Dry Matter Productivity and Overwintering Ability of the Dwarf and Normal Napiergrasses as Affected by the Planting Density and Cutting Frequency

Muhammad Mukhtar, Yasuyuki Ishii, Sayan Tudsri*, Sachiko Idota and Tatsunobu Sonoda

(Faculty of Agriculture, Miyazaki University, Miyazaki 889-2192, Japan; *Faculty of Agriculture, Kasetsart University, Bangkok 10903, Thailand)

Abstract: The effects of planting density and cutting frequency on dry matter productivity and overwintering ability were compared in the years following establishment among dwarf varieties (early-heading, DE and late-heading, DL) and normal varieties, Wruk wona (Wr) and Merkeron (Me), in the southern part of Kyushu, Japan. The planting densities examined were high (16 plants m\(^{-2}\), 25 cm \(\times\) 25 cm of spacing), medium (8 plants m\(^{-2}\), 50 cm \(\times\) 25 cm), and low (4 plants m\(^{-2}\), 50 cm \(\times\) 50 cm) for Wr, DE and DL, and was only medium for Me. The cutting frequency was three times at about 60-day intervals in 1999 and two times at about 90-day intervals in 2000. Irrespective of the planting density, dwarf varieties were higher in tiller number (TN), leaf area index (LAI) and dry weight percentage of leaf blade (PLB) than normal varieties, but lower in plant height (PLH), mean tiller dry matter weight (MTW) and total dry matter weight at all planting densities in both years. With the increase in planting density, TN and annual herbage dry matter yield (HDMY) increased. The annual HDMY was higher in 2000 (cut twice) than in 1999 (cut three times), and the difference in annual HDMY between the dwarf and normal varieties was reduced by planting at a high density and cut twice. This was due to higher MTW in dwarf varieties than in normal varieties at the higher TN conditions. The percentage of overwintered plant (POP) tended to be higher in DL than in other varieties and was higher in 2000 than in 2001 for all varieties, while it tended to decrease with the increase in planting density. Even though the dry matter productivity was higher in the normal varieties than in the dwarf varieties at any planting density and cutting frequency, DL tended to show a stable productivity with high PLB irrespective of planting density and cutting frequency. In addition, it had a high overwintering ability compared with the other varieties.

Key words: Cutting frequency, Dry matter productivity, Dwarf napiergrass, Normal napiergrass, Overwintering, Planting density.

Received 22 March 2002. Accepted 14 September 2002. Corresponding author: Y. Ishii (yishii@cc.miyazaki-u.ac.jp, fax +81-985-58-7251).

Abbreviations: HDMY, Herbage dry matter yield; MTW, mean tiller dry matter weight; PLB, percentage of leaf blade; POP, percentage of overwintered plant; TN, tiller number.
part under infrequent cutting. However, the low leaf blade/stem ratio is associated with low forage quality such as low digestibility and low crude protein content (Ishii et al., 1996b; Sunusi et al., 1997), which are observed commonly under infrequent cutting. Sollenberg and Jones (1989) showed that a dwarf napiergrass of “Mott” produced excellent forage yield under the continuous grazing management and achieved the live weight gain of nearly 1 kg day^{-1} for the beef cattle in Florida, USA, which was superior to the ordinary “Pensacola” bahiagrass. Thus, the relationship between DMY and ratio of leaf blade to stem should be examined in the dwarf and normal napiergrasses as affected by the cutting frequency. The annual DMY of napiergrass in the year of establishment differs from that in the following year. The DMY in the established year is used to increase the regrowth in the following year (Ito et al., 1988). The growth rate in the following year (regrowing from the stubble) is higher than that in the transplanted plant, if the overwintering percentage is sufficiently high. In this study, only the plants in the year after establishment were used, since the productivity of napiergrass in this region of southern Kyushu island is closely correlated with the overwintering ability (Ishii et al., 2000) as in some other tropical grasses (Cai et al., 1999).

The objective of this study was to examine the effects of planting density and cutting frequency on dry matter productivity in the years after establishment and overwintering ability in the dwarf and normal napiergrasses in the southern part of Kyushu, Japan.

Materials and Methods

1. Plant materials

The research was carried out at the Experimental field, Miyazaki University from May 1999 to April 2001. The examined varieties were two normal varieties, Wruk wona (Wr) and Merkeron (Me), and two dwarf varieties introduced from Thailand to Japan in 1996. Since the two dwarf varieties were definitely different in heading date, early-heading variety was termed DE and late-heading variety DL. DE was originally bred in Florida, USA and was brought to Dairy Promotion Organization (DPO) of Thailand by Dr. Vitoon (Head Professor from Florida. Therefore, DE was named as DLD line and DL DPO line. Normal variety of Me was a leading variety in Miyazaki and used as a check variety. Overwintered tillers of each variety were planted in May 1998, and the overwintered stubbles were used for the experiments in 1999 and 2000 except DE, which was established by planting overwintered tillers on May 5, 1999 and May 12, 2000 due to its low overwintering ability.

As a basal dressing, fermented cattle manure at 600 g m^{-2} and slaked lime at 400 g m^{-2} were applied in May, and 10 g of N, P_{2}O_{5} and K_{2}O m^{-2} of chemical compound fertilizer were applied as additional dressing three times in both 1999 and 2000. In May 2001, chemical characters of the soil at the top 5 cm layer were analyzed. The pH was measured with a pH meter (HM-7E, TOA Electronic Co. Ltd.), electric conductivity (EC) at soil: water = 1: 5 (v/v) with an EC meter (CM-40S, TDA Co. Ltd.) and chemical contents with a Dr. Soil kit (Fujihira Kougyou Co. Ltd.). The pH (H2O), pH (KCl at pH 7) and EC were measured at 7.4, 6.7, and 64.1 μS cm^{-2}, respectively, and NO3-N, NH4-N and available P2O5 contents were estimated to be 1, 5, and 15.8 mg in 100 g soil, respectively.

2. Experimental design

The experimental plots were arranged in a blocked design of Latin square method with three replications for each planting density. Each variety was planted at a high density (16 plants m^{-2}, 25 cm × 25 cm of spacing), medium density (8 plants m^{-2}, 50 cm × 25 cm), and low density (4 plants m^{-2}, 50 cm × 50 cm) except Me, which was planted only at the medium density. Plot sizes were 5 m² (2 m × 2.5 m), 7.5 m² (2.5 m × 3 m), and 12 m² (3 m × 4 m) for the high, medium and low density, respectively. The plants were cut three times at about 60-day intervals, on July 5, September 11 and November 23 in 1999, and two times at about 90-day intervals on July 31 and November 3 in 2000. The cutting height was 10 cm above the ground surface. The plots were harvested when Wr plants reached a height of about 2.0 m and about 2.5 m in 1999 and 2000, respectively.

3. Growth analysis

A single plant per replication (three replications for each density) was sampled and divided into herbage part, stubble part and underground part. The herbage part was cut at 10 cm above the ground surface, and measured for plant height (PLH), tiller number (TN), leaf area (LA) and dry matter weights (DMWs) of leaf blade (LB), stem with leaf sheath (ST) and dead parts (D).

The stubble part was cut at the ground surface, and measured for DMWs of LB, ST and D.

The underground part was measured for DMW of underground stem (UG) excluding roots.

Fresh and dry matter yields (FMY and DMY) were measured for five plants in each replication and three replications per variety.

4. Measurement of the overwintering ability

The overwintering ability was determined by the percentage of overwintered plants (POP), regrowing plant number (RPN) and regrowing tiller number (RTN) in all plants excluding border plants on May 1, 2000 and April 28, 2001. The POP was calculated by the number of plants that emerged one or more regrow-
Fig. 1. The mean air temperature (MT, ◦), solar radiation (SR, △) and precipitation (PRE, □) during the experimental period in 1999 (A) and 2000 (B).

5. Data analysis

The data were analyzed statistically by the analysis of variance and the difference in the mean value was calculated by the LSD method at 5% level.

Results

1. Climatic conditions

Figure 1 shows mean air temperature, solar radiation and precipitation during the growing period in 1999 and 2000 from the data of Miyazaki Meteorological Observatory. Mean air temperature and solar radiation were generally higher in 2000 than in 1999, except in July and August. Since the average precipitations in a normal year are 288 and 294 mm in July and August, respectively, the amount of rainfall was much larger, and mean air temperature and solar radiation were lower in July and August in 1999 than those in a normal year. In 2000, mean air temperature and solar radiation from late June to middle July were higher than in a normal year.

2. Growth characters and dry matter weight

The changes in growth characters and DMW with time were compared among normal (Wr and Me) and dwarf (DE and DL) varieties in the medium-density plot cut three times in 1999 (Fig. 2) and two times in 2000 (Fig. 3).

Plant height (PLH) was generally larger in normal varieties, Wr and Me, than in dwarf varieties, DE and DL in both years, except in November 2000 when DE and Wr had a similar PLH. Both the normal and dwarf varieties reached a maximum PLH in September and November in 1999 and 2000, respectively. Since the regrowth period from the first to the second cutting was longer in 2000 than in 1999, PLH in November 2000 reached almost 3 m in all varieties except DL. This indicated that normal varieties and DE elongated stems after reproductive organs initiated. The PLH in Wr tended to be larger in the low-density plots than in higher density plots. On the contrary, PLH in DL was less than 2 m, irrespective of planting density, which matched with the previous study for the uncut vegetative height in dwarf varieties (Sollenberg and Jones, 1989; Burton, 1989).

Tiller number (TN) was larger in dwarf varieties than in normal ones in both years, and TN at the first cutting was similar to that at the second cutting, while that at the third cutting in 1999 was higher. The TN was generally larger in 1999 (cut three cuttings) than in 2000 (cut twice), which was the same tendency as the reports of Hsu and Hong (1993) and Sunusi et al. (1997).

The mean tiller dry matter weight (MTW) was the heaviest in normal Wr, followed by Me, DE, and the lowest in DL at all cuttings in both years. It was the heaviest in September 1999 and November 2000 when PLH was the largest. In all varieties, total DMW at the second cutting was heavier than that at the first cutting in both years, but that at the third cutting in 1999 was lighter. The order of total DMW among varieties tended to vary with the cutting times in both years. It tended to be larger in normal varieties than in dwarf ones at the first cutting in both years, but the order reversed at the second cutting in 1999, and the difference in total DMW among varieties was small at the last cutting in both years.

Leaf area index (LAI) was generally higher in the dwarf varieties than in normal ones, except at the third cutting in 1999 and at the first cutting in 2000. In 1999, LAI tended to decrease by repeated cuttings except in DE, while LAI at the first cutting was similar to that at the second cutting in 2000. The LAI was larger at both cuttings in 2000 than at all cuttings in 1999 due to longer regrowth period.
The dry weight percentage of leaf blade (PLB) was also larger in the dwarf varieties than in the normal ones in both years, except for DE at the second cutting in both years. The PLB at the second cutting was lower than that at the third cutting in all varieties in both years, but that at the third cutting in 1999 was similar to that at the first cutting.

The effect of planting density on TN and MTW are shown in Table 1 (A) and (B), respectively. The TN increased with the increase in planting density in all varieties in both years, and was higher in dwarf varieties than in normal ones at any planting density. The MTW at all cuttings in 1999 and at the second cutting in 2000 tended to decrease with the increase in planting density, while it was unrelated to planting density at the first cutting in 2000. The MTW was the highest in Wr, followed by Me, DE and DL at all densities in both years. Thus, dwarf varieties, especially DL tended to emerge more tillers with less dry matter (MTW) than normal varieties. Since dry matter accumulates in the stem at a higher percentage than in the leaf blade in napiergrass (Ishii et al., 1996b), storage capacity in stem for dry matter was larger in normal varieties than in dwarf ones, except in the stem of DE elongated after the first cutting.

The relationships between MTW and TN at a medium density were analyzed in normal and dwarf varieties in 1999 and 2000. The relationships were negative and logarithmic in 1999 and linear in 2000 (Fig 4). The ratio of MTW to TN tended to be larger in dwarf varieties than in normal varieties when TN was above 100 tillers m$^{-2}$ in 1999 and above 40 tillers m$^{-2}$ in 2000.

3. Herbage yield

The annual total of herbage dry matter yield (HDMY), the cumulative HDMY at each cutting, and PLB in the herbage part at each cutting in 1999 and 2000 are shown in Fig. 5. The yield was higher in 2000 (cut twice) than in 1999 (cut three times) in all varieties. HDMYs were the highest in the second cutting, followed by the first cutting in both years and were the lowest in the third cutting in 1999 in all varieties. The present study indicated that the increase in cutting frequency (from two to three times) reduced the annual HDMY. The annual HDMY increased as planting density increased in all varieties in both years. The total annual HDMY was the highest in Wr, followed by Me, DE and DL in both years, while the difference in HDMY among varieties was the least at a high density under twice cutting in 2000.

PLB was slightly affected by planting density, except for DE at the first cutting in both years when PLB tended to increase with the increase in planting density. It was higher in dwarf varieties than in normal varieties at all cuttings in 1999 and tended to be higher in both
Fig. 1. Changes with time in plant height (PLH, A), tiller number (TN, B), total dry matter weight (TDMW, C), leaf area index (LAI, D), mean tiller DMW (MTW, E), and dry weight percentage of leaf blade (PLB, F) in the medium-density plot in 2000. Wruk wona (Wr, ○), Merkeron (Me, △), Dwarf-early (DE, ●), and Dwarf-late (DL, ▲). Arrows indicate the dates of cutting at 10 cm above the ground surface. Figures with different letters denote significant difference among varieties at the same cutting date at 5% level. ns: not significant.

Table 1. Tiller number (TN, A) and mean tiller weight (MTW, B) as affected by planting density in 1999 (cut three times) and in 2000 (cut twice).

| Cutting time | Variety | LD | MD | HD | LD | MD | HD | LD | MD | HD |
|--------------|---------|----|----|----|----|----|----|----|----|----|
| First        | Wr      | 50.40<sup>a</sup> | 64.96<sup>b</sup> | 75.68<sup>b</sup> | 21.88<sup>c</sup> | 32.07<sup>d</sup> | 37.28<sup>d</sup> | 21.88<sup>c</sup> | 32.07<sup>d</sup> | 37.28<sup>d</sup> |
|              | Me      | 89.60<sup>d</sup> | 89.60<sup>c</sup> | 89.60<sup>c</sup> | 57.64<sup>d</sup> | 57.64<sup>d</sup> | 57.64<sup>d</sup> | 57.64<sup>d</sup> | 57.64<sup>d</sup> | 57.64<sup>d</sup> |
|              | DE      | 61.88<sup>e</sup> | 117.56<sup>c</sup> | 136.48<sup>c</sup> | 49.34<sup>d</sup> | 62.95<sup>d</sup> | 81.13<sup>d</sup> | 49.34<sup>d</sup> | 62.95<sup>d</sup> | 81.13<sup>d</sup> |
|              | DL      | 90.92<sup>e</sup> | 129.60<sup>c</sup> | 161.12<sup>c</sup> | 81.33<sup>d</sup> | 68.38<sup>d</sup> | 98.08<sup>d</sup> | 81.33<sup>d</sup> | 68.38<sup>d</sup> | 98.08<sup>d</sup> |
| Second       | Wr      | 36.52<sup>a</sup> | 41.04<sup>c</sup> | 49.12<sup>c</sup> | 21.88<sup>c</sup> | 26.64<sup>d</sup> | 32.00<sup>d</sup> | 21.88<sup>c</sup> | 26.64<sup>d</sup> | 32.00<sup>d</sup> |
|              | Me      | 45.84<sup>d</sup> | 45.84<sup>d</sup> | 45.84<sup>d</sup> | 42.64<sup>d</sup> | 42.64<sup>d</sup> | 42.64<sup>d</sup> | 42.64<sup>d</sup> | 42.64<sup>d</sup> | 42.64<sup>d</sup> |
|              | DE      | 52.52<sup>a</sup> | 57.04<sup>c</sup> | 99.20<sup>b</sup> | 32.86<sup>d</sup> | 44.24<sup>d</sup> | 51.20<sup>d</sup> | 32.86<sup>d</sup> | 44.24<sup>d</sup> | 51.20<sup>d</sup> |
|              | DL      | 101.32<sup>e</sup> | 114.04<sup>c</sup> | 126.88<sup>c</sup> | 51.46<sup>d</sup> | 65.60<sup>d</sup> | 84.16<sup>c</sup> | 51.46<sup>d</sup> | 65.60<sup>d</sup> | 84.16<sup>c</sup> |
| Third        | Wr      | 114.40<sup>d</sup> | 142.00<sup>c</sup> | 147.20<sup>c</sup> | 51.46<sup>d</sup> | 65.60<sup>d</sup> | 84.16<sup>c</sup> | 51.46<sup>d</sup> | 65.60<sup>d</sup> | 84.16<sup>c</sup> |
|              | Me      | 122.64<sup>d</sup> | 122.64<sup>d</sup> | 122.64<sup>d</sup> | 122.64<sup>d</sup> | 122.64<sup>d</sup> | 122.64<sup>d</sup> | 122.64<sup>d</sup> | 122.64<sup>d</sup> | 122.64<sup>d</sup> |
|              | DE      | 248.55<sup>d</sup> | 389.60<sup>c</sup> | 426.72<sup>c</sup> | 44.24<sup>d</sup> | 44.24<sup>d</sup> | 44.24<sup>d</sup> | 44.24<sup>d</sup> | 44.24<sup>d</sup> | 44.24<sup>d</sup> |
|              | DL      | 194.12<sup>e</sup> | 267.64<sup>c</sup> | 328.48<sup>c</sup> | 44.24<sup>d</sup> | 44.24<sup>d</sup> | 44.24<sup>d</sup> | 44.24<sup>d</sup> | 44.24<sup>d</sup> | 44.24<sup>d</sup> |

1) Planting density: LD (4 plants m<sup>-2</sup>), MD (8 plants m<sup>-2</sup>), HD (16 plants m<sup>-2</sup>).
2) Values with different letters denote significant difference among different densities and varieties at 5% level.
3) Not determined.

The percentage of overwintered plants (POP), regrowing plant number (RPN) and regrowing tiller number (RTN) per m<sup>2</sup> at each planting density in both years are shown in Fig. 6. The POP was higher in DL and Me (above 80%) than in DE and Wr (below 60%) in 2000. POP in 2001 was lower than that in 2000 as a whole. It was the highest in Me (about 60%) followed by DL, Wr and DE (less than 40%) in 2001, and the POP in Wr at the low density was relatively high in both years. The POP tended to decrease with the increase in planting density, particularly in Wr.
Fig. 4. Relationships between tiller number (TN) and mean tiller dry matter weight (MTW) in the medium density plot in 1999 (A) and 2000 (B).

(A) Wr, Me: \( y = 92.90 - 18.94 \ln(x) \), \( R^2 = 0.948 \) (\( P < 0.01 \)), DE, DL: \( y = 101.4 - 19.82 \ln(x) \), \( R^2 = 0.958 \) (\( P < 0.01 \)).

(B) Wr, Me: \( y = 132.4 - 2.180x \), \( R^2 = 0.583 \) (\( P > 0.10 \)), DE, DL: \( y = 104.8 - 1.300x \), \( R^2 = 0.853 \) (\( P < 0.10 \)).

Fig. 5. Annual total of herbage dry matter yield (HDMY) and dry weight percentage of leaf blade (PLB) in 1999 (A) and 2000 (B).

Bar chart (HDMY): First-cut (□), second-cut (●), and third-cut (▲).

Dot chart (PLB): First (1st)-cut (○), second (2nd)-cut (●), and third (3rd)-cut (▲).

Density: H (16 plants m\(^{-2}\)), M (8 plants m\(^{-2}\)) and L (4 plants m\(^{-2}\)).

Figures with different letters on the bar and besides the bar denote significant difference in PLB and HDMY, respectively, among different densities and varieties at 5% level.

Both of RPN and RTN per m\(^2\) were the highest in Me, followed by DL, Wr and DE at all planting densities in both years, and tended to increase with the increase in planting density in both years.

**Discussion**

1. Effects of planting density and cutting frequency on dry matter yields

HDMY increased with the increase in planting density from 4 to 16 plants m\(^{-2}\) in this experiment. It was already reported in napiergrass that HDMY increased as planting density increased from 1.6 to 4 plants m\(^{-2}\) by Miyagi (1980), and from 4 to 8.2 plants m\(^{-2}\) by Ito et al. (1989). In this experiment, the range was expanded to 16 plants m\(^{-2}\). TN increased as planting density as the same as in Miyagi (1980) and Ito et al. (1989), while MTW tended to decrease as the planting density increased in all cuttings, except for the first cutting in 2000 (when MTW was not influenced by planting density).

The logarithm of DMY usually shows a negative linear relationship with planting density in field crops such as maize (Gardner et al., 1985). In the grasses with many tillers also, a negative linear relationship between the logarithm of TN and MTW is expected. Gardner et al. (1985) reported that the higher the planting density required for maximum DMY, the flatter the logarithm
Fig. 6. Correlation of planting density (Density) with percentage of overwintered plants (POP, A, D), regrowing plant number (RPN, B, E) and regrowing tiller number (RTN, C, F) in the overwintered plants on May 1, 2000 and April 28, 2001. Wruk wona (Wr, ○), Merkeron (Me, △), Dwarf-early (DE, ●) and Dwarf-late (DL, ▲). Figures with different letters denote significant difference among different densities and varieties at 5% level.

slope. In the present experiment, the ratio of MTW to TN tended to be higher in dwarf varieties than in the normal varieties when TN was higher than about 40 tillers m$^{-2}$ in 2000 and about 100 tillers m$^{-2}$ in 1999. This relationship suggests that the dwarf varieties should be planted at a higher planting density than normal varieties to obtain a maximum HDMY. In 2000, HDMY showed the saturated response to planting density at medium to high densities in Wr and DE, while it tended to be saturated only at a high density in DL. The difference in the response of HDMY to planting density between DE and DL in 2000 may be derived from the difference in leaf angle. Since DL had a more vertical leaves than DE in our observation, it is suggested that DL is more fitted to higher LAI for increasing the efficiency of solar radiation interception as observed in forage crops such as maize (Gardner et al., 1985) and in normal napiergrass (Ito et al., 1989). These points will be analyzed in the following paper.

HDMY decreased as cutting frequency increased from twice (2000) to three times (1999), although MTW also decreased severely as cutting frequency increased. Since the effect of cutting frequency was estimated by comparing the results obtained in the different years (1999 and 2000) in this study, it is necessary to consider the climatic conditions in the two years. Plants hardly suffered from drought stress in both summers, though there was less precipitation in 2000. In normal napiergrass, HDMY decreases with the increase in cutting frequency (Miyagi, 1985; Woodard and Prine, 1991; Sunusi et al., 1997). Woodard and Prine (1991) reported that the dwarf variety of Mott was less sensitive to the increased cutting frequency than normal varieties, although the two dwarf varieties in the present study were sensitive to cutting frequency. This characteristic, insensitive to the cutting frequency may be due to the earlier recovery of ground cover by the leaching after harvest (Gardner et al., 1985) because of larger TN in dwarf varieties than in normal varieties. It is necessary to compare the change in relative light intensity at the ground surface after cutting among varieties to support the above idea.

The dry matter productivity in normal napiergrass is sensitive to the decrease in air temperature (Miyagi, 1980; Ito and Inanaga, 1988; Ito et al., 1989; Ishii et al., 1996b). From the experiment in 1999, DL is assessed to be more sensitive to the decrease in air temperature than normal ones. A great decline of HDMY at the third cutting in DL may be attributed to the non-heading characteristics of DL. Since elongated stem functions as a storage organ, DL may lack in the sink capacity under a low air temperature at the third cutting in 1999.

LAI positively correlated with HDMY and negatively with PLB in both years. These correlations suggest that as planting density increases, LAI increases with the concomitant increase in HDMY and decrease in PLB, and that as cutting frequency increases, LAI decreases with the concomitant decrease in HDMY and increase in PLB. These correlations should be considered with aspect to herbage quality (Cuomo et al., 1996; Ishii et al., 1996b; Sunusi et al., 1997).
2. Effect of planting density on overwintering ability

With the increase in planting density, POP tended to decrease in all varieties in both years. After overwintering tiller buds emerged from the underground stems (Ishii et al., 1996a), as the planting density increased.

The POP was higher in 2000 than in 2001 in all varieties. In the other words, POP in the plant cut three times (1999) was higher than that in plants cut twice (2000), although frequent cutting often reduced the POP in tropical grasses. Average of minimum temperature and sum of precipitation from December 1999 to February 2000 were 3.7°C and 146 mm, respectively and those from December 2000 to February 2001 were 4.4°C and 239 mm, respectively. Therefore, we suppose that lower precipitation in the 1999–2000 overwinter season was beneficial for the overwintering of napiergrasses, even though the average of the minimum temperature was lower.

In this experiment, all plants were cut at 10 cm above the ground surface before wintering season. Napiergrass is susceptible to the frost and low temperature, and POP decreases when the plants were cut near the ground surface (Ishii et al., 1995; 1996a). Therefore, it is necessary to cut higher than 10 cm at least at the final cutting before the wintering season to improve the overwintering ability. However, POP in DE was extremely low in 2000, and DE is recommended to propagate by transplanting in every spring.

A high RTN correlates with a high regrowth rate, which is essential to obtain a high HDMY at the first cutting after overwintering, and RTN increased as planting density increased. The season at the first cutting (early July) is the off season of grass harvest between temperate and tropical grasses and it is actually important to be able to cut the first herbage of napiergrass as soon as possible after overwintering.

As mentioned above, growing napiergrass at a high density of 16 plants m$^{-2}$ with less cutting frequency (twice per year) is suitable to obtain a high annual HDMY, especially in dwarf varieties.

However, we found that planting at a high density is required to establish more plants per unit area (Mukhtar et al., 2002). Because the number of stem nodes having the potential to be established was 1.5 times higher in DL than in WR and DE, DL may be superior in the establishment efficiency than WR and DE (Mukhtar et al., 2002).

In conclusion, even though dry matter productivity was higher in the normal varieties than in the dwarf varieties, dwarf variety DL (DPO line of Thailand) tended to show a stable productivity at any planting density irrespective of cutting frequency. This characteristic may have derived from the high capacity of tiller emergence at the cutting as well as after overwintering and high dry weight percentage of leaf blade in DL, compared with the normal varieties.

Acknowledgment

The authors express sincere thanks to Mr. H. Kinoshita for assistance in the field measurement.

References

Burton, G.W. 1989. Registration of Merkeron napiergrass. Crop Sci. 29: 1327.

Cai, Q.S., Ishii, Y. and Ito, K. 1999. Effects of cutting and fertilizing treatments before wintering on the overwintering ability in relation to growth characteristics among six Panicum varieties. Grassl. Sci. 45: 217–225.

Cuomo, G.J., Blouin, D.C. and Beatty, J.F. 1996. Forage potential of dwarf napiergrass and a pearl millet × napiergrass hybrid. Agron. J. 88: 434–438.

Gardner, F.P., Pearce, R.B. and Mitchell, R.I. 1985. Physiology of Crop Plants. Iowa State University Press: Ames. pp. 1–327.

Hanna, W.W. and Monson, W.G. 1986. Registration of dwarf N75 napiergrass germplasm. Crop Sci. 26: 870–871.

Hanna, W.W., Monson, W.G. and Hill, G.M. 1993. Evaluation of dwarf napiergrass. Proc. 17th Int. Grassl. Congr., Palmerston North, New Zealand. 402–403.

Hsu, F.K. and Hong, K.Y. 1993. Effect of nitrogen and potassium fertilizer on forage yield and quality of dwarf napiergrass. Proc. 17th. Int. Grassl. Congr., Palmerston North, New Zealand. 864–865.

Ishii, Y., Ito, K. and Numaguchi, H. 1995. Effects of cutting date and cutting height before overwintering on the spring regrowth of summer-planting napiergrass (Pennisetum purpureum Schumach). J. Japan. Grassl. Sci. 40: 396–409.

Ishii, Y., Ito, K. and Numaguchi, H. 1996a. Effects of cutting intensity and stubble-cover with soil before overwintering on the spring regrowth of three-year-old napiergrass (Pennisetum purpureum Schumach). J. Japan. Grassl. Sci. 42: 20–29.

Ishii, Y., Ito, K. and Numaguchi, H. 1996b. Genotypic and annual variations in the dry matter yield and in vitro dry matter digestibility in napiergrass. Proc. 2nd Asian Crop Sci. Conf. 444–445.

Ishii, Y., Tudsri, S. and Ito, K. 1998. Potentiality of dry matter production and overwintering ability in dwarf napiergrass introduced from Thailand. Bull. Fac. Agric., Miyazaki Univ. 45: 1–10.

Ishii, Y., Ito, K. and Fukayama, K. 2000. Effect of several cultivation factors on the overwintering ability of napiergrass in the Southern Kyushu. Jpn. J. Crop Sci. 69: 209–216.

Ito, K. and Inanaga, S. 1988. Studies on dry matter production of napiergrass. I. Comparison of dry matter productivities and growth parameters between Tokyo and Miyazaki. Jpn. J. Crop Sci. 57: 90–96.

Ito, K., Murata, Y., Inanaga, S., Ohkubo, T., Takeda, T., Numaguchi, H., Miyagi, E. and Hoshino, M. 1988. Studies on dry matter production of napiergrass. II. Dry matter productivities at six sites in southern area of Japan. Jpn. J. Crop Sci. 57: 424–430.

Ito, K., Takaki, K., Misumi, M. and Numaguchi, H. 1989. Relations between leaf area index and crop growth rate of napiergrasses (Pennisetum purpureum Schumach) under different planting densities. J. Japan. Grassl. Sci. 54: 257–263.

Kipnis, T. and Bnei-Moshe, S. 1988. Improved vegetative propagation of napiergrass and pearl millet × napiergrass interspecific...
Miyagi, E. 1980. The effect of planting density on yield of Napiergrass. Sci. Bull. Coll. Agric. Univ. Ryukyus. 27: 293-301*.
Miyagi, E. 1985. The effect of cutting intervals on the yields of napiergrass (Pennisetum purpureum SCHUMACH) (II). Sci. Bull. Coll. Agric. Univ. Ryukyus. 32: 111-119*.
Mukhtar, M., Ishii, Y., Kinoshita, H., Idota, S. and Sonoda, T. 2002. Observation of established method of forage field in the dwarf and normal napiergrasses. Rep. Kyushu Br. Japan. Grassl. Soc. 32 (I) : 55-56**.
Rusland, G.A., Sollenberg, L.E. and Jones, C.S. 1993. Nitrogen fertilization effects on planting stock characteristics and establishment performance of dwarf elephantgrass. Agron. J. 85: 857-861.
Sollenberg, L.E. and Jones, C.S. 1989. Beef production from nitrogen-fertilized "Mott" dwarf elephantgrass and Pensacola bahiagrass pastures. Trop. Grassl. 23: 129-133.
Sollenberg, L.E., Prine, G.M., Ocumpaugh, W.R., Hanna, W.W., Jones, C.S., Schank, S.C. and Kalmbacher, R.S. 1989. Registration of "Mott" dwarf elephantgrass. Crop Sci. 29: 827-828.
Sanusi, A.A., Ito, K., Tanaka, S., Ishii, Y., Ueno, M. and Miyagi, E. 1997. Yield and digestibility of napiergrass (Pennisetum purpureum Schumach) as affected by the level of manure input and the cutting interval. J. Japan. Grassl. Sci. 45: 209-217.
Williams, M.J. and Hanna, W.W. 1995. Performance and nutritive quality of dwarf and semi-dwarf elephantgrass genotypes in the south-eastern USA. Trop. Grassl. 29: 122-127.
Woodard, K.R. and Prine, G.M. 1991. Forage yield and nutritive value of elephantgrass as affected by harvest frequency and genotype. Agron. J. 83: 541-546.

*In Japanese with English summary.
**In Japanese.