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GENOTYPIC DIFFERENCES IN FORAGE QUANTITY AND QUALITY OF CANOPY STRATA IN NAPIERGRASS (Pennisetum purpureum SCHUMACH)

ABSTRACT

To assess grazing suitability of napiergrass genotypes across real dwarf Taiwan 7734 (7734), semi-dwarf (DL) and normal-tall Merkeron (ME), yield and quality attributes were determined in canopy strata. Plant densities of 7734, DL, and ME were 4, 2, and 1 plants m⁻², respectively, and relative light intensity (RLI) and dry weight of plant fractions were obtained by stratified clipping at the first and second cuttings in early September and late November, respectively. Results of this study revealed that plant height was in the order of ME (199 cm), followed by DL (128 cm) and 7734 (88 cm) at the first cutting, and 7734 tended to have higher tiller density, dry matter yield, and leaf area index than DL and ME at both cuttings. Canopy RLI in 7734 tended to decrease higher with strata than in DL and ME, which was corresponded with the lowest K in 7734, followed by DL and ME at both cuttings. Genotype 7734 had the highest digestibility and crude protein concentration, and lowest structural carbohydrate concentrations across genotypes, which would be favorable to grazing use by breeding beef cows.

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1 Introduction

Napiergrass (Pennisetum purpureum) is used extensively in Japan as a forage crop for cattle, has a quick growth and produces a high amount of dry matter (Vicente-Chandler et al., 1974). The grass is tolerant to an extensive range of soil conditions, is drought tolerant, and exhibits a high efficiency of photosynthesis and excellent water use efficiency (Anderson et al., 2008). High digestibility of feedstock helps enzymatic saccharification with cellulose (Kai et al., 2010; Knoll et al., 2012; Na et al., 2015).

Napiergrass has a range of phenotypic variation from real-dwarf, semi-dwarf, to normal-tall genotypes. Dwarf type napiergrass (semi-dwarf [dwarf late-heading type; DL]) originated from Florida, in the United States (Sollenberger et al., 1988), was then brought to the Dairy Promotion Organization (DPO) in Thailand, and was finally introduced to Japan in 1996 (Ishii et al., 1998). Although the DL napiergrass has been adopted in tropical and subtropical countries, it has been recently introduced and examined for growth attributes and adaptability to be more suitable for grazing use than normal variety of napiergrass in temperate Japan (Mukhtar et al., 2003; Ishii et al., 2005). In vitro dry matter digestibility (IVDMD), crude protein concentration, and overwintering ability of DL napiergrass were superior to the normal napiergrass genotype in various tropical and sub-tropical areas in the world (Tudsrì et al., 2002). It is important to examine growth attributes along with forage quality of dwarf types in comparison with normal-tall Merkeron (ME) in the region.

Dry matter yield and forage quality suitable for biomass use are expected to be variable, dependent on variations in growth attributes among genotypes of napiergrass, as affected by climate and soil factors at the observed site and dependent on the growth stage of herbage (Woodard & Prine, 1991; Ishii et al., 1998). High leaf expansion, vigorous tillering, and rapid dry matter production in tall canopy are categorized as important factors to attain high production of napiergrass (Ferraris et al., 1986; Matsuoka et al., 1991; Wadi et al., 2004).

Little information has been accumulated for variations of growth and forage quality across canopy strata in a range of napiergrass genotypes (Khairani et al., 2013), which is closely related with the solar radiation interception and the efficiency in converting solar radiation to the canopy plant growth (Stejskalová et al., 2013). The present study was conducted to determine yield and quality attributes across several canopy strata for 7734 and DL compared with normal ME napiergrass for estimating carrying capacity of the napiergrass pastures by grazing system.

2 Materials and Methods

2.1 Plot design, Transplantation and Sward Management

The field experiment was conducted at Miyazaki, Japan (E131°25', N31°54') in 2015, using a randomized complete block design (RCBD) with 3 replications. Three genotypes of real-dwarf (Taiwan line 7734), semi-dwarf (DL), and normal-tall genotype, ME napiergrass were selected. Plot size was fixed at 6 m² (2 m × 3 m) for both DL and 7734, while for ME, plot size was fixed at 12 m² (3 m × 4 m), which had 60, 105, and 12 plants per plot for DL, 7734, and ME, respectively. Density and spacing of plants were 1 plant m⁻² with 1 m × 1 m spacing for ME, 2 plants m⁻² with 1 m inter-row with 0.5 m intra-row spacing for DL, and 4 plants m⁻² with 0.5 m of both inter-row and intra-row spacing for 7734. The previous crops were removed, and cow manure at 3 kg m⁻² and slaked lime at 150 g m⁻² were added on April 22nd, 2015. Rooted tillers of 7734, DL, and ME were transplanted at the density of 4, 2, and 1 plants m⁻², respectively, on May 26th-27th, 2015. Chemical compound fertilizer at 5 g each of N, P₂O₅, and K₂O m⁻² was supplied twice before the first cutting and just after the first cutting on September 4th for an annual total of 15 g each of N, P₂O₅, and K₂O m⁻². Weeds were removed by hand as required.

2.2 Sampling methods and growth characters to be determined

Growth attributes including plant height, plant length, tiller density, and leaf area were measured for 2 plants per plot on June 15th, July 24th, September 4th, October 15th, and November 28th, 2015. Samples were randomly selected and plants were cut at 10 cm above the ground as reported by Ishii et al. (2005) to measure fresh weight (FW). From these, subsamples approximately 300–400 g FW were separated into leaf blade (LB), stem inclusive of leaf sheath (ST), and dead part (D) and then oven-dried at 70°C using the ventilation oven (model DKM 600, Yamato Scientific Co. Ltd, Tokyo, Japan) for 3 days (72 hours) to determine the percentage of dry matter (DM) in each plant fraction. Plants were measured for relative light intensity (RLI) in every 30 cm strata from the top of the canopy to the ground and harvested by the stratified clipping method of 30 cm strata to measure FW and percentage of DM on September 4th for all genotypes at the first cutting and on November 28th for ME at the second cutting. The width of strata decreased to 20 cm for DL and 7734 due to lower plant height on November 28. The bottom strata were harvested at 10 cm above the ground.

2.3 Chemical analysis of herbage

The ground samples for 3 genotypes of napiergrass were passed through a 1 mm screen in herbage for LB and ST. They were then analyzed for in vitro dry matter digestibility (IVDMD), crude protein (CP), and structural carbohydrates such as neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL) by detergent methods (Van Soest, 1994). IVDMD was measured in the case of duplication by pepsin-cellulose digestion method (Goto & Minson, 1977) using the in vitro incubator (Model: ANKOM DAISY II, ANKOM Technology, New York, USA).
2.4 Statistical analysis

Analysis of variance was performed using Excel Statistics (OMC Co. Ltd., Saitama, Japan). Differences in mean values were assessed at the 5% probability level using the least significant difference (LSD) method.

3 Results and Discussion

3.1 Climatic Conditions

Monthly mean temperature and precipitation in 2015 are shown in Figure 1, compared with those in the normal year (NY) averaged from 1981 to 2010 data determined at Miyazaki Meteorological Observatory in Japan Meterological Agency (Japan Meterological Agency). The mean temperatures in June and July 2015, respectively, were lower at 21.8°C and 25.7°C than those in the NY at 23.1°C and 27.3°C. Monthly precipitation in June and July, 2015 was 840 and 573 mm, respectively, which was higher than those in the NY at 429 and 309 mm month⁻¹. Monthly mean temperature and precipitation in August and September, 2015 were similar to those in the NY. Therefore, the climatic conditions were lower temperature and higher precipitation in June and July than in the NY. In addition, a drought condition appeared at 19 mm precipitation in October, 2015 compared with 182 mm in the NY, which suppressed plant growth severely.

Figure 2 Changes in plant height for the 3 genotypes in 2015. The symbol shows mean values ± standard deviation (n=3). ↓: Cutting. Symbols with different letters denote significant difference at the 5% level by LSD test. ns: P > 0.05.
Figure 3 Changes in tiller density for the 3 genotypes in 2015. The symbol shows mean values ± standard deviation (n=3). ↓: Cutting. Symbols with different letters denote significant difference at the 5% level by LSD test.

3.2 Changes in growth attributes

Changes in plant height per month across the 3 genotypes 7734, DL, and ME are shown in Figure 2. Plant height was generally larger in the normal ME than the semi-dwarf and the dwarf genotypes (Mukhtar et al., 2003; Khairani et al., 2013), showing the highest in ME (199 cm), followed by DL (128 cm), and 7734 (88 cm) at the first cutting on September 4th, while the order between the semi-dwarf and dwarf genotypes was reversed (105 cm for 7734 and 79 cm for DL) at the second cutting on November 28th. In the regrowth period after the first cutting, probably due to higher sensitivity to short day length in 7734, the day length might trigger the ear initiation in the dwarf 7734, which should release the suppression of internode elongation, resulting in a higher plant height in 7734 than in DL at the second cutting.

Changes in tiller density per month across the 3 genotypes are shown in Figure 3. Tiller density in 7734 was constantly higher across growing seasons than the other 2 genotypes, showing the maximum at 175 m⁻² in 7734, followed by DL and ME, which was positively correlated with the difference in plant density among the 3 genotypes. Decrease in tiller density from October to November in 7734 may be caused by self-shinning of tillers (Matsuda et al., 1991) from the maximum tiller density in mid-October, while the other genotypes maintained tiller density from October to November.

Figure 4 Changes in dry matter yield of the 3 genotypes in 2015. The symbol shows mean values ± standard deviation (n=3). ↓: Cutting. Symbols with different letters denote significant difference at the 5% level by LSD test. ns: P > 0.05.
Changes in DM yield in the 3 genotypes across the growing season are shown in Figure 4. DM yield was almost constantly higher in 7734, followed by ME and DL, except for when ME had the lowest weight in October. In the first cutting on September 4th, 7734 had the highest DM yield at 830 g m⁻², followed by ME at 640 g m⁻², and DL at 590 g m⁻². In the second cutting, DM yield was not significantly different among cultivars. Therefore, annual total DM yield was significantly higher in 7734 at 1223 g m⁻², followed by ME at 906 g m⁻², and DL at 793 g m⁻². The slow recovery on October 15th from the first cutting may be adversely affected by the lowest monthly precipitation (19 mm) in October, which was abnormally lower than the NY monthly precipitation (182 mm). On the other hand, management of N fertilizer is the most effective tool in enhancing and manipulating both herbage yield and quality in normal genotypes (Broyles & Fribourg, 1958; Boonman, 1993) as well as in dwarf genotypes (Muhammad et al., 1988; Wadi et al., 2004). Utamy et al. (2011) reported that DM yield in DL was so variable across the observed sites in southern Kyushu, ranging from 70–1360 and 20–1580 g m⁻² year⁻¹ in 2007 and 2008, respectively. It is clear that significantly positive correlation was obtained from the study between DM yield and nitrogen fertilizer supply. In the present study, annual fertilizer supply was limited to 15 g m⁻², which might be suboptimal to normal ME and semi-dwarf DL.

Changes in dry matter partitioning of plant fractions (LB, ST, and D) in the 3 genotypes are shown from June 15th to November 28th in Figure 5. Percentage of LB was higher in the second than in the first cutting for all genotypes, while the ST percentage and D percentage were higher in the first than in the second cutting. Percentage of LB was higher in DL than in 7734 and ME at both cuttings, except for June 15th when the highest LB (100%) in both DL and ME occured, showing a simple index for crude protein concentration of herbage. LB percentage tended to increase from the first to the second cuttings across the 3 genotypes, corresponding with the previous study for DL (Hasyim et al., 2014), showing that the ratio of leaf blade to stem (LB/ST) was lower at the first cutting in the year of establishment than at the other 2 cuttings and tended to decrease with increasing DEM application across the seasons. In the first defoliation of DL napiergrass, when the plant height reached 111–132 cm, DM yield and LB percentage were recorded at 226–717 g DM m⁻² and 61-87%, based on early pasture management practices for prompt weeding and fertilization (Ishii et al., 2013), which was comparable to the present DL in the first cutting.

3.3 Canopy structure

Changes in the relative light intensity (RLI) of the canopy and canopy architecture were observed in the first and second cuttings on September 4th and November 28th, respectively, across the 3 genotypes (Figure 6). Canopy RLI decreased with strata, and the decreased percentage tended to be more severe in 7734 than in DL and ME. Stratified clipping was conducted at every 30 cm strata for all genotypes in September and for ME in November, when the clipping at 20-cm interval was applied to 7734 and DL due to lower plant height. The LB biomass yield gradually increased from the upper to the bottom strata for each genotype in the first and second cutting, except for the lowest strata, which had lower yield. The ST biomass yield peaked in the lowest strata for all genotypes. Even though RLI tended to decrease slowly in the second cutting on November 28th, the amount of leafages was lower in the second cutting on November 28th than in the first cutting on September 4th.
Table 1: Crude protein concentrations (mg g⁻¹ DM) of plant fractions in napiergrass genotypes.

| Strata | September | November |
|--------|-----------|----------|
|        | LB 7734 DL ME 7734 DL ME | LB 7734 DL ME 7734 DL ME |
| 2      | 117       | 151      |
| 3      | 100       | 151      |
| 4      | 129ᵃ 102ᵇ | 91ᵇ 144ᵇ |
| 5      | 145ᵃ 116ᵇ 92ᵇ | 69ᵇ 129ᵃ 127ᵇ 129ᵇ 112ᵇ 64ᵃ |
| 6      | 111ᵃ 81ᵇ 77ᵇ 102ᵃ 82ᵃ 39ᵇ | 112ᵃ 104ᵇ 115ᵇ 103ᵇ 47ᵇ 57ᵇ |
| 7      | 82ᵃ 58ᵇ 94ᵇ 91ᵇ 70ᵇ 31ᵇ | 114ᵃ 87ᵇ 114ᵇ 91ᵇ 52ᵇ 45ᵇ |

Strata: 2 (Upper) to 7 (Bottom). LB, leaf blade; ST, stem inclusive of leaf sheath. Figures with different letters denote significant difference at the 5% level by LSD test.

Figure 6: Changes in relative light intensity (RLI) in the canopy and canopy architecture at the first cutting on September 4 (I) and at the second cutting on November 28 (II).

The symbol shows mean values (n=3).
The canopy extinction coefficient (K) was the lowest in 7734 at 0.36 and 0.61 for the first and second cuttings, respectively, followed by DL at 0.56 and 1.06 and ME at 0.60 and 1.15 for the first and second cuttings, respectively. Therefore, canopy K increased from September to November in all genotypes, reflected by a lower leafage amount in November (Nagasuga et al., 2002), while K was the lowest in 7734, followed by DL and ME commonly at both cuttings due to the steeper leaf angle in 7734 than in the other genotypes.

It might be possible that through seasonal variations in LAI and K, the canopy of napiergrass can maintain higher efficiency, even when solar radiation is intercepted for long time during its growth. Zhang et al. (2014) showed that K is an important factor that affects carbon fixation of the ecosystem, as well as water and energy transmission. A low K indicates that a lot of radiation can reach the bottom of canopy strata, while a high K indicates that only a little radiation can penetrate to the bottom of the canopy. Zhang et al., (2014) reported that cropland had the highest K (0.62), followed by broadleaf forest (0.59), shrubland (0.56), and grassland (0.50) across the several ecosystems. In the present study, the average K for all genotypes at both cuttings was 0.72, while 7734 had the lowest K at 0.36 at the first cutting, which was superior to that in the grassland (Zhang et al., 2014). Annual mean K values were higher in the normal than in the dwarf genotypes among different planting densities (Mukhtar et al., 2003), which was consistent with the present study.

3.4 Forage Quality in Canopy

Changes in crude protein (CP) concentration of plant fractions for LB and ST in every strata of the 3 genotypes were determined for the first and second cuttings, on September 4th and November 28th, respectively (Table 1). CP concentration of both LB and ST were higher in the second than in the first cutting in all 3 genotypes, except for lower CP concentration in ST for ME. In general, CP concentration was the highest in 7734, ranging from 82 to 145 mg g⁻¹ DM for LB and 91 to 102 mg g⁻¹ DM for ST in the first cutting and was increased to 114 to 206 and 91 to 181 mg g⁻¹ DM for LB and ST, respectively, in the second cutting, followed by DL and ME. CP concentration in ME ranged from 90–183 and 60–180 mg g⁻¹ DM in LB and ST, respectively, and LB tended to have higher CP concentration than ST (Fukagawa et al., 2000). The dwarf genotypes of napiergrass tended to have higher CP concentration than the normal genotypes (Sollenberger et al., 1988; Muinga et al., 1993; Silva et al., 1994; Chaparro & Solレンberger, 1997; Tudsri et al., 2002), which is consistent with the present study. CP concentration was higher in the upper than in the bottom strata for every genotype, which is closely related with animal performance when napiergrass is used for grazing (Silva et al., 1994).

Changes in in vitro dry matter digestibility (IVDMD) of plant fractions for LB and ST in every strata of the 3 genotypes were determined at the first and second cutting in September and November, 2015, respectively (Figure 7). IVDMDs of both LB and ST were higher in dwarf 7734 and semi-dwarf DL than in the normal ME in the first and second cuttings. In 7734, IVDMD was higher for LB in the first than in the second cutting, while ST had a higher IVDMD in the second than in the first cutting. In DL, IVDMD for LB was lower in the first than in the second cutting, while ST had higher IVDMD in the first than in the second cutting. In ME, IVDMD for LB was higher in the second than in the first cutting. Therefore, IVDMD was the highest in 7734, followed by DL and ME, tended to be higher in LB than in ST, and was higher in the upper than in the bottom strata for each genotype.
Table 2 Structural carbohydrate concentration (mg g\(^{-1}\) DM) of plant fractions in NDF (A), ADF (B) and ADL (C) for the 3 napiergrass genotypes.

| Strata | September  | November |
|--------|------------|----------|
|        | LB         | ST       | LB         | ST       |
| 2      | 7734       | DL       | 7734       | ME       |
| 3      | 676        | 590      |
| 4      | 635        | 664      | 667        | 632      |
| 5      | 629        | 646      | 683        | 677      |
| 6      | 647        | 659      | 692        | 694      |
| 7      | 659        | 698      | 704        | 701      |

| (A) NDF | September  | November |
|---------|------------|----------|
|         | LB         | ST       | LB         | ST       |
| 2       | 7734       | DL       | 7734       | ME       |
| 3       | 676        | 590      |
| 4       | 635        | 664      | 667        | 632      |
| 5       | 629        | 646      | 683        | 677      |
| 6       | 647        | 659      | 692        | 694      |
| 7       | 659        | 698      | 704        | 701      |

| (B) ADF | September  | November |
|---------|------------|----------|
|         | LB         | ST       | LB         | ST       |
| 2       | 7734       | DL       | 7734       | ME       |
| 3       | 676        | 590      |
| 4       | 635        | 664      | 667        | 632      |
| 5       | 629        | 646      | 683        | 677      |
| 6       | 647        | 659      | 692        | 694      |
| 7       | 659        | 698      | 704        | 701      |

| (C) ADL | September  | November |
|---------|------------|----------|
|         | LB         | ST       | LB         | ST       |
| 2       | 7734       | DL       | 7734       | ME       |
| 3       | 676        | 590      |
| 4       | 635        | 664      | 667        | 632      |
| 5       | 629        | 646      | 683        | 677      |
| 6       | 647        | 659      | 692        | 694      |
| 7       | 659        | 698      | 704        | 701      |

It is reported that IVDMD in ME was variable from 567–772 and 619–786 mg g\(^{-1}\) DM in LB and ST, respectively, indicating that ST tended to have higher digestibility than LB (Fukagawa et al., 2000).

In normal ME, digestibility tends to be higher in ST than in LB at the juvenile stage, while this tendency is reversed in the mature stage, since the decreasing rate in digestibility of ST during maturing was larger than that of LB. As for semi-dwarf DL, IVDMDs in LB ranged from 570–712 and 560–681 mg g\(^{-1}\) DM in 2007 and 2008, respectively, while those in ST were higher than those in LB, and ranged from 619–747 and 637–765 mg g\(^{-1}\) DM in 2007 and 2008, respectively (Utamy et al., 2011).

Changes in structural carbohydrates concentration were determined in every strata at the first and second cutting in September and November, 2015, respectively (Table 2). Structural carbohydrate concentrations in NDF, ADF, and ADL (Lignin) were the lowest in 7734, followed by DL and ME in the first cutting, while in the second cutting, NDF, ADF, and ADL concentrations followed the same order as those in the first cutting, except for ME, which had a lower concentration than DL, NDF and ADF concentrations were
lower in LB than in ST for DL and ME, and these concentrations were lower in the upper than in the bottom strata of each plant fraction for all 3 genotypes for both the first and second cutting. Aroeira et al. (1999) reported that, for normal napiergrass, NDF concentration ranged from 688 to 752 ± 2.2 mg g⁻¹ DM, and ADF concentration ranged from 383 to 439 ± 2.9 mg g⁻¹ DM, with the highest values generally found in the summer. Similar fiber contents were reported for the dwarf genotype (Silva et al., 1994).

Conclusions

Under the highest plant density (4 plants m⁻²), the dwarf 7734 achieved the comparative yielding ability to DL and ME, due to the steeper leafage of the canopy. Forage quality tended to be the highest in 7734, followed by DL and ME in terms of IVDMD, and concentrations of CP and structural carbohydrates. The results suggest that the 7734 genotype is the most efficient type of napiergrass for both forage quality and quantity.

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Conflict of interest

Authors would hereby like to declare that there is no conflict of interests that could possibly arise.

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