パニカム属6品種における生育の季節的変化と越冬性との関係

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Seasonal Changes in Growth and their Relations with Overwintering in Six Varieties of *Panicum*

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Synopsis

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The growth characteristics before winter and their relations to overwintering were investigated from July, 1995 to May, 1996, using 6 varieties in *Panicum maximum* and *P. coloratum* grown in the field, for clarifying their variations in cold-tolerance and assisting genetic improvement for overwintering ability.

Before winter, there were quite different changes among 6 varieties in the total number of living tillers, which increased steadily in Makarikari, while decreased gradually in the others of *P. coloratum*, i.e. Tayutaka and Tamidori, and did rapidly in 3 varieties of *P. maximum*, i.e. Natsukaze, Green panic and Gatton. The number of living vegetative tillers (VTs) was the highest and the percentage of number of reproductive tillers to the total number of living tillers (Prt) was the lowest in Makarikari. Percentage of regrown plants, i.e. the percentage of the number of plants with new regrown tiller (s) to all of the plants in spring (PRplant) was the highest in Makarikari, followed by Tayutaka, Gatton and Green panic and nil in Natsukaze and Tamidori. The PRplant was correlated positively with the number of VTs and negatively with the Prt from late October to late December, but was not significantly correlated with plant dry weight. In conclusion, the variety with a high overwintering ability in the genus *Panicum* has the characteristics of the greater number of VTs before winter, and has the higher ratio of living tiller buds on VTs.

Key words : Living tiller bud, Overwintering, *Panicum coloratum, Panicum maximum*, Reproductive tiller, Vegetative tiller.

Introduction

The species of *Panicum maximum* and *P. coloratum* within the genus *Panicum* are promising grazing and fodder grasses in tropical and subtropical areas[1]. They are native to Africa. By accompanying with some other genera of tropical grasses, those two species of *Panicum* were introduced into the southern Kyushu island in Japan about 30 years ago[4,11]. Many researches on their breeding, cultivation, grassland development and management have been accumulated since 1970's[4,6,11-13]. Some new and highly productive varieties such as Natsukaze of *P. maximum* and Tayutaka of *P. coloratum* have been raised for summer fodder grasses in the southwestern Japan. In general, the tropical grasses grown in the temperate zone are sensitive to low temperature and difficult to regrow after winter. This is one of major causes of impediment to the cultivation of tropical grasses in the southwestern Japan[5-7,13]. Thus, it should be very important to solve the problem on overwintering of tropical grasses for further popularization, and to aim at reducing the cost of forage production and at achieving the sustainable animal husbandry. Since there have been found for a great genetic variations among *P. maximum* and *P. coloratum* in the environmental response[1-3,8,16], and their varietal differences in the capability of winter survival and cold resistance, which have been researched in a winter at the National Grassland Research Institute in Tochigi prefecture of Japan[13], there remains the possibility to select and develop a new variety with both high productivity and strong cold-tolerance in the southwestern Japan. For realizing those possibilities, this study was carried out to obtain the primary information on the growth characteristics from summer to the next spring and the situation of overwintering in the southwestern Japan, and their relations by using 6 varieties belonging to 2 species, *P. maximum* and *P. coloratum*.

Materials and Methods

1. Plant culture

Three varieties in *P. maximum*, i.e. Natsukaze (Designated as NAT, raised by Kyushu National Agricultural Experiment Station and a commercial variety in the southwestern Japan[12]), Gatton (GAT, an intermediate type[1]) and a variety introduced from Australia) and Green panic (GRP, a small type[1,16]) and a commercial variety in the southwestern Japan), and 3 in *P. coloratum*, i.e. Makarikari grass (MAK, a distinctive type[1,9]) and named as var. *makarikariense*), Tayutaka (TYT, named as var. *kabulabula*, a new released variety raised by and the seeds were supplied by Aichi Prefectural Agricultural Research Center) and Tamidori (TMD, named as Coloured guineagrass) were examined. Seeds were sown in the glasshouse on May 9 and seedlings were transplanted into the field of the Sumiyoshi ranch, Miyazaki University on June 17, 1995.

The plot size was 5.5 m×5.5 m per variety with a density of 16 plants m^{-2}. The plots were supplied with 200 g m^{-2} of slaked lime and 450 g m^{-2} of fermented manure as the basal dressing. The chemical fertilizer, which contained equal amount of N, P_2O_5 and K_2O were supplied at the element rates of 1 g m^{-2} at one week after transplanting and of 6 g m^{-2} once per month from July 27 till the end of October. All plants were cut at 7 cm above ground level on August 29. Experiments were conducted till spring in 1996.

2. Plant growth characteristics

The samplings for plant growth characteristics were conducted in 6 plants of each variety almost every month from late July to late December, i.e. July 27, August 29, September 29, October 27, November 23 and December 24, in 1995. At each sampling, the tillers were divided into living and dead ones. When whole of the aerial parts in a tiller withered, i.e. all of leaves and the whole of stem became to be greenless, that tiller was considered as dead one. The number of vegetative tillers (VTs), and stem-elongating and heading tillers (regarded as reproductive tillers (RTs)) in living tillers were measured. Each tiller was oven-dried at 70℃ for 72 hr and weighed.

The vitality of tiller buds on the underground parts of stem was judged by the TTC (2, 3, 5-triphenyl tetrazolium chloride) method[14]. The tillers grown before spring regrowth were tested in 3 plants of each variety on May 1. After counting the number of nodes and tiller buds, the underground parts of stem were immersed in 1% TTC solution at 37℃ for 24 hr. The reddish stained tiller buds were judged as living tiller buds.

3. Spring regrowth characteristics

The number of regrown tillers per plant and their dry weight were measured during the periods of rising air temperature from late February to early May, 1996. The percentage of the regrown plants (PRplant) was determined by the percentage of the number of the plants, which had one or more regrown tiller (s), to all of plants in the field on May 1, 1996.

Results

1. Climatic conditions

The climatic data of Miyazaki meteorological observatory during the experimental period are shown in Fig. 1. The data from the temperature recorder set in the experimental field were almost the same as those shown in Fig. 1.

The daily mean air temperatures in the period from July to October, and in November and December were about 2℃ higher and 1℃ lower in 1995 than in a normal year, respectively. Those in the period from January to March in 1996 were almost similar to those in a normal year, while about 2 to 3℃ lower than normal in April. During the experimental period except October of 1995 and January of 1996, the total solar radiation was higher by 1–2 MJ m^{-2} day^{-1} than that in a normal year.

After transplanting on June 17, the seedlings grew under a suitable climatic condition with enough amount of precipitation till early July. Both solar radiation and air temperature increased sharply from late June to late July. The high intensity of solar radiation and a steady high temperature continued till early September. The daily mean temperature decreased gradually from middle September to next early February and it kept below 10℃ from early December to early February. The first and the last frosted dates were November 30 and April 12, respectively, and the frosted days amounted to 16 throughout the season. Both the first and the last frost were later than in a normal year.

2. Changes in plant dry weight

The dry weight of plant (PDW, Fig. 2 A) increased under the high air temperature in summer (from July

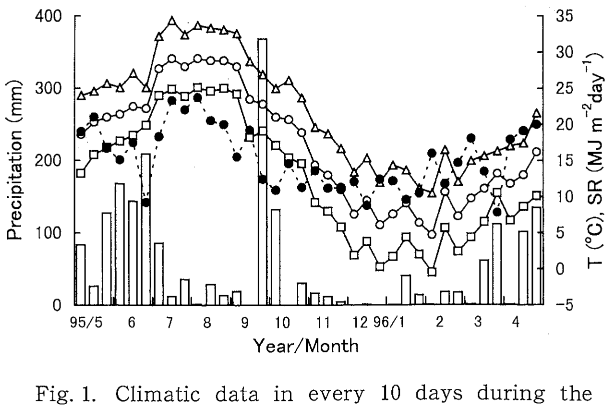

Fig. 1. Climatic data in every 10 days during the experimental period.
□ : precipitation ; —●— : mean of daily total solar radiation (SR) ; —○—, —△— and —□— indicate mean, maximum and minimum of the daily air temperatures (T), respectively.

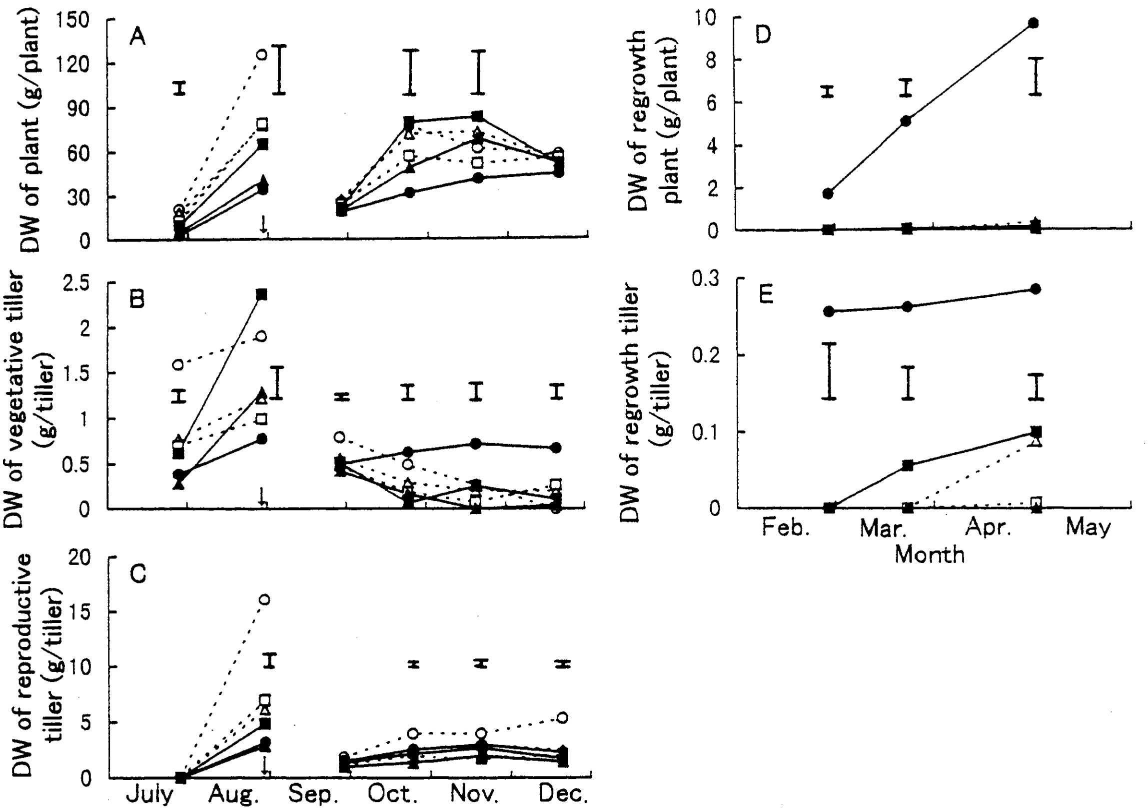

Fig. 2. Changes in dry weight (DW) of plant (A), vegetative tiller (B) and reproductive tiller (C) from late July to late December, and regrown plant (D) and regrown tiller (E) from late February to May.
Natsukaze (NAT, ○), Gatton (GAT, △), Green panic (GRP, □), Makarikari (MAK ●), Tamidori (TMD ▲), Tayutaka (TYT ■).
Inserted bars show LSD at 5% level at each date.
↓ denotes date of cutting.

27 to August 29) in all of varieties.

The PDW on August 29 was higher in 3 varieties of *P. maximum* than of *P. coloratum*. Especially, the PDW increased more rapidly and was significantly higher in NAT than in the others at the cutting. However, such distinct differences among varieties were not found from September to December, except MAK, which still showed smaller PDW than other varieties.

The PDW in all of varieties still increased from late September to late October, when the daily minimum air temperature declined below 15℃. After then, there was no further increase of PDW in *P. maximum* till late December, when the daily minimum air temperature declined constantly. On the contrary, the PDWs in TYT and TMD increased till late November, and moreover the PDW in MAK increased continuously from late September to late December.

The dry weight per vegetative tiller (DW-VT, Fig. 2B) in all of varieties increased in summer. However, the DW-VT in 5 varieties except MAK tended to decrease continuously during the period from late September to late December, and declined below 0.5 g after late October. The DW-VT in MAK did not decrease and was significantly higher than that in the others after late October. This result indicated that the VT of MAK grew continuously, even under the declining air temperature.

The dry weight per reproductive tiller (DW-RT, Fig. 2C) in NAT increased much more rapidly than in the others during late July to late August, and was significantly higher in NAT than in the others on August 29. The DW-RT of each variety during the period from late September to late December was appreciably lower and increasing rate was also smaller than in summer.

Aboveground plant parts withered completely in all of varieties in January. However, new regrown tillers in MAK were observed in late February (Fig. 2D). The spring regrown tillers in TYT, GAT and GRP were also observed from late March to May 1 (Fig. 2E). The dry weight of spring regrown tiller of MAK was the highest, followed by that of TYT, GAT and GRP (Fig. 2E). No spring regrowth was found at all in NAT and TMD.

3. Changes in tiller number and tiller composition

The number of total living tillers, number of VTs and the percentage of reproductive tillers to total number of living tillers (Prt) are shown in Fig. 3. The total number of living tillers in all of varieties in *P. maximum* decreased from late July to late August (Fig. 3 A). On the contrary, that in *P. coloratum* increased, especially in MAK. A great number of tillers were regrown within one month after cutting in 6 varieties. After then, the total number of living tillers declined continuously in all of varieties except MAK. The decreasing rate in TYT and TMD was relatively smaller than in *P. maximum* varieties with a little erratic fluctuation in late November. The total number of living tillers was higher in the varieties of *P. coloratum* than in those of *P. maximum* in late December. Only MAK increased continuously its number of living tillers from summer to winter. Eventually, the number of living tillers in late December was the highest in MAK and the lowest in NAT.

The reverse tendency in the number of VTs and Prt, i.e. the decrease in the number of VTs and increase in the Prt at the same period was observed in the varieties except MAK from July 27 to August 29 and from September 29 to October 27, when such tendencies appeared to be the most significant (Fig. 3 B and 3 C). This was resulted from the rapid conversion of VT to RT in those 5 varieties. On the contrary, the number of VTs in MAK increased constantly from summer to winter, accompanying with the relatively stable Prt since late September. The marked differences both in the number of VTs and in the Prt were observed between MAK and the other 5 varieties after cutting. The Prt was significantly much higher in MAK than in the others in late September, while the case was reversed from late October to late December.

The decrease in total number of living tillers in *P. maximum* from late July to late August may be caused by the withering of young VT under the rapid reproductive development, since the decreased number of VTs was more than the increased number of RTs. There also occurred the decrease in the total number of living tillers in all of the varieties except MAK from late September to late October, together with the rapid conversion of VT to RT. It was inferred that the young and small VTs could not get enough nutrient in competition with RTs.

Under the decreasing air temperature from late October to late December, the decreased numbers per plant in RTs were about 8, 5 and 2 in NAT, GAT and GRP, respectively, and those in VTs were 1.5, 3.5 and 6. From this result, it is considered that the decrease

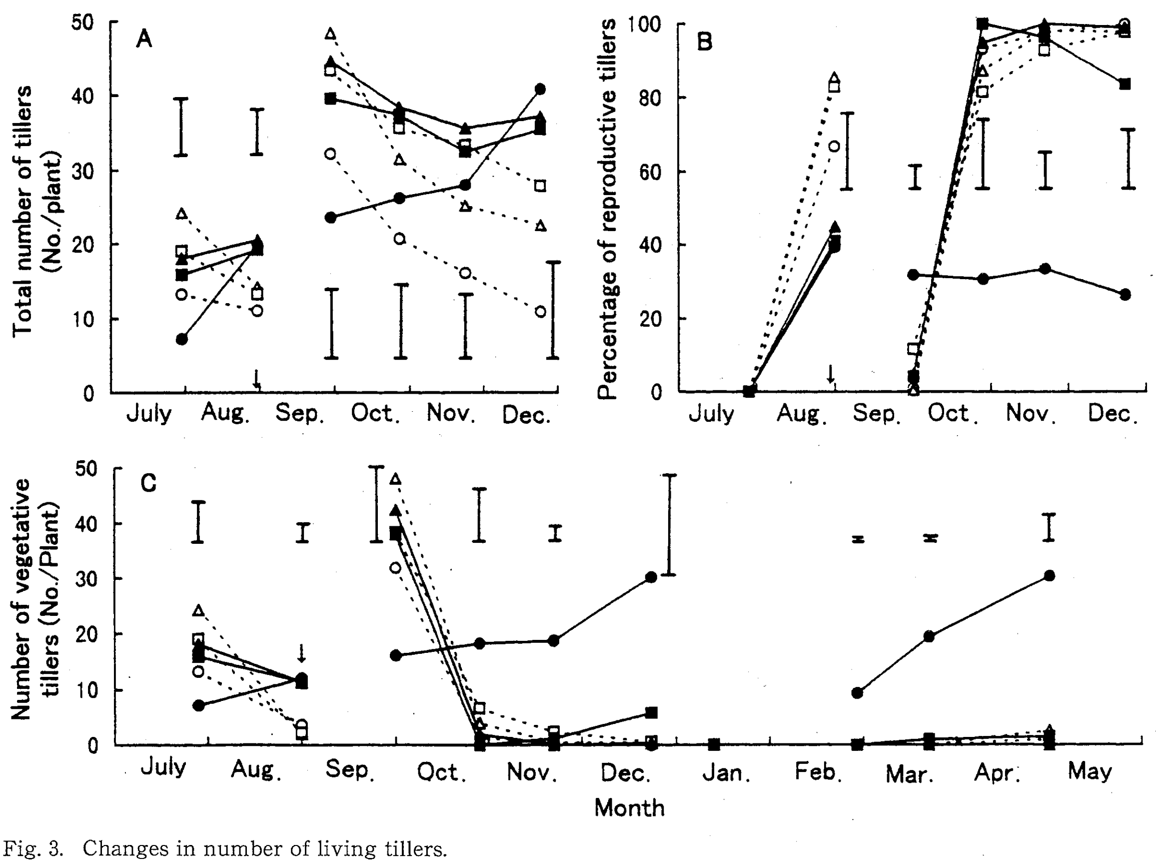

Fig. 3. Changes in number of living tillers.
A, total number of tillers ; B, the percentage of reproductive tillers ; C, the number of vegetative tillers. Symbols are the same as in Fig. 2.

in total number of living tillers in *P. maximum* in that period was due to the decreasing number of RTs and VTs influenced by the decreasing air temperature.

The changes in the number of living tillers showed that *P. maximum* was more sensitive to the low temperature than *P. coloratum*.

In addition, the number of regrown tillers was significantly higher in MAK than that in TYT, GAT and GRP in the next spring, and there were no regrown tillers in NAT and TMD (Fig. 3 C).

4. Overwintering and spring regrowth

The percentage of regrown plants (PRplant) on May 1, 1996 is shown in Table 1.

The MAK had the highest PRplant as much as nearly 90%, followed by TYT, GAT and GRP with the further lower percentage of about 20%, 10% and 6%, respectively.

The correlation analyses between PRplant in spring and some plant growth characteristics from September to December in 6 varieties are shown in Table 2 by using the varietal mean values.

The PRplant was not significantly correlated with PDW, the DW-RT and number of RTs at any sampling date. It seemed difficult to obtain some stable correlation of the PRplant with DW-VT and number of VT till late October. This was caused by the rapid conversions from VT to RT which occurred in all of the varieties except MAK from late September to late October, and this conversion of growth phase was almost completed in NAT and TMD with nil PRplant. Therefore, there were obtained for the significant positive correlation of PRplant with the number of VTs and DW-VTs, and negative correlation with Prt after late October.

Table 1. The percentage of regrown plant (PRplant) on May 1.

Variety[1)]	PRplant
NAT	0.00[e2)]
GAT	9.98[c]
GRP	5.20[d]
MAK	89.90[a]
TMD	0.00[e]
TYT	16.26[b]

1) As for the abbreviation of the variety, refer to the note of Fig. 2.

2) The values with the different letters denote significant difference at 5% level.

5. Winter survival of tiller buds

Table 3 shows the characteristics of tillers, nodes and tiller buds attached on the underground parts of stem, formed during the period from cutting on August 29 to the next May 1. All of the stubble tillers cut on the above date had completely decayed at the sampling on May 1.

Hereafter, the regrown tiller in spring was designated as new tiller, and the others were as old tillers, which were sub-divided into RT and VT. The MAK had the highest number of new tillers, VTs and the lowest Prt among 4 overwintered varieties.

There were no significant differences among 4 varieties in the number of nodes on the underground stem parts per RT, while that per VT was significantly higher in MAK than in the others.

The numbers of living tiller buds per plant both on VT and on RT were significantly much higher in MAK than those in the others. In addition, the percentage of the number of living tiller buds to total number of tiller buds was much higher on VT than that on RT. In other words, the winter survival was stronger in the tiller buds of VT than those of RT.

Discussion

In general, tropical grasses grow vigorously in summer and do hardly or quite slowly in winter, and some of them can not overwinter even in the lowland area of the southwestern Japan[7)]. It was suggested that the tropical grasses with the higher growth rate in summer exhibited the weaker cold tolerance in winter[10)]. We found, however, non-significant relations between the PRplant in spring and PDW at any

Table 2. Correlation coefficients between the percentage of regrown plant (PRplant) and some plant growth characteristics before winter for 6 varieties.

Sampling date	PDW	DW-RT	DW-VT	No. of VT	No. of RT	Prt
Sep. 29	−0.451	0.243	−0.203	−0.713	−0.752	0.923**
Oct. 27	−0.710	0.036	0.653	0.861*	−0.651	−0.946**
Nov. 23	−0.744	0.157	0.929**	0.976**	−0.590	−0.983**
Dec. 24	−0.651	−0.167	0.931**	0.995**	−0.353	−0.988**

PDW, DW-RT and DW-VT are abbreviations of dry weights of plant, reproductive tillers, and vegetative tillers, respectively.

No. of VT, No. of RT and Prt art abbreviations of number of vegetative tillers and reproductive tillers in plant, and percentage of reproductive tillers to total number of tillers, respectively.

* and ** indicate statistical significance at $P<0.05$ and 0.01, respectively. Data without * or ** mean non-significant.

Table 3. The characteristics of tillers, nodes and living tiller buds in underground stem parts in 4 varieties with spring regrowth on May 1, 1996.

Characteristics	Variety[1)]			
	GAT	GRP	MAK	TYT
No. of tillers per plant				
New tiller	2.67[b2)]	1.00[b]	30.33[a]	1.50[b]
Old tiller : Reproductive tiller	16.00[NS]	27.00[NS]	21.67[NS]	37.50[NS]
Vegetative tiller	5.00[b]	3.00[b]	15.67[a]	9.00[a]
Percentage of reproductive tillers	76.19[c]	90.00[a]	58.03[d]	80.65[b]
No. of nodes in underground parts of stem				
per reproductive tiller	6.02[NS]	5.41[NS]	6.41[NS]	5.09[NS]
per vegetative tiller	2.80[b]	3.33[b]	5.23[a]	1.78[b]
No. of living tiller buds per plant				
in reproductive tiller	0.43[b]	0.11[b]	14.67[a]	1.00[b]
in vegetative tiller	2.00[b]	1.00[b]	29.33[a]	3.08[b]
Percentage of living tiller buds to total number of tiller buds				
in plant	2.89[b]	1.22[b]	23.23[a]	2.26[b]
in reproductive tiller	0.59[bB]	0.12[cB]	14.00[aB]	0.61[bB]
in vegetative tiller	17.05[bA]	22.36[bA]	34.66[aA]	18.65[bA]

1) As for the abbreviation of the variety, refer to the note of Fig. 2.

2) The values within a line and within a column followed by different small letters and capitals, respectively, are significantly different at 5% level.

sampling date before winter in 6 varieties of *Panicum*, though the correlation coefficients between them were always negative. This suggested that the difference in PDW before overwintering should not be the primary factor in regulating the variant differences in cold-tolerance among the *Panicum* varieties examined in the present study. The same result was found in *Lolium perenne* L[15].

According to Tajima and Shimizu[13], Makarikari grass was one of *Panicum* grasses, which hardly survived in winter at Tochigi Prefecture. However, at Miyazaki, it has been observed that MAK has the highest ability of winter survival among 6 *Panicum* varieties in the present study. This difference in the overwintering ability of *P. coloratum* var. *makarikariense* might be caused by the difference in strain and/or environmental conditions.

From the fact that the survival ratio of the tiller buds per tiller in both VTs and RTs was the highest in MAK (Table 3) and this variety can produce VTs until later season than the other varieties (Fig. 3 C), it can be concluded that MAK had the highest cold tolerance among the varieties used in the present study. However, the survival ratio of the tiller buds was higher in VTs than in RTs even in MAK (Table 3). Therefore, the higher Prt or the fewer number of VTs in the plant before winter were the factors to lower the overwintering ability. The RTs wither inevitably and the tiller buds on them will die incidentally. The ratio of numbers of the withering tillers to total number of VTs will be determined by the temperature- and cold-tolerance of the varieties. Moreover, the cold tolerance of the VT might be affected by the growth level of the tiller.

Numaguchi[10] pointed that the plant with many VTs which contained high number of leaves before winter had strong cold tolerance in dallisgrass and indicated the importance for maintaining this grass to produce VTs enough matured before frosting to overcome the winter damage. In this study, all of the varieties except MAK almost terminated their vegetative growth with the progress of autumn season. The VTs almost disappeared by the conversion of VTs to RTs and by the minimum new production of VTs with the decrease of air temperature after late October. On the contrary, the early reproductive type, MAK[6], increased continuously its DW-VT and the number of VTs, even under the lower temperature. The differences in the tiller composition and the DW-VT before winter were coincided with the differences in overwintering ability among varieties of *Panicum*.

As for RTs, it can be also presumed that the younger ones might die earlier than old ones under low temperature. If this consumption is true, the heading of many tillers in the late autumn as seen in *P. maximum* is one of the factors to lower the overwintering ability. The effect of growth phase of tiller on the overwintering should be investigated hereafter.

According to Bogdan[1], both *P. maximum* Jacq. and *P. coloratum* L. are perennials. However, NAT with the highest Prt and the lowest capability of producing new tiller was more inclined to behave as annuals rather than as perennials, and showed the lowest overwintering ability. While MAK with the lowest Prt and the highest capability of continuously producing new tiller showed the highest overwintering ability among 6 varieties. This suggested that the varieties in the perennial species, *P. maximum* Jacq. and *P. coloratum* L. had the characteristics with the variant overwintering abilities which related to the growth characteristics of tillers in the southwestern Japan.

YAMASHITA *et al*[15] reported that tetraploids had a higher degree of winter survival compared to the diploids in temperate grass of *Lolium perenne* L. The research on the differences in winter survival among the varieties with different number of chromosomes in *Panicum* grasses is going to be carried out.

In this study, significant differences in growth characteristics of VT and RT and in the vitality of tiller buds, and their close relationship with cold-tolerance for overwintering among 6 *Panicum* varieties were cleared. In addition, the higher number of VTs before winter might be one of indexes for the selection and improvement of overwintering ability in *Panicum*, due to the significantly positive correlation between the number of regrown new tillers in spring and that of old vegetative tillers ($r=0.806$, $P<0.01$) among 4 overwintered varieties with 3 replication. It is necessary to make further investigations for the effects of variant growth situation in tiller composition before winter on the overwintering in different plants within each variety, for realizing these possibility in selection and improvement of *Panicum* grasses.

In conclusion, according to this study, the variety with a high overwintering ability in *Panicum* has the characteristics of the greater number of VTs before winter, and those VTs have the higher ratio of living tiller buds on the underground parts of stem. The higher number of VTs or the lower Prt before winter may be one of primary characteristics for enhancing the overwintering ability of varieties in *Panicum*.

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* : In Japanese with English summary.
** : In Japanese only. Translated title by the present authors.

要　　旨

蔡　慶生・伊藤浩司・続　栄治・村山盛一*・石井康之（1997）：パニカム属6品種における生育の季節的変化と越冬性との関係. *Grassland Science* **43**, 103-110. 宮崎大学農学部（889-21 宮崎市学園木花台西 1-1）*琉球大学農学部（903-01 沖縄県中頭郡西原町千原 1）

圃場栽培した *Panicum maximum* と *P. coloratum* 各3品種の越冬性を比較した。株の越冬率（全株数に対する越冬株数の比率）は

マカリカリが最も高く，次いで，タユタカ，ガットン，グリーンパニックの順であり，ナツカゼとタミドリは越冬しなかった。越冬率は，12月末までの乾物生産速度とは有意な相関がなく，10月から12月末までの生殖茎率とは有意な負の相関，栄養茎数とは有意な正の相関を示した。各分げつの地下節位分げつ芽の生存率は，12月末には生殖茎よりも栄養茎の方が著しく高かった。これらのことより，12月末において株当たりの栄養茎数の多いことは越冬性の高い品種の特性であると推察された。

キーワード：栄養茎，越冬性，カラードギニアグラス，ギニアグラス，生殖茎，生存分げつ芽.