

Effects of Cutting Interval and Cutting Height on Dry Matter Yield and Overwintering Ability at the Established Year in *Pennisetum* Species

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Abstract : The effects of cutting interval and cutting height on dry matter productivity and overwintering ability were compared among 4 *Pennisetum* species, napiergrass, kinggrass, hybrid napiergrass and pearl millet in the established year to examine the suitable cutting practice for the productivity and persistence. The cutting intervals were 60 and 90 days, and the cutting heights were 0 and 30 cm above the ground. Annual herbage dry matter yield (HDMY) was the highest in kinggrass, followed by hybrid napiergrass, napiergrass and pearl millet, and was higher in the plants at a 90-day interval and 0-cm height than at a 60-day interval and 30-cm height, respectively. The percentage of dry matter to fresh matter did not correlate with the annual HDMY or cutting height. The plants cut at a 90-day interval at a 0-cm height had the highest in mean tiller weight, crop growth rate, net assimilation rate and HDMY, but the lowest tiller number and percentage leaf blade to the whole harvested plant. Thus, the correlation coefficients between HDMY and plant characters were positive for plant height, mean tiller weight, leaf area index and crop growth rate in all 4 species and were negative for tiller number and percentage leaf blade except for pearl millet. Both percentage overwintered plants and regrown tiller number were the highest in kinggrass followed by napiergrass and hybrid napiergrass; these were nil in pearl millet under all cutting practices, and were higher in the plants cut at a 30-cm height than at a 0-cm height. This tended to be associated with higher tiller bud number and higher total nonstructural carbohydrate concentration in the stubble after cutting at a 30-cm height. Regrown tiller number was higher in the plants cut at a 60-day interval than at a 90-day interval in all species except for pearl millet, but the percentage overwintered plants was not affected by the cutting interval. Thus, the combination of highest annual HDMY and highest overwintering ability was attained by cutting at a 90-day interval at a 30-cm height in kinggrass.

Key words : Cutting interval and height, Dry matter yield, Overwintering, *Pennisetum*.

Pennisetum species, especially in pearl millet, are widely grown in tropical and subtropical regions for forage as well as for grain (Vicente-Chandler et al., 1959; Muldoon and Pearson, 1979; Mendoza and Schank, 1987; Ito and Inanaga, 1988; Woodard and Prine, 1993; Sunusi et al., 1999; Wadi et al., 2003a). Among *Pennisetum* species, there are many relatives which were bred by reciprocal crossing, such as kinggrass or banagrass (napiergrass (*Pennisetum purpureum*) × pearl millet (*P. thypoides*)), and hybrid napiergrass or Pusa Giant Napier (*P. thypoides* × *P. purpureum*) (Pieterse et al., 1993; Schank et al., 1993).

Napiergrass was precisely examined for the wide profitability at several sites in western Japan. However, since the stem of napiergrass is easily hardened after elongation, the plants for forage should be cut at intervals before stem elongation (Sunusi et al., 1997). This growth characteristic obstructs the popularization of napiergrass among farmers. Thus, in the normal napiergrass, the optimum cutting interval was determined to be 2 months on a quality basis, and 3

months on a yield basis (Sunusi et al., 1997). Usually, the farmers cut plants at 30 cm above the ground level, when the stem is elongated.

The forage quality of napiergrass is improved by introducing the characters of crossing-bred *Pennisetum* to pearl millet (Kritayanavach, 1968; Muldoon and Pearson, 1979; Siregar, 1989; Pieterse et al., 1993; Schank et al., 1993) or by introducing the dwarfism to napiergrass (Mukhtar et al., 2003). Although the former method was used in the border area between the sub-tropical and the temperate, such as Florida, USA (Schank et al., 1993), the overwintering ability should be an important character for the crossing-bred *Pennisetum* in the frost-prone area in Southern Kyushu. The productivity and quality of *Pennisetum* species markedly varies with the method of cutting practice (Siregar, 1989; Mukhtar et al., 2003), which also affects the overwintering ability. Cutting close to the ground level at the final harvest reduces the overwintering ability in the normal napiergrass (Ishii et al., 1995; 1997; 2000).

The overwintering ability is a generalized concept including the cold tolerance and regrowth ability after winter (Kobayashi and Nishimura, 1978), and was quantified as a percentage of plants surviving in the field after winter (Abe, 1977). The cutting method significantly affects the seasonal change in dry matter productivity and overwintering ability of *Pennisetum* species through the effect on the productivity (Ishii et al., 1997; Ishii et al., 2000). In southern Kyushu, the climatic condition in summer is suitable for the growth of tropical grasses, but the cold and frosty climate in winter severely suppresses their growth. The overwintering ability of *Panicum* species was investigated with respect to tiller-bud turnover, dry matter productivity and carbohydrate concentration in the basal part of the stem, as affected by the methods of cutting and fertilization (Cai et al., 1997; Cai, 1998). The annual productivity of tropical grasses in this area is greatly affected by the abilities of overwintering and spring regrowth (Inosaka et al., 1973). Some tropical perennial grasses which are not hardened, are significantly injured by frost and fail to survive in winter (Numaguchi, 1983).

This study aimed to examine the suitable cutting interval and cutting height for obtaining high herbage dry matter yield (HDMY) and good overwintering ability in napiergrass, kinggrass, hybrid napiergrass and pearl millet at the established year.

Materials and Methods

1. Grass species, plant establishment and managements

Grass species examined were napiergrass (*Pennisetum purpureum*, cv. Wruk wona) that is a promising high yielding napiergrass variety (Sunusi et al., 1999), kinggrass (*P. purpureum* × *P. thypoides*, maintained in Hasanuddin University, Indonesia), hybrid napiergrass (*P. thypoides* × *P. purpureum*, hybrid hexaploid named BG-4) from Prof. S.C. Schank, University of Florida, USA and pearl millet (*P. thypoides*, cv. Yukijirushi line) at the first established year. Napiergrass, kinggrass and pearl millet were examined in 2001 and hybrid napiergrass in 2002.

Rooted tillers of napiergrass and kinggrass were transplanted at 50 cm × 50 cm spacing (4 plants m⁻²) on May 5, 2001, and hybrid napiergrass on May 7, 2002. The seeds of pearl millet were sown at the spacing of 50 cm × 50 cm on May 9, 2001. The plants of each species were divided into two groups, and cut at 60-day and 90-day intervals (main plots), and each group was subdivided into two groups (subplot) and cut at 0 cm and 30 cm from ground level. The area of each subplot was 2.5 m × 2.5 m. The tiller-bud turnover was investigated in the second year (mid-December 2002) under the same managements as in 2001.

Subplots were set for each species in a Latin square

method with three replications. As a basal fertilizer, manure at 6 ton ha⁻¹ and lime at 4 ton ha⁻¹ were applied 2 weeks before planting. Top dressing of 300 kg N ha⁻¹ year⁻¹ was applied equally by split-application 6 times from May to October in both years.

2. Measurements of plant growth characters

Fresh matter weight of harvested plants was recorded for 9 plants, and dry matter weight and some plant characters such as plant height, tiller number and leaf area were measured for 3 plants from each subplot at each sampling time. Harvested plants were divided into leaf blade, stem with leaf sheath and dead part, and dried at 70°C for more than 3 days to determine dry matter weight. Fresh and dry matter yields were the product of fresh matter weight and dry matter weight of each harvested plant with plant density, respectively. Percentage dry matter was as dry matter weight divided by fresh matter weight × 100.

3. Measurements of tiller-bud turnover, overwintering ability and storage carbohydrate

To determine tiller-bud turnover, we counted the numbers of stubble tillers, nodes in the subterranean stem and tiller buds per plant at each replication (totally three plants) in napiergrass, kinggrass and hybrid napiergrass cut at a 60-day interval in mid-December 2002.

To examine the overwintering ability, we examined the percentage overwintered plants and number of regrown tillers per plant in eight plants for each replication in early May 2002 in napiergrass, kinggrass and pearl millet, and in late April 2003 in hybrid napiergrass.

The concentration of storage carbohydrate (total nonstructural carbohydrate (TNC) including starch and total sugars) in the subterranean stem before wintering season was determined in napiergrass, kinggrass and hybrid napiergrass by the enzymatic method of the F-kit, starch (Roche-Diagnostics Co. Ltd.).

Results

1. Herbage dry- and fresh-matter yields

Annual HDMY was the highest in kinggrass (100%), followed by hybrid napiergrass (93 %), napiergrass (85 %) and the lowest in pearl millet (54 %) on the average of all plants cut at various heights in kinggrass (Table 1). The annual HDMY of the plants cut at a 90-day interval was superior to the plants cut at a 60-day interval and that of plants cut at a 30-cm height was superior to that of the plants cut at a 0-cm height in all 4 species examined. The coefficient of variance (CV) at HDMY was the smallest in pearl millet. It was smaller in the plants cut at a 60-day interval than that at a 90-day interval, and was smaller in the plants cut at a 30-cm height than at a 0-cm height (Table 1). The

Table 1. Effect of variants on annual herbage dry matter yield (HDMY) and coefficient of variance (CV) in HDMY.

Variants					
Species ¹⁾		Kg	Hn	Na	Pm
	HDMY (kg m ⁻² yr ⁻¹)	2.26 ^{a2)}	2.09 ^a	1.91 ^a	1.23 ^b
		(100) ³⁾	(92.5)	(84.5)	(54.4)
	CV (%)	29.93	25.42	33.87	13.6
Cutting interval		90-day interval		60-day interval	
	HDMY (kg m ⁻² yr ⁻¹)	2.26 ^a		1.48 ^b	
		(100)		(65.5)	
	CV (%)	28.59		21.38	
Cutting height		0-cm height		30-cm height	
	HDMY (kg m ⁻² yr ⁻¹)	2.04 ^a		1.70 ^b	
		(100)		(83.3)	
	CV (%)	34.41		32.12	

- 1) Na: Napiergrass, Kg: Kinggrass, Hn: Hybrid napiergrass, Pm: Pearl millet.
- 2) Figures with different letters of a, b and α , β denote the significant difference between elements of each variant at 5% and 10% levels, respectively.
- 3) Values in parentheses are percentages of HDMY to that in the maximum element.

smaller CVs in pearl millet and in the plants cut at a 60-day interval were partly due to a smaller value of HDMY.

The annual total of herbage fresh matter yield was higher in the plants cut at a 90-day interval than at a 60-day interval and in the plants cut at a 0-cm height than at a 30-cm height. Thus, the highest herbage fresh matter yield and HDMY (161 t ha⁻¹ and 29.7 t ha⁻¹, respectively) were obtained by cutting at a 90-day interval at a 0-cm cutting height in kinggrass, and the lowest annual HDMYs (about 11.0-11.2 t ha⁻¹) by cutting at a 60-day interval at a 0-cm or 30-cm height in pearl millet.

The difference in annual HDMY among species was smaller in the plants cut at a 60-day interval than at a 90-day interval, which was due to the reduced difference in HDMY in the aftermath, although regrowth in pearl millet was quite poor under both 60-day and 90-day cutting intervals.

The plants cut at a 90-day interval at a 0-cm height had the highest HDMY, mainly due to the highest HDMY at the first cutting in all 4 species.

2. Percentage dry matter

The percentage dry matter was the highest in pearl millet followed by napiergrass, kinggrass and hybrid napiergrass, on the average of plants under all cutting practices. The percentage dry matter was higher in the plants cut at a 90-day interval than at a 60-day interval and in the plants cut at a 30-cm height than at a 0-cm height. The CV in percentage dry matter was the smallest in napiergrass and tended to be smaller in the plants cut at a 0-cm height than at a 30-cm height (Table 2). There was a significantly positive correlation between the percentage dry matter and its CV ($r = 0.714$, $P < 0.05$). However, the differences in

Table 2. Effect of variants on percentage dry matter (PDM) and coefficient of variance (CV) in PDM.

Variants					
Species ¹⁾		Pm	Na	Kg	Hn
	PDM	21.7 ^{a2)}	16.15 ^b	15.77 ^b	14.65 ^b
		(100) ³⁾	(74.4)	(72.7)	(67.5)
	CV (%)	35.14	13.92	14.39	17.48
Cutting interval		90-day interval		60-day interval	
	PDM	19.76 ^a		15.27 ^b	
		(100)		(77.3)	
	CV (%)	25.88		26.86	
Cutting height		30-cm height		0-cm height	
	PDM	17.99 ^a		16.14 ^b	
		(100)		(89.7)	
	CV (%)	33.57		22.26	

- 1) Na: Napiergrass, Kg: Kinggrass, Hn: Hybrid napiergrass, Pm: Pearl millet.
- 2) Figures with different letters of a, b and α , β denote the significant difference between elements of each variant at 5% and 10% levels, respectively.
- 3) Values in parentheses are percentages of PDM to that in the maximum element.

percentage dry matter between the plants cut at 90- and 60-day intervals were small in all 4 species, except hybrid napiergrass and pearl millet at the time of the second cutting with a 90-day interval, which had a high percentage dry matter due to the leaf drying after the frost damage.

3. Plant characters and their relationships to herbage dry matter yield

Table 3 shows the annual means of the plant characters of 4 species cut at different cutting intervals and at different heights. In the plants cut at a 90-day interval, plant height, mean tiller weight, percentage dry matter, HDMY, leaf area index and crop growth rate were higher, but tiller number and percentage leaf blade were lower than in those cut at a 60-day interval. In the plants cut at a 0-cm height, mean tiller weight, HDMY, crop growth rate and net assimilation rate tended to be higher, but plant height, tiller number and percentage leaf blade were lower than in those cut at a 30-cm height, and percentage dry matter and leaf area index were not responsive to the cutting height. HDMY in the aftermath decreased at the second and third cutting times and was lower when cut at a 30-cm height than at a 0-cm height at both cutting intervals in all species, except for pearl millet that had a limited number of tillers at the final cutting at a 0-cm height (data not shown). Most of the tillers whose shoot apices remained as stubbles after cutting, regrew rapidly whereas the cutting at a 0-cm height at a 90-day interval possibly removed the shoot apices of many tillers. Since many new tillers appeared from the nodes below a 30-cm height in all species, regrowth was less variable in the plants cut at a 30-cm height.

Table 4 shows the correlation coefficients of HDMY with each plant character and cutting interval. The HDMY positively correlated with plant height, mean

Table 3. Annual mean in plant characters¹⁾ in four *Pennisetum* species grown by cutting at different intervals and different heights.

Cutting interval	Species ²⁾	Cutting height	PH (cm)	TN (No. m ⁻²)	MTW (g tiller ⁻¹)	PLB (%)	PDM (%)	HDMY (g m ⁻²)	LAI	CGR (g m ⁻² d ⁻¹)	NAR (g m ⁻² d ⁻¹)
90-day	Na	0-cm	232	29	51.3	33.3	18.4	1360	7.6	13.4	1.8
		30-cm	237	32	38.6	40.1	18.2	1066	6.9	10.6	1.6
	Kg	0-cm	252	27	58.6	34.0	18.1	1484	7.5	14.6	1.9
		30-cm	251	34	45.4	40.8	17.9	1332	8.4	13.1	1.5
	Hn	0-cm	221	75	28.3	26.1	21.5	1392	6.9	15.6	2.3
		30-cm	220	76	20.6	35.1	16.6	1060	7.5	11.8	1.5
	Pm	0-cm	134	36	18.8	18.1	20.3	732	2.5	6.5	3.8
		30-cm	149	52	14.6	17.9	30.5	606	2.3	5.5	3.0
60-day	Na	0-cm	153	48	16.0	48.1	14.3	582	4.1	8.6	2.0
		30-cm	166	73	11.4	62.0	15.1	446	4.4	6.7	1.4
	Kg	0-cm	167	62	16.1	47.6	13.9	636	4.9	9.5	1.8
		30-cm	170	79	12.0	62.1	14.7	499	4.4	7.4	1.6
	Hn	0-cm	121	121	11.2	49.7	13.0	652	5.9	11.2	1.8
		30-cm	134	126	8.4	63.0	12.8	500	5.2	8.6	1.4
	Pm	0-cm	98	44	7.7	39.3	16.6	368	3.2	4.9	2.4
		30-cm	132	76	6.1	34.0	21.9	373	3.3	5.6	2.4

1) PH: plant height, TN: tiller number, MTW: mean tiller weight, PLB: percentage leaf blade, PDM: percentage dry matter, HDMY: herbage dry matter yield, LAI: leaf area index, CGR: crop growth rate, NAR: net assimilation rate.

2) Na: Napiergrass, Kg: Kinggrass, Hn: Hybrid napiergrass, Pm: Pearl millet.

Table 4. Correlation coefficients between herbage dry matter yield (HDMY) and each plant character¹⁾ in four *Pennisetum* species.

Species	PH	TN	MTW	PLB	PDM	LAI	CGR	NAR	CI
Na	0.891** ²⁾	-0.729*	0.956**	-0.878**	0.749*	0.852**	0.904**	0.476	0.853**
Kg	0.938**	-0.761*	0.979**	-0.850**	0.693*	0.868**	0.924**	0.570	0.896**
Hn	0.917**	-0.853**	0.915**	-0.905**	0.362	0.838**	0.915**	0.686*	0.530
Pm	0.919**	-0.249	0.971**	-0.041	0.050	0.733*	0.908**	-0.561	0.737*

1) CI: Cutting interval. As for PH, TN, MTW, PLB, PDM, LAI, CGR, and NAR, refer to Table 3.

2) **, *: Significant at 1% and 5% level, respectively.

tiller weight, leaf area index, crop growth rate and cutting interval, but negatively correlated with tiller number and percentage leaf blade, among all plants (4 species) cut at different intervals and heights, except for pearl millet.

The relationship between leaf area index and crop growth rate was positive and linear among the plants cut differently in each species (Fig. 1). The regression coefficient (=slope) in this relationship was the highest in hybrid napiergrass (2.48) followed by napiergrass (2.03), kinggrass (1.74) and was the lowest in pearl millet (1.26). This suggests that the dry matter productivity was increased more efficiently by expansion of leaf area in hybrid napiergrass than in other species.

4. Overwintering ability

The percentage overwintered plants was the highest in kinggrass followed by napiergrass and

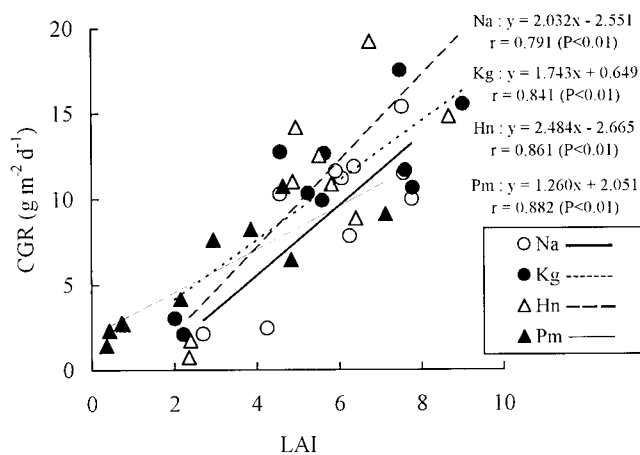


Fig. 1. Relationships between leaf area index (LAI) and crop growth rate (CGR) in four *Pennisetum* species. Data of all plants cut at 60- and 90-day intervals at 0- and 30-cm heights are included. Species: Napiergrass (Na), Kinggrass (Kg), Hybrid napiergrass (Hn), Pearl millet (Pm).

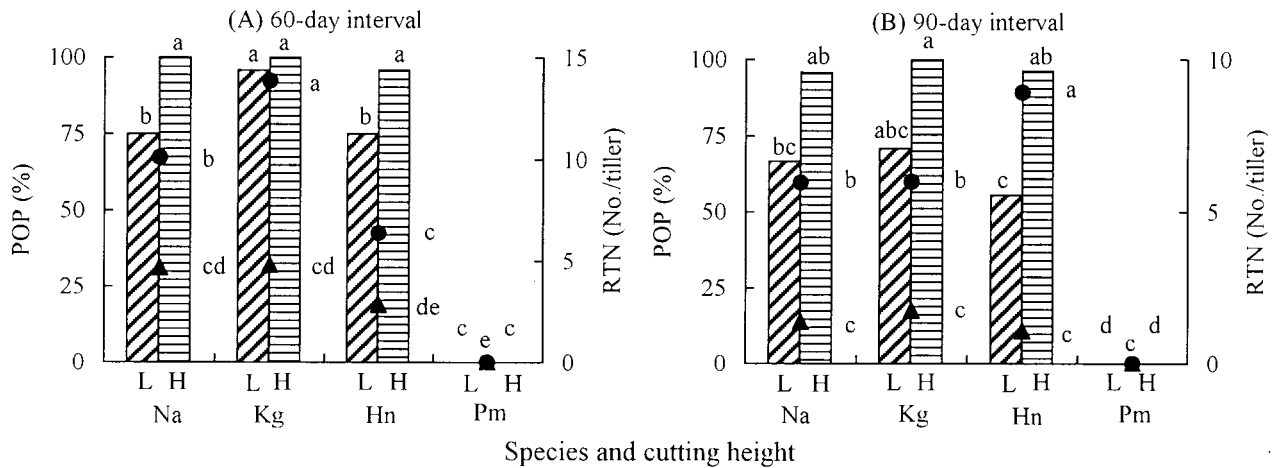


Fig. 2. Percentage overwintered plants (POP) and number of regrown tillers per plant (RTN) in the overwintered plants when grown by cutting at a 60-day interval (A) and 90-day interval (B) observed in napiergrass, kinggrass and pearl millet on May 3, 2002 and in hybrid napiergrass on April 23, 2003. POP: Cut at 0-cm height (L, ▨) and 30-cm height (H, ▩). RTN: Cut at 0-cm height (L, ▲) and 30-cm height (H, ●). Symbols with different letters of a, b, c, d and e denote the significant difference among cutting practices at 5% level.

Table 5. Stubble tiller number (STN), node number in subterranean stem (NN), tiller-bud number (TBN) and percentage of tiller bud (TBN/NN, TBN/STN) as affected by cutting height in three *Pennisetum* species at a 60-day interval in the mid-December, 2002.

Species ¹⁾	Na		Kg		Hn	
	L	H	L	H	L	H
STN (No. plant ⁻¹)	18.33 ^{ns3)}	14.33 ^{ns}	15.33 ^{ns}	15.33 ^{ns}	17.67 ^{ns}	11.67 ^{ns}
NN (No. plant ⁻¹)	155 ^{ns}	129.33 ^{ns}	126.33 ^{ns}	122.67 ^{ns}	117.67 ^{ns}	82.33 ^{ns}
NN/STN (No. tiller ⁻¹)	8.43 ^a	9.12 ^a	8.41 ^a	8.19 ^{ab}	6.63 ^c	7.02 ^{bc}
TBN (No. plant ⁻¹)	8.0 ^{ns}	16.7 ^{ns}	6.7 ^{ns}	16.7 ^{ns}	11.0 ^{ns}	10.0 ^{ns}
TBN/NN (%)	5.2 ^{bc}	13.2 ^a	4.9 ^c	13.9 ^a	8.6 ^{abc}	11.7 ^{ab}
TBN/STN (%)	43.7 ^β	122.81 ^α	41.4 ^β	114.07 ^α	59.82 ^β	83.1 ^{αβ}

1) Na: Napiergrass, Kg: Kinggrass, Hn: Hybrid napiergrass.

2) L: 0-cm height, H: 30-cm height.

3) Figures with different letters of a, b, c and α , β denote the significant difference among species and cutting heights at 5% and 10% levels, respectively. ns: not significant ($P > 0.10$).

hybrid napiergrass and was nil in pearl millet due to its annuality, irrespective of the cutting interval and cutting height (Fig. 2). It was higher in the plants cut at a 30-cm height than at a 0-cm height. The number of regrown tillers was higher in the plants cut at a 60-day interval than at a 90-day interval in all species except for hybrid napiergrass cut at a 30-cm height (Fig. 2). The percentage overwintered plants was unaffected by the cutting interval, when cut at a 30-cm height. Thus, the highest percentage overwintered plant with highest number of regrown tillers was attained by cutting at a 60-day interval at a 30-cm height in napiergrass, kinggrass and hybrid napiergrass, although the number of regrown tillers in hybrid napiergrass cut at a 90-day interval at a

30-cm height was also high. The number of regrown tillers significantly and positively correlated with the percentage overwintered plants ($r = 0.808$, $P < 0.01$) among the plants cut at different intervals and heights, in napiergrass, kinggrass and hybrid napiergrass (Fig. 2).

5. Tiller-bud turnover before wintering season

Effect of cutting height on tiller-bud turnover was determined in mid-December only for the plants cut at a 60-day interval in napiergrass, kinggrass and hybrid napiergrass (Table 5), since both the percentage overwintered plants and number of regrown tillers tended to be higher in the plants cut at a 60-day interval than at a 90-day interval, and the effect of

cutting height on these overwintered characters was more marked than that of cutting interval.

Both stubble tiller number and node number in the subterranean stem tended to be lower in the plants cut at a 30-cm height in napiergrass and hybrid napiergrass, and were unaffected by the cutting height in kinggrass. However, tiller-bud number in the subterranean stem, number of tiller buds per node in the subterranean stem and that per stubble tiller were uniformly higher in the plants cut at a 30-cm height than at a 0-cm height in all 3 species (Table 5).

There was a significantly positive correlation between tiller-bud number and number of regrown tillers in the plants cut at a 60-day interval ($r = 0.834$, $P < 0.05$) (Fig. 3.). The number of tiller buds per node and that per stubble tiller also showed a significant positive correlation with number of regrown tillers ($r = 0.788$, $P < 0.10$ and $r = 0.857$, $P < 0.05$, respectively) in the

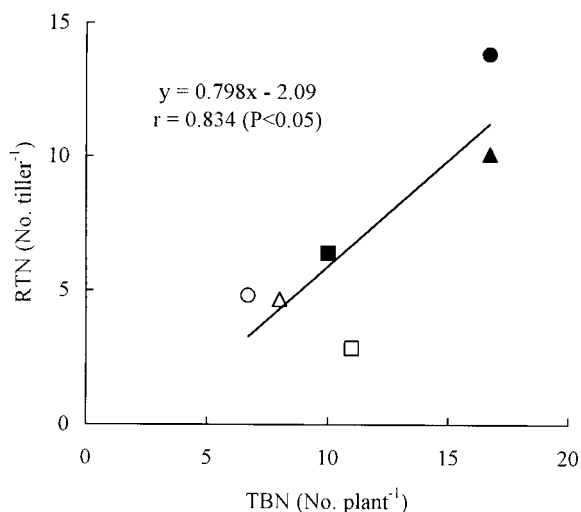


Fig. 3. Relationship between tiller-bud number (TBN) and number of regrown tillers per plant (RTN) in *Pennisetum* species grown by cutting at a 60-day interval. Cut at 30-cm height: Napiergrass (▲), Kinggrass (●), Hybrid napiergrass (■). Cut at 0-cm height: Napiergrass (△), Kinggrass (○), Hybrid napiergrass (□).

plants cut at a 60-day interval.

6. Storage carbohydrate concentration in the subterranean stem of stubble tillers and its relationship to overwintering ability

The concentrations of starch, total sugars and TNC in mid-December were higher in the plants cut at a 30-cm height than at a 0-cm height, in napiergrass and hybrid napiergrass, although they did not vary with the cutting height in kinggrass. Thus, the concentrations in the plants cut at a 30-cm height were higher in napiergrass and hybrid napiergrass than in kinggrass. The dry matter weight of the subterranean stem did not correlate with TNC concentration in 3 species (Table 6).

There was a positive correlation between the TNC concentration and the percentage overwintered plants ($r = 0.986$, $P < 0.05$) in napiergrass and hybrid napiergrass, but in kinggrass the percentage overwintered plants was high enough irrespective of TNC concentration. This relationship indicated that the plants with a high TNC concentration would have a large number of tiller buds per node before the wintering season in napiergrass and hybrid napiergrass.

Discussion

1. Effect of reciprocal crossing between napiergrass and pearl millet on herbage dry matter yield

This experiment showed the effect of reciprocal crossing between napiergrass (*Pennisetum purpureum*) and pearl millet (*P. thypoides*) on HDMY, since the crossing between napiergrass and pearl millet produced kinggrass and the reciprocal crossing between pearl millet and napiergrass produced hybrid napiergrass.

HDMY in napiergrass was increased by the crossing with pearl millet and the HDMY was higher in kinggrass than in hybrid napiergrass (Table 1). The effects of cutting interval and cutting height on annual HDMY were similar in napiergrass, kinggrass and

Table 6. Concentrations of starch, total sugars and total nonstructural carbohydrate (TNC) and dry matter weight (DMW) in the subterranean stem in three *Pennisetum* species in mid-December 2002.

Species ¹⁾	Na		Kg		Hn	
	L	H	L	H	L	H
Starch (%)	3.12 ^{h3)}	3.77 ^b	2.94 ^b	3.58 ^b	2.24 ^b	5.67 ^a
Total sugars (%)	11.6 ^b	18.3 ^a	13.4 ^b	11.6 ^b	13.0 ^b	16.6 ^a
TNC (%)	14.7 ^b	22.0 ^a	16.4 ^b	15.2 ^b	15.2 ^b	22.3 ^a
DMW (g plant ⁻¹)	78.3 ^{ns}	65.1 ^{ns}	58.4 ^{ns}	63.1 ^{ns}	57.1 ^{ns}	34.8 ^{ns}

1) Na: Napiergrass, Kg: Kinggrass, Hn: Hybrid napiergrass.

2) L: 0-cm height, H: 30-cm height.

3) Figures with different letters denote the significant difference among species and cutting heights at 5% level. ns: not significant ($P > 0.10$).

hybrid napiergrass, but extremely low in pearl millet, as shown by the lowest CV in HDMY.

In banagrass which was produced by the same crossing as kinggrass, annual HDMY of the plants cut at a 40-day interval was 23 t ha⁻¹ in Nigeria (Chheda et al., 1973) and 24-26 t ha⁻¹ under irrigation in Pretoria, South Africa (Koster et al., 1992). Annual HDMY of kinggrass was also reported to be 10-19 t ha⁻¹ when cut at 4- or 14-week intervals in Indonesia (Reksohadiprodjo, 1994) and be 21 t ha⁻¹ when cut at a 6-week interval in Gainesville, Florida (Schank et al., 1993). The yielding data for kinggrass in the present study (15.0-29.7 t ha⁻¹) were almost in the same range as in these previous data for banagrass and kinggrass.

In the hybrid napiergrass, annual HDMY was higher than that in Krish (*Sorghum* sp.), *S. almum* cv. Crooble and pearl millet, and this hybrid napiergrass had superior plant characters such as disease resistance, high percentage of leaf blade to whole harvested plant, high nitrogen content in the stem and high stem digestibility compared to other *Sorghum* species and pearl millet grown by cutting at 8-, 10-, 12- and 15-week intervals at Lawes, Australia (Pritchard, 1971). The annual HDMY was higher in the plants cut at a 2-month interval than in those cut at a 1- or 1.5-month interval in hybrid napiergrass in Thailand, and was 11-18 t ha⁻¹ and 20-25 t ha⁻¹ under the dry and irrigated condition, respectively (Nern-Urai, 1968). The annual HDMY in hybrid napiergrass cut at a 6-week interval in Gainesville, Florida, was 17 t ha⁻¹ (Schank et al., 1993). These yield data were consistent with the annual HDMY in the plants cut at a 60-day interval (15.0-19.6 t ha⁻¹) in the present study. However, in the tropics, the annual HDMY in hybrid napiergrass was as high as 50 t ha⁻¹ when grown without stress management for cutting four times at a 50-day interval in Bet-Dagan, Israel (Kipnis et al., 1985), and was 43 t ha⁻¹ when grown by cutting at a 1-month interval throughout the year in Sri Lanka (Appadurai and Goonewardene, 1974).

2. Effects of cutting interval and cutting height on herbage dry matter yield and percentage dry matter

The CV in HDMY among 4 different cutting practices was 34% in napiergrass and 30% in kinggrass, but it was 25% in hybrid napiergrass and only 14% in pearl millet as shown in Table 1. The high CV suggested a high response of HDMY to the method of cutting. On the other hand, the low CV in pearl millet was derived from the inferior regrowth and possibly from the early heading in autumn (Table 3).

The CV of percentage dry matter in the plants cut by 4 different methods was the highest in pearl millet (35%) followed by hybrid napiergrass (17.5%), and was about 14% in kinggrass and napiergrass. Although the high CV of percentage dry matter in pearl millet was partly due to the frost damage at the third cutting

at a 60-day interval before wintering season, pearl millet and hybrid napiergrass also had a higher percentage dry matter in the plants cut at a 90-day interval than at a 60-day interval. The flexible increase in percentage dry matter was principally derived from the drop in water content of stem by hardening during stem elongation in pearl millet and hybrid napiergrass, which was directly related with the annual habit of pearl millet. The drop in water content or increase in percentage dry matter, caused by stem-hardening decreased the digestibility and palatability of stem at maturity in pearl millet and hybrid napiergrass (Schank et al., 1993).

3. Plant characters that determined herbage dry matter yield under different cutting practices

HDMY was positively correlated with plant height, mean tiller weight, leaf area index, crop growth rate and cutting interval and negatively with tiller number and percentage of leaf blade to whole harvested plant, except for pearl millet. HDMY is calculated by several ways; For example, as the product of tiller number with mean tiller weight, and the product of cutting interval with crop growth rate that is equal to the product of leaf area index with net assimilation rate. Thus, the change in HDMY was closely correlated with that in mean tiller weight, that in cutting interval and leaf area index in the 4 *Pennisetum* species. However, the change in net assimilation rate did not closely correlate with that in HDMY and the increase in HDMY often led to a decrease in percentage leaf blade. Since heading reduced tiller number and leaf production especially at the second and third cuttings in the plants cut at a 90-day and 60-day interval, respectively when HDMY was quite low in pearl millet, HDMY were significantly correlated neither with tiller number nor percentage leaf blade in pearl millet.

4. Effects of cutting practices on tiller-bud turnover and overwintering ability in each species

Since the percentage overwintered plants was not significantly influenced by the cutting interval, relationships between tiller-bud turnover and overwintering ability were examined in the plants cut at a 60-day interval. Both stubble tiller number per plant and node number in the subterranean stem of the stubble tiller per plant tended to be higher in the plants cut at a 0-cm height in napiergrass and hybrid napiergrass, and were similar in the plants cut at a 0-cm and 30-cm height in kinggrass (Table 5). At the time of cutting in November, tiller number in the plants cut at a 30-cm height was 1.4-1.9 times higher than that in the plants cut at a 0-cm height in both napiergrass and kinggrass. However, most of the tillers developed from the node above the ground surface and stubble tiller number after cutting tended to be lower in the plants cut at a 30-cm height than at a 0-cm

height in napiergrass and hybrid napiergrass (Table 5).

The number of tiller buds per plant tended to be higher in the plants cut at a 30-cm height in napiergrass and kinggrass, and was similar in the plants cut at a 30-cm and 0-cm height in hybrid napiergrass. Both the numbers of tiller buds per node and those per stubble tiller were always higher in the plants cut at a 30-cm height than at a 0-cm height in all 3 species (Table 5). In napiergrass cv. Merkeron, cutting at a high position in November led to a high percentage of surviving tiller buds in the next May after overwintering (Ishii et al., 1995).

5. Relationship between storage carbohydrate and overwintering ability

TNC is considered as the source of energy and structural components for winter survival, regrowth after cutting and spring regrowth. Thus, a high TNC concentration may be beneficial to the tiller buds under a low temperature condition and may promote the capacity of spring regrowth (Kobayashi and Nishimura, 1978). Cutting at a high position was beneficial for securing the high TNC concentration as shown in napiergrass and hybrid napiergrass (Table 6). In several tropical grasses, the suppression of growth in autumn increased the TNC concentration in the stem during winter, and increased their winter survival and spring regrowth compared with the non-suppressed tropical grasses (Ito et al., 1985). There was a negative correlation ($r = -0.586$, $P > 0.10$) between HDMY at the third cutting before the winter season and TNC concentration in the plants cut at a 60-day interval in 3 *Pennisetum* species. This was partly supported by the hypothesis mentioned above.

In conclusion, dry matter productivity was higher in the plants cut at a 90-day interval than in those cut at a 60-day interval, and cutting at a 0-cm height sometimes reduced the annual HDMY and overwintering ability, especially in the plants cut at a 90-day interval. The interspecific hybrids, kinggrass and hybrid napiergrass, had higher HDMY than their parents in the first established year.

The increases in plant height, mean tiller weight, leaf area index and crop growth rate were correlated with the increase in HDMY, and variation in annual HDMY among 4 species was reduced by cutting at a 30-cm height at a 60-day interval.

Thus, the combination of high HDMY and good overwintering ability was attained by cutting at a 90-day interval at a 30-cm height in all *Pennisetum* species except for pearl millet.

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* In Japanese with English summary.

** In Japanese only.