded paddy field were suppressed compared to those in the upland field. There may have been suppressed stalk numbers to increase new stalks under the excess water condition or low-oxygen partial pressure. We found that every sugarcane cultivar and high biomass clone in the paddy field formed aerenchyma in the stalk center and above-ground adventitious roots every year. These characteristics are reported to improve flood tolerance[3, 7] and seem to make sugarcane more tolerant to a flooded condition than other grasses usually planted in an upland field. The average plant length in 2005 was higher than in 2003 and 2004 (Table 4, P = 0.01 in 2003 and P < 0.01 in 2004 and 2005), and the average proportion of plant lengths in 2005 was also higher than in 2003 and 2004 (Table 4, P < 0.05), suggesting that the ill-drained condition was better than the flood-irrigated condition for increasing plant length. The shorter plant length in the ill-drained paddy field compared to that in the upland field was also responsible for the lower DM yield. A possible reason for the shorter plant length is that the plants could generate new stalks after draining water, leading to an insufficient growth period for new stalks.

Improved initial growth rates and winter survivability is necessary for commercial cultivation of high biomass clones in the Kanto region. This will be achieved by breeding wild sugarcane relatives that can survive under the cold temperature of winter in the Kanto region, such as 'JW630' (*Erianthus* spp.) or 'JW 599' (*Saccharum spontaneum* L.)[1]. Harvesting a crop for several years could be possible with these traits and DM yield of the ratoon crop would increase with savings in production cost and manual labor. Cooperation with the livestock industry should also be considered for the commercial use of high biomass clones. The livestock industry has a problem with processing huge amounts of waste[4]. If high biomass clones can be grown well in abandoned paddy fields with compost made from waste, they will be a suitable source of forage and a fine solution for both processing the huge amount of waste and improving the food self-sufficiency rate in Japan. Furthermore, if low-cost ethanol production from plant cellulose is developed, abundant biomass production in paddy fields would be possible by planting high biomass clones.

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