Original Article (Full Paper)

Adaptability of Dwarf Napiergrass under Cut-and-carry and Grazing Systems for Smallholder Beef Farmers in Southern Kyushu, Japan

Renny Fatmyah UTAMY, Yasuyuki ISHII[1], Sachiko IDOTA[1],
Naoto HARADA[2] and Kiichi FUKUYAMA[1]

Interdisciplinary Graduate School of Agriculture and Engineering, University of Miyazaki, Japan
[1]*Faculty of Agriculture, University of Miyazaki, Japan*
[2]*Kagoshima Livestock Experiment Station, Japan*
(Received: 29 October 2010 / Accepted: 5 February 2011)

ABSTRACT Smallholder beef farmers, particularly in isolated islands, were highly aged, holding limited arable lands with poor machinery equipment. Demand for herbage production increases rapidly due to high cost of imported herbage supply. We investigated the adaptability of dwarf napiergrass (*Pennisetum purpureum* Schumach) of late-heading type (dwarf-late, DL) to 12 sites including isolated islands in 3 Prefectures of southern Kyushu by determining soil properties, plant growth characters, herbage yield and quality, and overwintering ability in 2007–2009. The dry matter (DM) yield of DL napiergrass ranged in 0.7–13.6 and 0.2–15.8 Mg/ha/yr in 2007 and 2008, respectively. There were significantly positive correlations between N fertilizer supply and DM yield ($r = 0.844$, $P < 0.01$ and $r = 0.928$; $P < 0.001$ in 2007 and 2008, respectively). However, not only by the rate of fertilizer application, DM yield was also variable depending on soil fertility and weed control across the examined sites. Herbage quality in leaf blade and stem inclusive of leaf sheath, as assessed by *in vitro* DM digestibility and crude protein (CP) content, ranged in 56–76% and 6–18%, respectively. In some cases, CP content declined below the critical level as a feed for breeding cows, since the herbage quality in leaf blade had significantly negative correlation with cutting interval ($P < 0.05$). Results revealed that DL napiergrass should adapt to the examined sites including isolated islands in the established and subsequent years. However, it is necessary to maintain the satisfactory level of herbage yield and quality by the minimum fertilizer application at least more than 100 kg N/ha/yr, and the optimum soil condition, cutting interval and weed control after establishment.

Journal of Warm Regional Society of Animal Science, Japan 54(1): 87-98, 2011

Key words : dwarf napiergrass, herbage quality, herbage yield, overwintering, soil property

Introduction

Japanese agriculture is facing to the rapid decrease in number of farms (1.7 million) and farmers (2.6 million) with the sharp increase in age of farmers averaged at 65.8 years old (MAFF 2010). In beef cattle production, percentage of aged farmers above 65 years old is higher than other agriculture sectors, such as dairy cow farming and protected horticulture. Besides, smallholder beef farmings, especially for calf production, are operated by aged farmers, who have retired from other business to succeed the agriculture and/or work hereditarily.

Beef cattle industry for calf production is much concentrated in southern Kyushu of Japan and occupies the major industry operated by aged smallholders in isolated islands. However, land, climate and human conditions for herbage production are so variable that optimum grass species fit to each condition of site have not determined yet. Smallholder farmers, especially who are living in isolated islands, face to many obstacles to the increase in livestock production. Since arable land area is relatively

Correspondence: Yasuyuki ISHII (tel・fax: +81-(0)985-58-7251, e-mail: yishii@cc.miyazaki-u.ac.jp)

limited, self-supplied herbage production becomes in shortage and machine equipment is inferior to farmers in non-isolated areas, resulting in the increase of production cost by human-labor operation. Temperate annual grasses, e.g. Italian ryegrass, are sown to be harvested in winter-spring, while wild herbage species with low feeding value and digestibility are often used by grazing in summer season in several isolated islands, such as Kuroshima, Mishima Village (Kagoshima Prefecture 2008; Mishima Village 2010). Therefore, smallholder farmers, especially in isolated islands, need to gain the novel grass species to improve herbage production and to increase livestock production.

Dwarf napiergrass (*Pennisetum purpureum* Schumach) of late-heading type (dwarf late, DL) bred in Florida, USA, was firstly introduced from Thailand as a line of Dairy Promotion and Organization (DPO), Thailand in 1996. This DL napiergrass can be utilized as a perennial in a low-altitudinal area of Kyushu Island (Ishii *et al*. 2005) under both cut-and-carry and grazing systems (Mukhtar *et al*. 2003, 2004; Ishii *et al*. 2005), where the lowest minimum temperature in the wintering period is higher than -6.2°C (Ishii *et al*. 2008). Also, this grass has a leafy structure, high biomass yield, with quality herbage (Tudsri and Ishii 2007) and no need of renovation if it is well established. Therefore, this grass can be a candidate to replace wild herbage species in summer season and is forecasted to have the potentials fit to the natural and human conditions in smallholder beef farmers in southern Kyushu, including of isolated islands.

The objectives of this study were to investigate the adaptability of DL napiergrass among 12 sites mainly in a low-altitudinal area of southern Kyushu, including of isolated islands, by determining soil condition, growth characters, yield, quality and overwintering ability of dwarf napiergrass in 1–2 years.

Materials and Methods

Site descriptions

The study was conducted at 12 sites in 3 Prefectures in southern Kyushu, such as Miyazaki and Kobayashi in Miyazaki Prefecture, Minamata, Reihoku, Itsuwa and Tamana in Kumamoto Prefecture and Kamikoshiki, Sato, Shimokishiki, Oosato, Katadomari and Sakurajima in Kagoshima Prefecture in 2007–2009 (Figure 1). These sites are classified into non-island sites such as

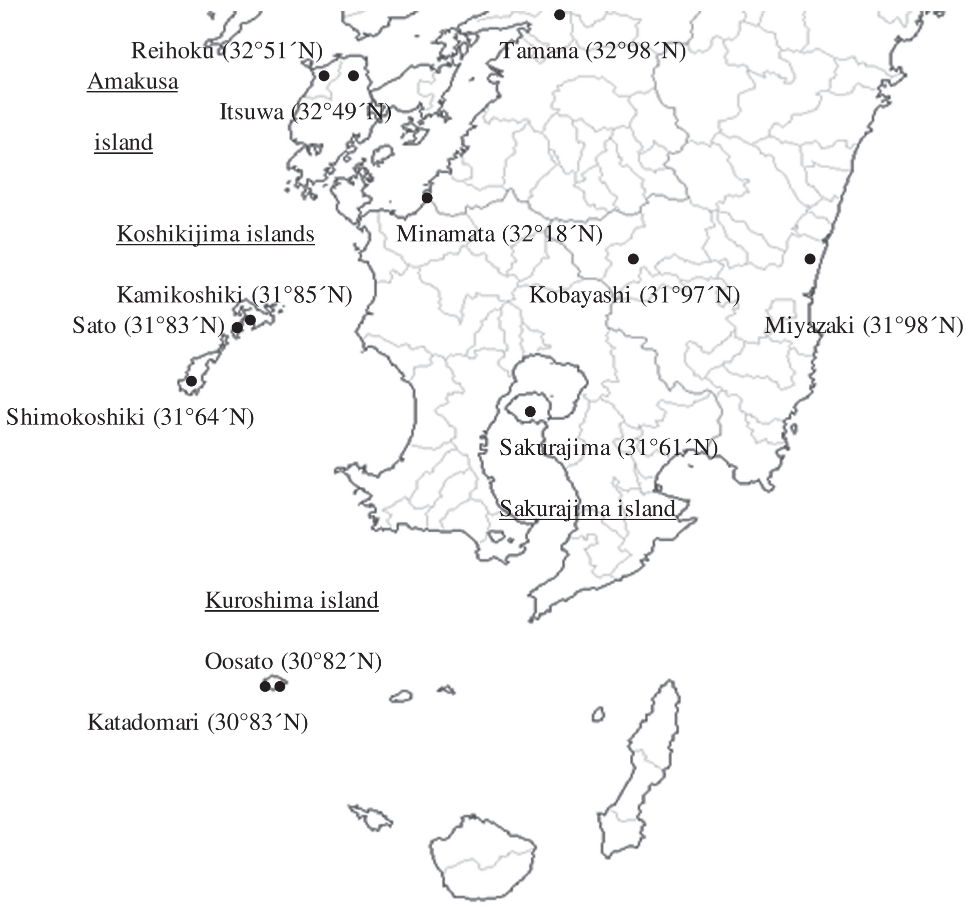

Figure 1 Experimental sites with latitude in 2007 and 2008.

Miyazaki, Kobayashi, Minamata, and Tamana, and sites in islands, such as Reihoku and Itsuwa in Amakusa island, Kamikoshiki, Sato and Shimokoshiki in Koshikijima islands, Oosato and Katadomari in Kuroshima island and Sakurajima in Sakurajima island. The lowest minimum temperature in the 2005–2006 wintering period, which should be a good index for the wintering feasibility due to the coldest year in the 21st century so far, satisfies the minimum requirements of air temperature at –6.2°C for the overwintering of dwarf napiergrass of late-heading type (dwarf-late, DL) napiergrass (Ishii *et al*. 2008). Therefore, 10 and 8 sites were selected in 2007 and 2008, respectively, to examine the adaptability of dwarf napiergrass. Annual mean temperatures and annual precipitation ranged in 16.8–20.2°C and 1554–2465 mm, respectively at 10 examined sites in 2007 and in 15.9–19.7°C and 1881–2797 mm, respectively at 8 examined sites in 2008 (Japan Meteorological Agency 2009). Lowest temperatures in the wintering season of 2007–2008 ranged in -4.5–1.2°C at the examined 5 sites, except for the isolated islands, measured by temperature sensor (Thermoleaf, Taisei E&L Ltd., Tokyo, Japan).

Plant cultivation

Plants of DL napiergrass were transplanted with rooted tillers in May–June 2007 and June 2008 in the selected 12 sites under several field areas. Plant density was basically 1 plant/m^2, except for Miyazaki, Kobayashi and Sato at 2 plants/m^2. Chemical fertilizer was supplied on the surface of soil additionally with 1-5 times of split-application after planting, except for Sakurajima where manure was supplied as a basal dressing in 2008. Weed control was conducted by hand-mowing machine into the inter-row space of DL napiergrass in Miyazaki 2007 and Kobayashi 2007 and 2008, by tillage in Reihoku 2007 and 2008, and by hand with sickle in Oosato 2007 and 2008 and Sakurajima 2008, while no weeding was conducted in other sites. Previous cultivations before planting of DL napiergrass and pasture management were shown in Table 1.

Tabel 1 Field area, establishment, fertilizer, weed and pasture management of dwarf-late (DL) napiergrass in the examined sites in 2007–2008

Measured site		Examined year	Field area (m^2)	Trans-planted plants (No.)	Plant density (No./m^2)	Rate (times) of chemical fertilizer supply (kg N/ha/yr)	Weed control†	Previous cultivation	Pasture manage-ment‡
Island	City/town								
Non-island	Miyazaki	2007	500	1020	2	280 (5)	HMM	Upland field	CC
		2008				112 (2)	None		
	Kobayashi	2007	125	252	2	234 (4)	HMM	Upland field	CC
		2008				234 (4)	HMM		
	Minamata	2007	1300	1300	1	112 (4)	None	Newly	GR
		2008				168 (3)	None		
	Tamana	2008	500	500	1	56 (1)	None	Paddy field	GR
Amakusa	Reihoku	2007	500	500	1	112 (2)	Tillage	Paddy field	CC
		2008				112 (2)	Tillage		
	Itsuwa	2007	500	517	1	112 (2)	None	Upland field	CC
		2008				112 (2)	None		
Koshikijima	Kamikoshiki	2007	300	300	1	56 (1)	None	Newly	CC
	Sato	2007	300	300	1	56 (1)	None	Newly	CC
	Shimokoshiki	2007	150	300	2	56 (1)	None	Pasture	CC
Kuroshima	Oosato	2007	900	900	1	32 (1)	HS	Newly	CC
		2008				144 (3)	HS		
	Katadomari	2007	300	300	1	32 (1)	None	Newly	CC
Sakurajima	Sakurajima	2008	2000	2000	1	92 §	HS	Newly	CC

† HMM: Hand-mowing machine; HS: Hand-weeding by sickle; Tillage: Tilling interrow spaces by tiller; None: Not conducted.
‡ CC: Cut-and-carry; GR: Rotational grazing.
§ Total nitrogen supply with Manure as a basal dressing.

Soil sampling and chemical analysis

In 2007 before planting, soils were sampled at 10 sites in Miyazaki, Kobayashi, Minamata, Reihoku, Itsuwa, Kamikoshiki, Sato, Shimokoshiki, Oosato and Katadomari by core-sampler (about 100 ml of volume) from 10-cm depth below the soil surface at 4 replications in line transect method of the field area and dried in an air for a week to pass 1 mm sieve. Soil chemical properties were determined in duplication for pH (H_2O) and electric conductivity (EC) by pH meter (Model: F-51, Horiba, Ltd., Kyoto, Japan) and EC meter (Model: CM-40S, DKK-TOA Corporation, Tokyo, Japan), respectively. Total nitrogen (TN) and total carbon (TC) contents were determined in duplication for each sample by nitrogen and carbon determination unit (Model: Sumigraph NC-220F, Sumika Chemical Analysis Service, Ltd., Osaka, Japan).

Determination of growth characters and yield

Growth characters such as plant height and tiller number were measured at 30–40 plants at all sites. Harvesting samples was conducted randomly at 10 plants by cutting plants at 10 cm above the ground as in the same height in Ishii *et al*. (2005) to measure fresh weight (FW). Sub-sample of around 300–400 g FW was then separated into leaf blade (LB), stem inclusive of leaf sheath (ST) and dead (D) leaf and oven-dried at 70ºC for 4 days to determine percentage of dry matter in each plant part. Dry matter (DM) yield of the site was calculated by plant FW multiplied with percentage of DM and plant density, since percentage of establishment was perfect after re-transplanting of plants.

Chemical analysis of herbages

After plant samples were ground by mill to pass through 1 mm mesh, *in vitro* DM digestibility (IVDMD) of the herbage part in LB and ST was measured in duplication by pepsin-cellulase digestion method (Goto and Minson 1977) using *in vitro* incubator (Model: ANKOM DAISY II, ANKOM Technology, NY, USA). The TN and TC contents of LB and ST were determined in duplication by nitrogen and carbon determination unit (Sumigraph NC-220F, Sumika Chemical Analysis Service, Ltd.) to determine crude protein (CP) content by TN content multiplied with 6.25.

Overwintering ability of plants

Overwintering ability of plants was determined by assessing percentage of overwintered plants (POP) and number of regrown tillers (RTN) per plant for 30–40 plants in May–June 2008 in 5 sites of Kyushu Island, excluding isolated islands, where subzero temperatures were so rare that this grass should safely maintain the perennial habit, if it is well established.

Statistical analysis

Correlation coefficient of DM yields with plant characters, N fertilizer supply and soil fertility across cutting dates was assessed by Pearson's correlation coefficient at 5% level. Linear regressions of DM yield with N supply and those of cutting period with IVDMD and CP content were determined at 0.1, 1, and 5% levels. Mean data of IVDMD, CP, POP and RTN with the examined site as independent variable was assessed by analysis of variance and the least significant difference test at 5% level (SPSS for Windows ver. 16.0, IL, USA).

Results

Soil properties, plant characters, herbage yield and quality

Soil type has a great deal of variability from Sandy Regosols (Miyazaki), Andosols or Kuroboku soils (Kobayashi), Gray Paddy soils (Reihoku), Red-Yellow soils (Itsuwa) to Brown Forest soils (Minamata, Kamikoshiki, Sato, Shimokoshiki, Oosato and Katadomari) (The Fourth Committee for Soil Classification and Nomennclature, The Japanese Society of Pedology 2003). The pH (H_2O) ranged in 5.7–6.9 was regarded as weakly acid and electric conductivity (EC), which is a measure of soluble salt content in soil solution (Gregorich *et al*. 2001), ranged below 0.1 dS/m, except for the highest EC at about 0.49 dS/m in Itsuwa. In addition, Kamikoshiki and Sato in Koshikijima islands had shallow soil layer at the sloped area with lowest EC below 0.04 dS/m and lower TN contents among the examined 10 sites. The TN and TC contents of soils were the lowest in Katadomari (Table 2).

Dry matter (DM) yield was so variable across the examined sites, ranging in 0.7–13.6 and 0.2–15.8 Mg/ha/yr in 2007 and 2008, respectively, and the highest record was obtained in Kobayashi in both years. Significantly positive correlation was obtained between DMY and fertilizer N supply ($r = 0.844$, $P < 0.01$ and $r = 0.928$, $P < 0.001$ in 2007 and 2008, respectively, Figure 2). The correlation of DM yield with plant height was significantly positive for the first and second cuttings in 2007 and for the first cutting in 2008, while that with tiller density was significantly positive only for the first cutting in 2007 (Table 4). However, correlation of DMY with either soil TN or soil TC contents was non-significant ($r = 0.488$ and $r = 0.467$, respectively, $P > 0.05$) for the first harvest in 2007 (Table 4).

As herbage quality, *in vitro* dry matter digestibility (IVDMD) in leaf blade (LB) ranged in 57.0–71.2 and 56.0–68.1% in 2007 and 2008, respectively. Compared with LB, the values of IVDMD in stem inclusive of leaf sheath (ST) were higher in both years, and ranged in 61.9–74.7 and 63.7–76.5% in 2007 and 2008, respectively (Table 3). Contrary to the trend in IVDMD between LB and ST, crude protein (CP) content tended to be lower in ST at 6.8–18.3 and 6.0–17.6% in 2007 and 2008, respectively, whereas that in LB ranged in 9.7–15.5 and 9.0–18.3% in 2007 and 2008, respectively (Table 3). The variation in herbage quality was partly mediated with that in cutting interval, ranging from 27–30 to 90–120 days for both years, and the significantly negative correlations of IVDMD and CP content with cutting interval ($r = -0.393$, $P < 0.05$ and $r = -0.366$, $P < 0.05$, respectively) were obtained only in LB across all the cuttings in both years (Figure 3).

Overwintering ability in DL napiergrass was assessed at 5 sites in Kyushu, excluding the sites at isolated islands and the monitored monthly minimum temperatures showed the lowest in January or February 2008, which was higher than -6°C (Table 5). Percentage of overwintered plants (POP) maintained uniformly above 94% in both May 2008 and May 2009, except for Minamata in May 2009, and tiller density by regrown plants ranged in 12–33 and 18–25 tillers/m^2 in May 2008 and May 2009, respectively (Table 5).

Discussion

In this research, soil properties such as soil type, pH, EC, TN and TC contents and C/N ratio were so variable across the examined sites (Table 2). Cook *et al.* (2005) pointed that napiergrass grows best in deep and well-drained friable loams with wide range of pH in 4.5–8.2 (optimal at 6.2), which was fit to the measured pHs in all

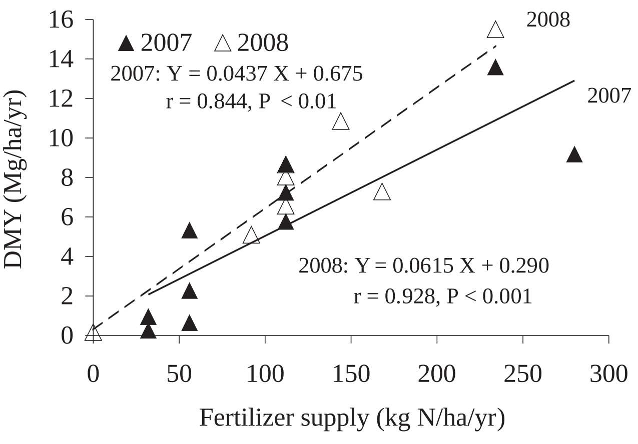

Figure 2 Relationship between total dry matter yield (DMY, Y) and nitrogen (N) fertilizer supply (X) of DL napiergrass in 2007 and 2008.
Solid line (——) and broken line (--------) show the linear regression lines for the year 2007 (n = 10) at 1% level and 2008 (n = 8) at 0.1% level, respectively.

Table 2 Soil property in the examined sites in 2007

Measured site		Soil property					
Island	City/town	Soil type†	pH (H_2O)	EC (dS/m)	TN‡ (%)	TC§ (%)	C/N ratio
Non-island	Miyazaki	Sandy Regosols	$6.10^{cd*} \pm 0.36$	$0.040^{b} \pm 0.009$	$0.176^{de} \pm 0.017$	$1.87^{d} \pm 0.15$	$10.67^{d} \pm 0.21$
	Kobayashi	Andosols (Kuroboku)	$6.43^{ab} \pm 0.11$	$0.100^{b} \pm 0.020$	$0.498^{a} \pm 0.039$	$5.35^{ab} \pm 0.40$	$10.74^{d} \pm 0.10$
	Minamata	Brown Forest	$6.30^{bc} \pm 0.20$	$0.060^{b} \pm 0.011$	$0.193^{de} \pm 0.036$	$2.28^{d} \pm 0.46$	$11.81^{cd} \pm 0.46$
Amakusa	Reihoku	Gray Paddy	$5.63^{f} \pm 0.06$	$0.068^{b} \pm 0.008$	$0.212^{d} \pm 0.015$	$1.81^{d} \pm 0.16$	$8.52^{e} \pm 0.34$
	Itsuwa	Red-Yellow	$6.10^{cd} \pm 0.31$	$0.488^{a} \pm 0.264$	$0.424^{ab} \pm 0.199$	$6.57^{a} \pm 3.65$	$15.04^{a} \pm 1.36$
Koshikijima	Kamikoshiki	Brown Forest	$5.77^{ef} \pm 0.04$	$0.031^{b} \pm 0.011$	$0.158^{de} \pm 0.048$	$2.11^{d} \pm 0.59$	$13.47^{b} \pm 0.66$
	Sato	Brown Forest	$5.93^{de} \pm 0.20$	$0.035^{b} \pm 0.025$	$0.273^{cd} \pm 0.134$	$2.95^{cd} \pm 1.28$	$10.99^{d} \pm 0.86$
	Shimokoshiki	Brown Forest	$5.83^{ef} \pm 0.22$	$0.063^{b} \pm 0.016$	$0.462^{a} \pm 0.103$	$5.43^{ab} \pm 0.84$	$11.90^{cd} \pm 1.08$
Kuroshima	Oosato	Brown Forest	$6.66^{a} \pm 0.32$	$0.071^{b} \pm 0.015$	$0.321^{bc} \pm 0.111$	$4.32^{bc} \pm 1.67$	$13.30^{bc} \pm 0.83$
	Katadomari	Brown Forest	$6.52^{ab} \pm 0.60$	$0.075^{b} \pm 0.046$	$0.080^{e} \pm 0.005$	$1.30^{d} \pm 0.30$	$16.16^{a} \pm 2.88$

† Source: Derived from 'The fourth Committee for Soil Classification and Nomenclature, The Japanese Society of Pedology (2003)'.
‡ TN = Total nitrogen. § TC = Total carbon. Values are mean ± standard deviation of the mean.
* Figures with different letters denote significant difference in each soil property among sites at 5% level by LSD test.

Table 3 Yield and forage quality of DL napiergrass in the examined sites in 2007 (A) and 2008 (B)

(A) 2007

Measured site		Dry matter yield (Mg/ha/yr)	Feed quality†			
			In vitro dry matter digestibility (%)		Crude protein content (%)	
Island	City/town		LB	ST	LB	ST
Non-island	Miyazaki	$9.19^{b*} \pm 2.01$	$66.79^{b} \pm 3.39$	$71.46^{b} \pm 1.47$	$15.51^{a} \pm 0.81$	$18.26^{a} \pm 2.14$
	Kobayashi	$13.56^{a} \pm 2.45$	$62.45^{cd} \pm 2.38$	$70.15^{bc} \pm 1.66$	$13.73^{b} \pm 0.73$	$15.26^{b} \pm 1.79$
	Minamata	$5.78^{d} \pm 1.92$	$63.04^{cd} \pm 5.50$	$65.27^{de} \pm 1.59$	$10.11^{df} \pm 0.92$	$6.81^{f} \pm 0.88$
Amakusa	Reihoku	$8.67^{bc} \pm 1.50$	$62.00^{cd} \pm 1.70$	$66.83^{d} \pm 1.38$	$10.90^{cd} \pm 1.20$	$9.76^{e} \pm 0.85$
	Itsuwa	$7.13^{cd} \pm 2.15$	$60.36^{cd} \pm 1.58$	$64.41^{e} \pm 2.73$	$9.95^{f} \pm 0.55$	$7.18^{f} \pm 0.98$
Koshikijima	Kamikoshiki	$0.67^{e} \pm 0.35$	$57.04^{e} \pm 1.91$	$61.93^{f} \pm 0.98$	$9.69^{f} \pm 0.57$	$6.95^{f} \pm 1.00$
	Sato	$2.32^{e} \pm 0.62$	$63.35^{cd} \pm 4.01$	$69.21^{c} \pm 2.57$	$14.06^{b} \pm 0.93$	$13.51^{c} \pm 1.12$
	Shimokoshiki	$5.24^{d} \pm 3.87$	$64.27^{bc} \pm 2.31$	$65.68^{de} \pm 1.08$	$11.13^{c} \pm 0.92$	$10.48^{e} \pm 0.83$
Kuroshima	Oosato	$0.96^{e} \pm 1.02$	$71.24^{a} \pm 2.69$	$74.73^{a} \pm 3.00$	$13.73^{b} \pm 0.93$	$11.74^{d} \pm 0.85$
	Katadomari	$0.27^{e} \pm 0.21$	—‡	—	—	—

(B) 2008

Measured site		Dry matter yield (Mg/ha/yr)	Feed quality†			
			In vitro dry matter digestibility (%)		Crude protein Content (%)	
Island	City/town		LB	ST	LB	ST
Non-island	Miyazaki	$8.66^{c} \pm 1.02$	$62.65^{c} \pm 2.56$	$68.77^{d} \pm 2.28$	$9.04^{d} \pm 0.63$	$6.00^{d} \pm 0.53$
	Kobayashi	$15.76^{a} \pm 3.23$	$66.33^{ab} \pm 3.03$	$76.46^{a} \pm 2.67$	$13.02^{c} \pm 0.11$	$9.02^{cd} \pm 0.81$
	Minamata	$7.28^{cd} \pm 1.37$	$63.04^{bc} \pm 5.50$	$65.27^{e} \pm 1.60$	$18.30^{a} \pm 1.55$	$12.68^{b} \pm 1.41$
	Tamana	$0.17^{f} \pm 0.03$	$64.87^{abc} \pm 2.63$	$72.19^{bc} \pm 1.17$	$10.75^{d} \pm 1.65$	$8.30^{cd} \pm 2.25$
Amakusa	Reihoku	$8.04^{cd} \pm 0.91$	$68.13^{a} \pm 3.58$	$75.28^{a} \pm 4.17$	$13.89^{bc} \pm 1.05$	$8.35^{cd} \pm 1.71$
	Itsuwa	$6.48^{de} \pm 1.11$	$65.92^{abc} \pm 1.02$	$74.44^{ab} \pm 1.48$	$10.35^{d} \pm 1.72$	$7.27^{cd} \pm 2.16$
Kuroshima	Oosato	$10.85^{b} \pm 3.22$	$55.96^{d} \pm 5.14$	$63.65^{e} \pm 1.85$	$15.22^{b} \pm 4.26$	$15.13^{a} \pm 5.55$
Sakurajima	Sakurajima	$5.10^{e} \pm 1.91$	$66.37^{abc} \pm 1.35$	$69.73^{cd} \pm 1.53$	$15.73^{b} \pm 0.70$	$17.61^{a} \pm 1.27$

† Data were presented on leaf blade (LB) and stem inclusive of leaf sheath (ST) at the first defoliation in each year.
‡ Not determined.
Values are mean ± standard deviation of the mean.
* Figures with different letters denote significant differences at 5% level by LSD test.

Table 4 Correlation coefficient of dry matter yield at each cutting with plant character, N supply and soil fertility in each cutting time across the examined sites

Year	Cutting times	n	Plant character		Rate of N fertilizer supply	Soil fertility	
			Height	Tiller density		Soil TN† content (%)	Soil TC‡ content (%)
2007	1st	10	0.743*	0.671*	0.619ns	0.488ns	0.467ns
	2nd	5	0.950*	0.680ns	0.325ns		
2008	1st	8	0.804*	0.664ns	0.341ns		
	2nd	6	0.657ns	0.528ns	0.216ns		
	3rd	5	0.362ns	0.285ns	0.299ns		

† TN = total nitrogen.
‡ TC = total carbon.
* $P < 0.05$, ns, $P > 0.05$ by Pearson's correlation coefficient.

Table 5 Minimum temperature and overwintering ability of DL napiergrass at 5 examined non-island sites in 2007 and 2008

Year	Character	Month	Measured site				
			Miyazaki	Kobayashi	Minamata	Reihoku	Itsuwa
2007–2008	Minimum temperature (°C)	November	1.9	8.2	8.9	6.5	4.5
		December	1.5	4.9	5.7	1.5	-0.5
		January	-1.1	2.9	4.2	-2.0	-3.5
		February	-3.2	-0.1	1.2	-3.5	-4.5
		March	0.6	4.9	5.4	—	—
2007–2008	Percentage of overwintered plants	May	100.0ns† ± 0.00	98.15 ± 3.21	97.23 ± 4.99	96.99 ± 5.12	94.26 ± 14.58
	Regrown tiller density (No./m^2)	May	12.83c‡ ± 1.39	18.23bc ± 3.51	33.30a ± 12.20	28.00ab ± 4.13	24.70b ± 6.66
2008–2009	Percentage of overwintered plants	May	—	96.30ns ± 3.21	89.90 ± 9.80	—	—
	Regrown tiller density (No./ m^2)	May	—	25.60ns ± 10.30	18.00 ± 11.10	—	—

† ns, $P > 0.05$.
Values are mean ± standard deviation of the mean.
‡ Figures with different letters denote significant differences at 5% level by LSD test.

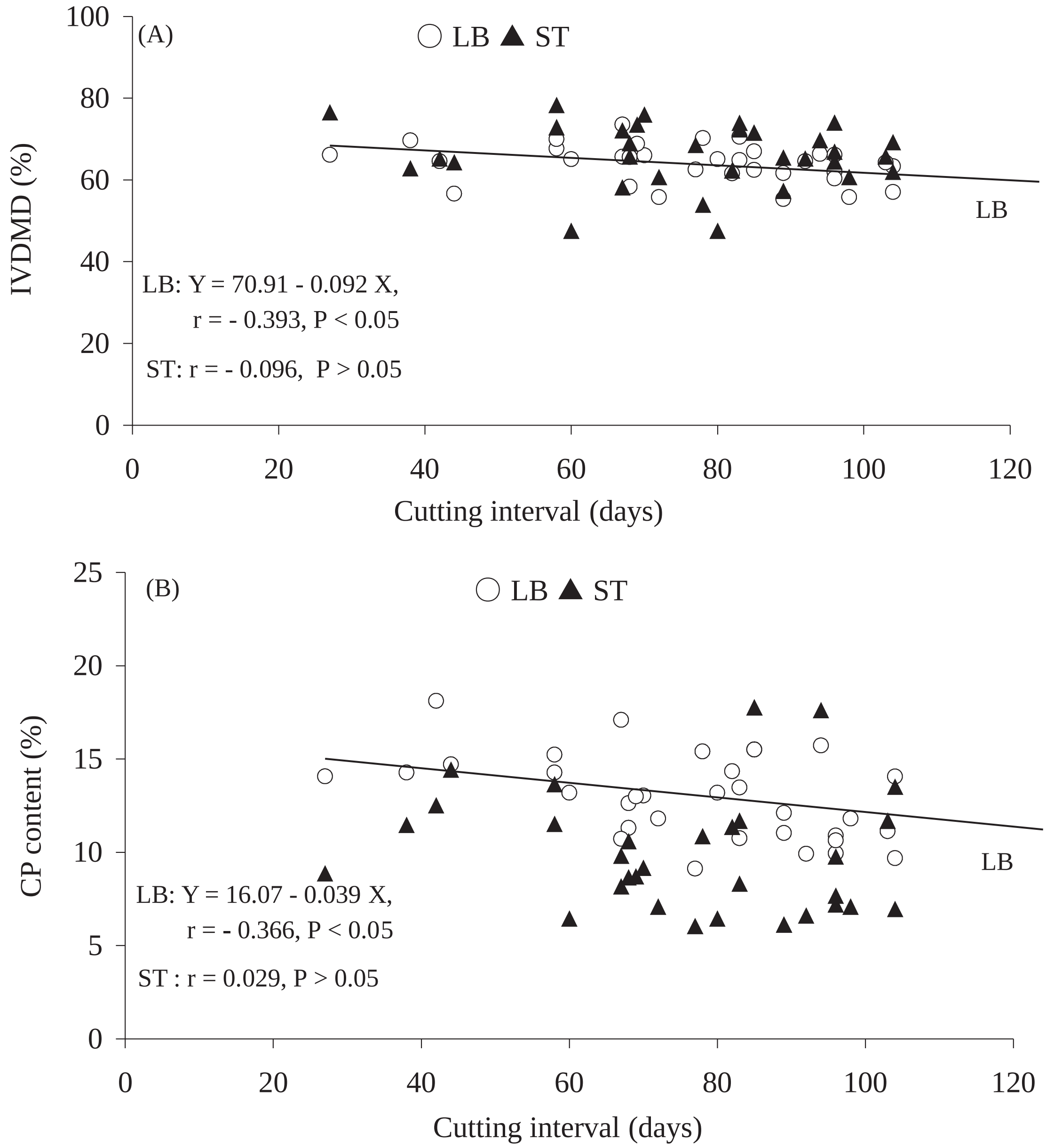

Figure 3 Relations of *in vitro* dry matter digestibility (IVDMD, A) and crude protein (CP) content (B) in both leaf blade (LB) and stem inclusive of leaf sheath (ST) of DL napiergrass with cutting interval in 2007 and 2008.
Solid line (——) shows the linear regression line for LB (n = 34) at 5% level.

sites. However, since Miller and Reetz (1995) pointed that there is a close relationship between soil pH and nutrient availability, which is greatest for nitrogen, phosphorus, potassium, sulfur, calcium and magnesium ions in the soil pH at 6.5–7.5, measured pHs in Reikoku and Koshikijima islands (Kamikoshiki, Sato and Shimokoshiki) were significantly lower to possibly reduce nutrient availability than other 4 sites (Kobayashi, Minamata, Oosato and Katadomari). In addition, Kamikoshiki and Sato in Koshikijima islands had shallow soil layer at the sloped area with lowest EC below 0.04 dS/m and lower TN contents among the examined 10 sites. The soil conditions in these 2 sites were similar to Oosato and Katadomari in Kuroshima island, where field was newly established from native weed vegetation and TN and TC contents were lowest in Katadomari, which may reduce DM yield at the first harvest in 2007, compared with other 6 sites. In Shimokoshiki of Koshikijima islands, where DL napiergrass was transplanted at the grazing pasture, DM yield was significantly higher than the other 2 sites in this island.

In addition with the effects of soil conditions and previous cultivation, we need to consider the effect of cultivation methods, such as fertilizer input, planting density, planting date and weed control on DM yield among the examined 10 sites. Chemical fertilizer (N) input had a great deal of variation among sites, ranging in 32–280 and 56–234 kg N/ha/yr in 2007 and 2008, respectively, as shown in Table 1. As a management, N fertilizer is the most potential tool in enhancing and manipulating both herbage yield and quality (Broyles and Fribourg 1959; Boonman 1993). There was the positive correlation between DM yield and fertilizer N supply in both 2007 and 2008 (Figure 2). It is a common feature that DM yield of napiergrass increased under high input of fertilizer in both normal (Mohammad 1988; Wadi *et al.* 2003) and dwarf genotypes (Hasyim *et al.* 2010). Hsu and Hong (1993) also reported the positive effect of nitrogen and potassium fertilizers on yield and digestibility in dwarf napiergrass. Irrespective of other cultivation factors, DM yield maintained 5 Mg/ha/yr in the established year in both 2007 and 2008 under the minimum fertilizer supply at around 100 kg N /ha/yr. This yielding level was not so high as in annual tropical grasses such as Rhodesgrass, averaged at around 15.5–20.5 Mg/ha/yr (Fukagawa *et al.* 2005) and forage maize, averaged at 8.6–10.3 Mg/ha/yr (Idota and Ishii 2007) grown on forage fields in Kyushu. However, perennial growth habit of dwarf napiergrass in the examined area tends to increase its DM yield in the subsequent year after establishment under proper pasture management as examined in Kobayashi, and no need to plow forage fields every spring as in the sowing of annual Rhodesgrass and maize should be suitable to smallholding farmers in isolated islands with poor machinery equipment. In addition, DM yield of dwarf napiergrass was absolutely higher than the perennial tropical species such as bahiagrass (Hirata *et al.* 2006) at the established year, when bahiagrass is hard to be harvested due to lower yield at 1.3-1.8 Mg/ha/yr (Wang *et al.* 2008).

In this research, we applied 2 planting densities at 1 and 2 plants/m^2, and the higher density was only applied in Miyazaki, Kobayashi and Shimokoshiki, where DM yield was maintained above 5 Mg/ha/yr in the established year. It is true that higher density lead to increase DM yield in DL napiergrass at the established year (Mukhtar *et al.* 2003), while larger number of nursery plants are required at the higher density due to vegetative propagation. Planting of DL napiergrass was carried out in May and/or June of each year, while delay in transplanting for Tamana and Sakurajima in June 2008 may reduce DM yield at the first harvest.

Other factor affecting on DM yield in DL napiergrass was weed control. In Reihoku and Itsuwa of Amakusa island, DM yield tended to be higher in Reihoku than in Itsuwa in both 2007 and 2008, and weed control was only conducted by inter-row tillage in Reihoku. Thus, highest EC in Itsuwa in 2007 did not lead to the higher DM yield of DL napiergrass, contrary to be in favor of vigorous weed growth. In Miyazaki, loss of weeding, combined with the decease of N input in 2008 resulted in decrease of DM yield from the previous year 2007, contrary to the increasing trend of DM yield in Kobayashi, 2008 under the same N input and weed control in both years.

As herbage quality, IVDMD was variable in 56.7–77.2 and 61.9–78.6% in LB and ST, respectively (Table 3), showing that ST tended to have higher digestibility than LB in both years. In napiergrass as in the same case for the most tropical grasses, herbage digestibility decreases as the maturity progresses and its digestibility tends to be higher in ST than in LB at the juvenile stage while this tendency turns to be reversed in the matured stage, since the decreasing rate in digestibility of ST during maturity was larger than that of LB (Ishii *et al.* 1993; Fukugawa *et al.* 2000). The CP content ranged in 9.0–18.3 and 6.0–18.3% in LB and ST, respectively, across both years, and LB tended to have higher CP content than ST in all cases, except for the case in high fertilizer and manure input in Miyazaki 2007 and Sakurajima 2008, respectively, where it suggests the accumulation of nitrate-N in ST (Ishii *et al.* 1999). If herbage CP content is lower than 7%, the micro-organism in the rumen cannot break down the feed efficiently, resulting in the decrease of animal body weight (Werner and Horne 2001) and dry matter intake of tropical grasses (Milford and Minson 1965), that was not the case in the present research. However, if only the supply of dwarf napiergrass should meet 12% of CP content required for breeding beef cows in Japanese Feeding Standard for Beef Cattle (NARO 2008), it is necessary to supply fertilizer above 150 kg N/ha/yr, as in Miyazaki and Kobayashi in 2007 and in Kobayashi, Minamata and Oosato in 2008. Both of IVDMD and CP content tended to decrease with the increasing cutting interval, while the negative correlation was only significant in LB (Figure 3). Cutting interval is the important factor influencing the composition and nutritive value of the herbage in dwarf napiergrass, as in the same tendency with normal napiergrass (Sunusi *et al.* 1997).

For sustainability of dwarf napiergrass as the perennial use, overwintering ability of DL napiergrass, assessed at 5 sites in Kyushu islands, excluding isolated islands, showed that the POP and RTN in late April to early May 2008 ranged in 95–100% and 12–33 tillers/m^2, respectively, and this high overwintering ability continued through May 2009 for both Kobayashi and Minamata

(Table 5). Among the examined 5 sites, the minimum temperatures did not drop below -6°C, which was above the critical lethal temperature for DL napiergrass at -6.2°C (Ishii *et al*. 2008). Slight drops of POP from 100% in Minamata and Itsuwa in Kumamoto Prefecture, 2008 were possibly due to the submerged areas and poor weeding management, respectively. Poor weed control should reduce overwintering ability in the first stage of establishment (Duke 1983). Decreasing trend of POP continued in Minamata 2009 by the loss of regrowth in the submerged area at the basement of sloped field, where plant growth of DL napiergrass in 2008 inhibited severely.

Conclusions

The results from the present research show that annual mean and lowest temperatures were sufficiently enough to support the establishment and overwintering of DL napiergrass in the examined 12 sites including isolated islands in southern Kyushu. However, soil properties affected DM yields significantly at the establishment. It is advisable that shallow soil in Brown Forest soils and submerged paddy soils should be escaped for the cultivation of DL napiergrass. Herbage quality components, such as IVDMD and CP contents, were almost higher than the minimum requirement at 7.0% of CP content, while it is necessary to supply fertilizer above 150 kg N/ha/yr, if only the supply of dwarf napiergrass should meet 12% of CP content in herbages required for breeding beef cows (NARO 2008). Therefore, DL napiergrass can adapt to the examined sites in southern Kyushu, including of isolated islands and produce the sufficiently high DM yield with satisfactory herbage quality to ordinary perennial tropical grasses, possessing the sustainable use under both cut-and-carry and rotational grazing systems if additional fertilizer application covers more than at least 100 kg N/ha/yr after establishment.

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要　約

南九州の小規模肉牛農家における採草および放牧体系下での矮性ネピアグラスの適応性

Renny Fatmyah UTAMY・石井康之[1]・井戸田幸子[1]・原田直人[2]・福山喜一[1]

宮崎大学大学院農学工学総合研究科・[1] 宮崎大学農学部・[2] 鹿児島県農業開発総合センター畜産試験場

連絡者：石井康之（tel・fax: 0985-58-7251, e-mail: yishii@cc.miyazaki-u.ac.jp）

南九州の，特に離島などにおける小規模肉牛農家では，高齢化，耕地の不足，機械化の遅れなどの問題を抱え，飼料価格の高騰などから，自給粗飼料生産に対する要望が高まっている。そこで本研究は，南九州の宮崎，熊本，鹿児島 3 県の離島を含む 12 調査地点における矮性ネピアグラスの適応性を，土壌特性，植物体の成長形質，飼料の収量と品質および越冬性に関して，2007 年と 2008 年に調査したものである。矮性ネピアグラスの乾物収量は，2007 年では 0.7 〜 13.6 トン /ha，2008 年では 0.2 〜 15.8 トン /ha の地域間差異が認められた。N 肥料供給量と乾物収量との間に両年ともに有意な正の相関関係があったが，乾物収量には，土壌の肥沃度や雑草防除の良否の影響も認められた。飼料品質としての *in vitro* 乾物消化率（IVDMD）と粗タンパク質（CP）含量は，両年ともにそれぞれ約 56 〜 76%，6 〜 18%の範囲であり，CP 含量は刈取り間隔との間に負の相関関係があることなどから，繁殖雌牛飼養にとっての限界値を下回る場合が認められ，矮性ネピアグラスのみの給与の場合には，施肥量を年間 150 kg N/ha 以上に挙げることが必要であった。したがって，矮性ネピアグラスは，適切な土壌条件の土地を選択し，最低年間 100 kg N/ha 以上の施肥と適切な雑草防除を行えば，離島を含む南九州において造成後 2 年間は，粗飼料として満足しうる収量と品質を挙げ，適応可能であることが示された。

日本暖地畜産学会報　54（1）: 87-98, 2011

キーワード：越冬性，飼料収量，飼料品質，土壌特性，矮性ネピアグラス