University of Miyazaki
PhD Dissertation

GENOTYPIC DIFFERENCES IN CANOPY STRUCTURE AND FEASIBILITY OF GRAZING ON WINTER AND SUMMER PASTURES OF NAPIERGRASS

（ネピアグラスの草冠構造と夏季および冬季草地の
放牧可能性における品種間差異）

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DEDICATION

I would like to dedicate this PhD dissertation to the soul of my lovely father, Late Mia sahib Abdul Raziq, a religion scholar and a personality who enthusiastically directed me in a unique way to complete the essential education in a very hard situation outside and inside of Afghanistan. I will never forget him in my all praying until I am a live and beg to Almighty Allah to grant him a suitable permanent settlement in paradise (Janat-e-Firdaws). I would also kindly request from Allah to make his soul happy in grave along with our other closed relatives and Muslims. (Amen)

LIST OF ABBREVIATIONS

ADF	**Acid Detergent Fiber**
ADG	**Average Daily Gain**
ADL	**Acid Detergent Lignin**
ANOVA	**Analysis of Variance**
CF	**Chemical Fertilizer**
CP	**Crude Protein**
D	**Dead leaf**
DE	**Dwarf and Early-heading type**
DEM	**Digested Effluent of Manure**
DL	**Dwarf and Late-heading type**
DM	**Dry Matter**
DMI	**Dry Matter Intake**
DMW	**Dry Matter Weight**
DMY	**Dry Matter Yield**
DPO	**Dairy Production Organization**
DG	**Daily Gain**
FW	**Fresh Weight**
HC	**Herbage Consumption**
IVDMD	***In Vitro* Dry Matter Digestibility**
IVOMD	***In Vitro* Organic Matter Digestibility**
JB	**Japanese Black**
K	**Canopy extinction coefficient**
LB	**Leaf Blade**
LB/ST	**Ratio of LB to ST**
LSD	**Least Significant Difference**
LW	**Live Weight**
ME	**Merkeron**
NDF	**Neutral Detergent Fiber**
NY	**Normal Year**
PU	**Percentage Utilization**

RCBD	**Randomized Complete Block Design**
RLI	**Relative Light Intensity**
SD	**Standard Deviation**
SE	**Standard Error**
ST	**Stem inclusive of leaf sheath**
USA	**United States of America**
USDA	**United States Department of Agriculture**
WK	**Wruk wona**

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ABSTRACT

Napiergrass (*Pennisetum purpureum* Schumach), a C_4 tropical grass that produces plentiful, nutritious green forage, is considered an excellent feed source for livestock raised under grazing systems and green chopping in tropical regions and temperate Kyushu, Japan. Napiergrass phenotypes include normal, semi-dwarf (DL), and dwarf Taiwan line (7734). The dwarf and DL genotype canopy structures contrast with that of normal Napiergrass, cv. Merkeron (ME), and the dwarf types are better suited for grazing than the normal type, as they have a higher tiller number and leaf blade (LB) percentage and exhibit high persistence in southern Kyushu. In the first part of this study, yield and quality attributes of the canopy structure were characterized over a range of Napiergrass genotypes (7734, DL, and ME) to assess their grazing suitability.

Leaves of tropical grasses, including Napiergrass, are susceptible to frost damage, and plant growth ceases when subjected to frost. However, frost-damaged leaves form foggage, which is expected to be suitable for use as stored herbage over winter in the same way as hay and silage are processed during the summer. However, no research findings are available for grazing of beef cows on Napiergrass foggage as an autumn-saved pasture. Rotational grazing is an intensive grazing management strategy that provides livestock with a continuous opportunity to consume fresh grass in an active growth stage. DL Napiergrass can adapt to intensive rotational grazing by beef cows, thus enabling expansion of cultivation areas in southern Kyushu. However, grazing management on 7734 Napiergrass pastures has not been examined in this region.

The tropical legume lablab bean (*Dolichos lablab* L.) was found suitable for mixed cropping with tropical grass to increase crude protein (CP) content in herbage and milk produced by grazing dairy cows in Thailand. The second part of this study, therefore, was conducted to examine grazing potential on foggage and fresh grass of semi-dwarf and true dwarf Napiergrass genotypes, intercropped with lablab bean in southern Kyushu.

In the first part of the study, 7734, DL, and ME plant densities were 4, 2, and 1 plant/m^2, respectively. The 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. Plant height was in the order ME (199 cm), DL (128 cm), and 7734 (88 cm) at the first cutting, and 7734 tended to have higher

tiller density, dry matter yield (DMY), and leaf area index than DL and ME at both cuttings. The canopy RLI of 7734 tended to decrease more with the depth in strata compared with DL and ME, which corresponded with the lowest K in 7734, followed by DL and ME at both cuttings. Steeper decrease in RLI can be linked to higher K. Genotype 7734 exhibited the greatest digestibility, highest CP concentration, and lowest structural carbohydrate concentration, which would be favorable for grazing breeding beef cows.

In one-day intermittent grazing by 24 Japanese Black (JB) beef cows on foggage pasture from December to March, 2017, 1-4 months after the first frost, grazing time on Napiergrass increased until late February, and pasture height and herbage mass decreased consistently with grazing. In rotational grazing on pastures of the two Napiergrass genotypes, the pre- and post-grazing plant height was higher for DL than 7734 in mixed cropping with lablab bean by three JB breeding beef cows during pregnancy over two cycles, from mid-July to early September 2017. Herbage mass was roughly comparable between the two genotypes in the first cycle, whereas it decreased considerably for 7734 in the second cycle. However, the genotypes exhibited similar herbage consumption (HC). Moreover, dry matter intake (DMI) tended to be higher for 7734 than for DL in the first cycle. Live-weight (LW) gain increased with grazing, averaging 0.79 kg/head/day under an average stocking rate of 8.6 cows/ha with 19 g DM/kg LW/day of DMI. Therefore, the live weight (LW) of breeding beef cows was at least maintained under rotational grazing without additional feed supply for 56 days in summer in southern Kyushu.

In order to maximize livestock production and pasture sustainability and longevity, the impact of grazing animals on sward canopy structure and strategies to maintain a functional ecosystem in the pasture must be considered in rotational grazing management. The grazing system described here thus represents a management tool that allows pasture managers to control the frequency and duration of grazing and rest periods to optimize both livestock and plant performance. The optimal, and therefore most sustainable, combination of year-round grazing management on dwarf-type pastures of Napiergrass in the Kyushu region remains to be determined.

CHAPTAR 1

GENERAL INTRODUCTION

The demand for livestock products such as meat and milk widely increases as the human population rises in the world. These two important animal products are rich in sources of protein and fat to human beings. It is predicted that meat demand in the developing countries will approximately increase to 122 million tons in 2020 (Anderson *et al*., 1999). In the meantime, Japan’s total domestic cattle slaughtered in 2016 is projected to fall for a 4th consecutive year (down 1 %) to 1.105 million head (total beef production of 475,000 tons), primarily due to the continuous calf production deficits dating back to both 2013 and 2014. According to the national cattle ID database, operated by National Livestock Improvement Center, the total number of cattle was 3,823,921 head on January 31, 2016, which decreased year by year. The Statistics Portal (Statista) reported that the world's beef and veal production was projected to reach the amount of 69.11 million tons in 2015. But this production was increased by 0.8%, from 68.4 million tons which extends the modest growth trend of the last several years. In the year 2050, the greatest part of the world residents in population at 10 billion will live in large cities and towns. To feed these people will need a 70-100% rise in the amount of food produced at the current time (Burney *et al.,* 2010). Not only the quantity of food is required but also more focus should be paid to the requirements for the quality which is desired for both consumers and managers.

The increasing animal products will be purchased in the supermarkets that has been already pre-packed and further processed. According to the report of US Census Bureau (2011), the world population on 31 December, 2011 was 6.985 billion and is expected to increase to 8.5 billion in 2020. Nearly all population will probably take place in the less developed regions of Asia and Africa where huge shortage in food supply is already available for the people due to the existence of poverty.

The global livestock sector is categorized by a contrast between developing and developed countries. Overall meat production in the developing countries was tripled between 1980 and 2002, from 45 to 134 million tons (World Bank, 2009). Great part of this growth was concentrated particularly in East Asian countries that experienced the rapid economic growth, and revolved in poultry and swine industry. In developed countries, livestock production and consumption are currently rising only slowly, so livestock production and marketing in industrialized countries account for 53% of agricultural GDP (World Bank, 2009). The combination of rising demand in the developing countries and slow demand in developed industrialized countries represents a huge opportunity for livestock owners in developing countries, where the maximum demand is met by local production, and likely to continue well into the foreseeable future. The growth of agricultural production needs to take place in a way to obtain benefit from increased demand that should regulate its effect on the environment.

Livestock products depend basically on forage production, which have to be further processed to green forage operated under cut-and-carry and grazing systems, hay (dehydrated green fodder), and silage (preserved under the anaerobic condition). Furthermore, production of pasture and stable crops is important in land use on arable lands as forage grasses grow (Mukhtar *et al.*, 2003).

Napiergrass (*Pennisetum purpureum* Schumach) is widely distributed in the natural humid and warm areas of tropical regions. It stays green in the dry season in sub-humid areas, while it is not suitable for semi-arid conditions. Napiergrass was rapidly appreciated for drought tolerant grazing grass or cut-fodder in the dry season (Vicente-Chandler *et al.*, 1974). In Napiergrass, the vegetative propagation is a more reliable technique for the establishment. While some hybrids of Napiergrass produce seed, they have very poor establishment. Vegetative propagation by rooted tillers is the best method of establishment and the weed control is essential at the early growth stage.

Dwarf genotype of the late heading type (DL) Napiergrass was bred in the US state of Florida (Hanna *et al.,* 1993) and then brought to the Dairy Promotion Organization (DPO) in Thailand by US scientist. After that, it was introduced to Japan in the year 1996 (Ishii *et al.*, 1998). The potential of DL Napiergrass was observed by the previous studies to have the suitability under cut-and-carry and grazing systems (Mukhtar *et al.*, 2003, 2004b; Ishii *et al.*, 2005), and to have high overwintering ability and superior utilization by animals (Ishii *et al.,* 2008, 2009). *In vitro* dry matter (DM) digestibility (IVDMD), crude protein (CP) content and the overwintering ability of dwarf Napiergrass were greater than those in the normal genotypes of Napiergrass and also dwarf Napiergrass started to test for the local adaptability in various tropical as well as sub-tropical areas in the world (Hanna *et al.*, 1993; Tudsri *et al.*, 2002b).

Napiergrass, particularly DL, has high adaptability for grazing use by beef and dairy cows and has superior local adaptability in several prefectures of southern Kyushu. DL genotype is superior in utilizing as a roughage. It is easy to control sward management of the genotype, which is suitable for cultivation on the sloped land of southern Kyushu. Utamy *et al.* (2011) revealed that annual mean and lowest temperatures were sufficient in supporting the establishment and overwintering ability of DL Napiergrass in the examined 12 sites including isolated islands in southern Kyushu. Herbage quality attributes as IVDMD and CP content were higher than the minimum requirement of CP content at 7.0%. DL Napiergrass can widely adapt to the examined sites in southern Kyushu including the isolated islands and produce the adequate high DM yield (DMY) with suitable herbage quality, compared with other ordinary perennial tropical grasses, owning the sustainable use under both cut-and carry and rotational grazing systems if annual fertilizer application covers more than 100 kg/ha.

Stratified clipping method data showed that beef cows grazed to consume the leafage of DL Napiergrass better with the time of grazing passed. Based on the percentage consumption at each stratum, leaves in the top two and third strata were grazed completely. The capacity in stem inclusive of leaf sheath (ST) was higher than in leaf blade (LB) in the bottom of fourth and fifth strata. Beef cows consumed herbage better in the upper fourth stratum than that in the bottom fifth stratum, because LB in the fifth stratum attached close to the bottom of the ground surface (Sollenberger and Burns, 2000).

Mukhtar *et al.* (2004) determined herbage DM weight and percentage of LB in 5 stratum using stratified clipping method at both pre- and post-grazing in 2001 and 2002. Percentage of pre-grazing LBs were 100% in the top first and second strata in both years, and were nearly 95% and 80% in the third strata in 2001 and 2002, respectively. Herbages of post-grazing in the top second and third strata were consumed by beef cows almost completely, from the first to the last grazing events both years, based on consumption percentage, while this consumption decreased to the bottom of strata.

The live weight (LW) of raising Japanese Black (JB) cows on DL Napiergrass pasture decreased in the first week and tended to increase with the grazing period after the first week and average daily gain (ADG) was 0.56 kg/day. Under the similar stocking rate (3684 kg LW/ha/day) of rotational grazing by raising beef cows on guineagrass (*Panicum maximum* cv. Natsukomaki) pasture in Kumamoto, Japan, ADG from mid-June to the end of October was reported at 0.56 kg/day by Hirano *et al.* (2004). Under the stocking rate of 3.3, 6.6 and 10 head/ha on *Paspalum atratum* cv. Suerte pastures in Florida, USA, ADGs were 0.71, 0.55 and 0.49 kg/day, respectively (Kalmbacher, 1997).

A Pangola grass pasture by steer (LW 312 kg) grazing in Queensland, Australia, ADG was under the stocking rate of 4.3 head/ha 0.62 kg/day (Holzknecht *et al.*, 2000). In the above mentioned several tropical grasses pastures, stocking rate and ADG of beef cows were comparable with the study under the rotational grazing of DL Napiergrass pasture. A 3000 m^2 DL Napiergrass pasture can supply enough herbage for 3 raising beef cows to keep ADG of 0.56 kg/day without concentrate feeding.

The potential of Napiergrass for weight gain in cows has been examined with or without energy or protein supplements. Results appear to vary widely depending on grass quality, cattle breeds, the level and the type of supplementary feed. Friesian heifers gained between 0.13 and 0.8 kg/day after fed on Napiergrass varying in maturity from flowering to early vegetative stage (CP 63 to 96 g/kg DM) and achieved a daily dry mater intake (DMI) of 2.1 to 3.1 kg per 100 kg LW (Arias, 1980).

Forage DMYs at pre- and post-grazing of Napiergrass pastures in rotational grazing period were 238.6–582.6 g/m^2 and 152.8–309.5 g/m^2, respectively. Suggesting that pasture of DL napiergrass extended the capacity to grazing use and supply sufficient herbage of beef cows for a week in each 5 weeks in a hot summer season. The forage DMY in the first week at post-grazing was higher than in the second week until the 5th week of the first cycle, because the beef cow in the first week was still process of grazing adaptability in Ako (2010).

Mukhtar *et al.* (2004b) investigated that dwarf types, particularly DL Napiergrass genotypes was higher in tiller number, leaf area index and percentage of LB, compared with other dwarf and normal Napiergrass genotypes, recommending that DL Napiergrass was more suitable for grazing use than other varieties. Comparing the grazing suitability among DL and normal Napiergrass varieties by dairy cows, DL was tolerant to the rotational grazing system and maintained a regrowth ability with one-month resting period throughout the hottest summer season. DL Napiergrass can be fixed to the intensive grazing pressure as in the other tropical grasses in the small paddock. Pre-grazing herbage mass during grazing on DL Napiergrass pasture by a standard herd of breeding JB beef cows, ranging from 389 to 703 g DM/m^2/year, herbage consumption (HC) from 214 to 484 g DM/m^2/year and pasture utilization from 44% to 85% across paddocks. Daily gain (DG) of matured beef cows was positive after cycle 2, averaged at 0.23 kg/head/day across cycles and paddocks, and the carrying capacity of DL Napiergrass pasture was calculated at 891 cow-day/ha. In contrast to raising cows, since matured breeding cows do not need LW gain, a lower DG of 0.23 head/day is recommended to be a satisfactory feeding system for breeding cows.

Hasyim *et al*. (2016**)** demonstrated that DL Napiergrass and Italian ryegrass (IR) pasture would accommodate rotational grazing to maintain the LW of grazing beef cows with 3.5 grazing months at the summer season for DL Napiergrass and 1 month at the spring for IR. The grazing period for DL Napiergrass was shorter compared to the previous rotational grazing by 3 head of adult JB beef cows grazed on 0.2 ha of DL Napiergrass pasture which had a lower stocking rate. Therefore, intercropping of DL Napiergrass with Italian ryegrass can be suggested as a sustainable and low-cost feeding system in the region to small-holder beef farmers.

The diet of ruminant animals that are producing meat for human consumption is becoming essential progressively for some reasons. The meat products might be advertised on the foundation of a greater nutritional quality rising from the diet fed to the animals and the consumers need guarantee to know that these products are in fact from the right production systems. Beef meat from grass-based production system is higher based on nutritionally desired n-3 fatty acids and conjugated linoleic acid than that from animals that were fed with unimproved cereal concentrates (Scollan *et al*., 2005). The Japanese traceability system, established in December, 2004, ensures customers that the beef meat is safe, with such free-flowing information, providing a model of achievement, in which the North American consumers should be taking note of the Japanese food companies that have been putting pictures of the farmers and producers of food supply on packaging for years.

Appropriate development of additional beef heifers should be critical and needs to be completed at lower cost without losing reproductive performance. These existing recommendations show heifers would reach about 65% of matured LW for fruitful reproduction at breeding stage (Patterson *et al.*, 1992; NRC 1996). Demand for preconditioned feeder cattle continues to rise in the beef industry based on marketing value and the available information indicates that pre trained forage-raised calves need less management and the mortality rate is lesser due to lower rate of illness, leading to the increase in the profitability for buyer and seller (Bailey, 2002).

The quality of beef carcasses is assessed with the amount of marbling or intramuscular fat presence, especially when carcass fat and meat color is not a concern. Beef breeds such as JB cattle, well known as Wagyu, have a unique fat deposition pattern characterized with a greater amount of marbling (Lunt *et al.*, 1993). Ozutsumi *et al.* (1984) reported that Japanese breeds had greater carcass fat proportions and lesser carcass lean and bone proportions than Holsteins. In the developed countries, a higher price is paid for carcasses with higher marbling than for those with a lower level of marbling.

Afghanistan is a land-locked country and has about 12% arable land and almost 80 percent people possess livestock. There are about 3 million of cattle (cows, ox and calves) in Afghanistan, and the number of cattle per family has recently increased from 1.3 to 3.7 (FAO, 2003). There is neither beef breed available in the country nor intensive farms for beef production in Afghanistan. Farming and livestock are the main sources of income and dietary food for Afghan farmers. Lack of highly productive animals, low supply of fodder, and crossbreeding of local cattle (Kunari, Sistani, Qandahari), lead farmers to grow poppy. In addition, crossing of animals by imported advanced semen without appropriate breeding policy for the maintaining and increasing a certain breed caused losses of the fine-adopted animals in tropical areas and the interest and demand is high for crossing and reforming foreign breeds. The consumption of beef meat is larger in comparison to poultry and lamb. However, Afghanistan imports a huge number of cattle including buffalos and cattle from Pakistan to maintain the demand of meat in the market. This indicates that the demand for beef meat is extremely higher than the production. On the other hand, no measures are taken for beef quality control in importing.

The objectives of this PhD dissertation are to investigate the effects of Napiergrass genotypes on herbage quality and animal production through the following research targets.

1: 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: To examine the grazing potential of semi-dwarf DL and real dwarf 7734 genotypes of Napiergrass foggage as fodder for breeding beef cows for 3 months as the first trial.

3: To determine the grazing potential of two Napiergrass genotypes mixed cropping with Lablab bean and LW gain for 3 JB breeding beef cows during summer season as the second trial in southern Kyushu.

CHPTER 2

REVIEW OF LITERATURE

2.1. Species of Pennisetum

Napiergrass (*Pennisetum purpureum* Schumach), also recognized as elephant grass, and is native to the continent of Africa. In the year of 1913, the United States Department of Agriculture (USDA) introduced this grass to the State of Florida, which is located in the southern part of the United States of America (USA) to observe its adaptability to local environment. The high potential of Napiergrass was first documented in 1909 and then it was soon introduced into tropical areas of the South and Central America and India (White, 1957). Napiergrass has been familiarized almost into all tropical and subtropical regions beginning from the sea level to higher altitudes up to 2000 m where annual rainfall exceeds 1000 mm and grows finest when temperatures are hot (30-35ºC). However, it can be tolerant of cool temperatures down to 10ºC before its ceases to grow (Russel and Webb, 1976; Ocumpaugh and Rouquette, 1985). Mendoza and Schank (1987) reported that Napiergrass has produced the highest DMY among tropical grasses. However, the concentration of CP in Napiergrass is normally lower than 100 g/kg, because Napiergrass is harvested to maximize DM production at the cost of its quality.

Kinggrass bred from the hybridization between Napiergrass and pearl millet, which happened naturally, was introduced to Panama in 1970 from the United States of America with the help of USDA and its plant introduction number was 300086. From Panama, kinggrass was further distributed to other Latin American countries (Mendoza and Schank, 1987). Similar hybrids, produced in the humid and tropical areas of India and other tropical countries, have yielded in good consequences for DM production and quality (Muldoon and Pearson, 1979).

Banagrass was developed in South Africa in the early 1950s by hybrids between the annual babla (*Pennisetum americium*) and the perennial Napiergrass (*Pennisetum purpureum*). It has been approved that *Pennisetum* hybrids are soft in texture, leafy that has a thinner stem, more juicy and, thus, more palatable as compared with Napiergrass (Jodhpur, 1965; Gupta *et al.,* 1997). The hybrid banagrass presented tremendously high green fodder yields about 110 t/ha/yr. The banagrass DMY at 23.2 t/ha was not significantly higher than that of kikuyu grass at 20.2 t/ha. In case of both pastures, the highest DM production was recognized in early autumn. Leaf: stem ratio was higher in banagrass in early summer than in late summer. The higher leaf: stem ratio in lower cell wall content was reflected, but the lower cell content did not accord with higher digestibility in Koster *et al.* (1992).

Hybrid Napiergrass is an interspecific hybrid among pearl millet (*Pennisetum typhoides*) and Napiergrass (*Pennisetum purpureum*). The parents of hybrid Napiergrass are tall and bunched grasses which are originated in tropical Africa. It is numerously identified as Napier × bajra hybrid, elephant × bajra hybrid or hybrid Napier and sometimes they have their cultivar names, such as Gajraj and Pusa giant Napier. The hybrid revealed significant variations in their yielding capacity under different cutting regimes. The possibility for using this hybrid as a forage crop has been studied in some countries to demonstrate its ability for producing more forage than Napiergrass in some conditions (Jodhpur, 1965) and more than millet in others (Powell and Burton, 1966).

It was recommended that in tropical countries it might perform as perennial (Burton and Powell, 1968) with higher yields and better forage quality than either parent. Pearl millet × Napiergrass interspecific hybrids are recognized for their potential to produce high yields of fairly good quality. It is palatable and willingly consumed by cattle and sheep, and is a good forage not only for the maintenance of cattle, but also useful for silage-making (Muldoon and Pearson, 1979; Hanna and Monson, 1980). Even though Napiergrass, pearl millet and its interspecific hybrids have a high DM production capacity, one of the most limiting factors for more extensive use of these pastures is their lower nutritive value in terms of CP content and DM digestibility which consequently affect forage voluntary intake by cattle (Mendoza and Schank, 1987).

Pearl millet (*Pennisetum typhoides*) is broadly grown in the tropical and subtropical regions for the purpose of grain production and to reduce the amount for forage production. It is phenotypically variable at an annual basis, while it normally produces 4-6 tillers and a plant height reaches 2-3 m after approximately 11 weeks from sowing (Begg and Burton, 1971). It is originated in the central tropical Africa, and was cultivated in India since 1200 BC. It is now extensively distributed in the drier tropics that has an average annual rainfall of 125-900 mm even at the higher altitude site, ranging from 800 to 1800 m. Temperatures in summer should be higher for the optimum growth of pearl millet, and the maximum germination happens at 25/20ºC of day/night temperature, while the temperature close to 0ºC is lethal to pearl millet (Russel and Webb, 1976).

Kikuyu grass (*Pennisetum clandestinum*) is a C_4 pasture species that is well-adapted to the main milk-producing areas in the Western province of South Africa. Kikuyu grass is very productive in summer and fall seasons, but DM production in winter and spring is low. Forage quality of kikuyu pasture is low and therefore, milk production per cow as compared to temperate grass (C_3) species is low too (Marais, 2001). Kikuyu grass occurs at high altitudes of tropical regions predominantly, where precipitation is high. This grass has also been introduced to lower altitudes of the world and has an ability to survive a wide range of conditions between 35°N and 35°S. To grow rapidly, it needs high level of nitrogen. It is fire-resistant and has the ability to tolerate moderate shade but is gradually decreased as the canopy cover increases. It also tolerates a wide range of soil pH with the acid soils to pH 4, and indicated tolerance of salinity up to 100 or 150 mM NaCl in South Africa, but is less tolerant of sodium sulphate or alkalinity. Its foliage is damaged by the frost, however, recovery can occur from underground if there is prolonged freezing of the soil (Radhakrishnan *et al.*, 2006).

2.2. Growth and yield of Napiergrass

Ahmad and Butt (1985) reported that application of nitrogen above the ceiling rate hardly affected yield as well as CP content. If the production of forage was highly dependent on the amount of rainfall, this climatic factor dominated the effect of nitrogen fertilization under the circumstance of subtropical environments with dry season. However, if growth was hardly inhibited by climatic factors, DMY and CP content of Napiergrass increased with the increase in nitrogen supply in a range of 120 to 1,200 kg N/ha below the ceiling rate in Miyazaki, Japan (Sunusi *et al.,* 1999). Jones (1985) also reported that Napiergrass needs heavy fertilization and careful management to maintain a speedy growth with higher forage quality under subtropical climate in Australia. Increase in DMY with nitrogen fertilization is required to be analyzed by the stimulated numerous processes of Napiergrass growth, such as leaf and tiller development.

Growth parameters and forage quality of Napiergrass are variable dependent on the growth stage of herbages (Mendoza and Schank, 1987; Woodard and Prine, 1991; Sunusi *et al*., 1997; Ishii *et al.,* 1999). High leaf expansion, vigorous tillering and quick production in tall canopy are categorized as important factors to attain high production of Napiergrass (Ferraris *et al*., 1986; Matsuda *et al.,* 1991; Wadi *et al*., 2003). The growth of Napiergrass is expressed by a strong thermal response (Ferraris, 1978), and growth rate of Napiergrass increases through increase of temperature (Ferraris *et al*., 1986).

In tropical areas and during the summer in subtropical regions, the productivity of cattle feed in the form of forages is limited due to the low quality of the forage species compared with the other factors. Some tropical grasses, for example Dwarf Napiergrass (*Pennisetum purpureum* Schum. cv. Mott), showed that it produced huge quantity of digestible DM per hectare among species of this category and also it is important for promoting higher LW gain per animal and per land area (Almeida *et al*., 2000).

Napiergrass cultivars that are currently in use were selected for animal feeds, with emphasis on high leaf percentage, high nitrogen concentration and low fiber levels. DMY was frequently sacrificed to obtain high feed quality. In contrast, for production of bioenergy, the objective is to get the maximum yield of biomass, with quality suitable for either direct combustion or ethanol. Many cultivars of the genus *Pennisetum*, including Napiergrass, contain the most productive tropical grasses. These cultivars from this genus are normally grown for animal feed, and Common napier, King napier, Bana, Wrukwona, ME and short (Mott dwarf) have the ability to produce biomass yields exceeding 25 t/ha/year DM when cut at 30-day intervals (Hoshino, 1975).

Napiergrass has the ability to bear an extensive range for soil conditions, and also has a good drought acceptance ability, higher efficiency of photosynthesis and better efficiency of water use (Anderson *et al.,* 2008). Moreover, when compared with other grass species or legumes, Napiergrass produces additional DM per unit time (Vincente-Chandler *et al.,* 1974). Because of its quick growth and degradable biomass properties, Napiergrass also has the potential to be converted to alcohol or methane production (Muldoon and Pearson, 1979; Anderson *et al.,* 2008).

2.3. Quality of Napiergrass

Seasonal changes of DM weight (DMW) as well as IVDMD between different sizes of Napiergrass tillers were compared among low and high altitudinal sites (Ishii *et al*., 1992, 1993). It was determined that DM productivity was lower in the high altitudinal sites as compared to the low altitudinal sites, whereas the number of smaller tillers increased in the high altitudinal sites (Ishii *et al*., 1992). The smaller tillers inclined to have higher IVDMD, which decreased the differences in the yield of IVDMD than the DMY among low and high altitudinal sites (Ishii *et al.,* 1993). This was originated from the negative relationships among DM weight and IVDMD of both ST and LB in a range of different size of tillers (Ishii *et al*. 1993, 1994, 1996). While considering for DM productivity between varieties which have different plant types, it is essential to determine the relationship between DM weight and IVDMD among tillers with different size as well as at a whole plant level.

Quality of Napiergrass in terms of IVDMD, CP, neutral detergent fiber (NDF), and acid detergent fiber (ADF) might depend on genotype and grass management. The tetraploid tall Kinggrass was lower in *in vitro* organic matter digestibility (IVOMD) as well as CF concentration, while the NDF and ADF concentrations are both higher (Cuomo *et al*., 1996). On the other hand, information related to the quality of Napiergrass and productivity under intensive nitrogen in a mixture with manure and irrigation management in tropical environment is not well recognized.

Herbage quality depends partly on value of digestibility which decreases as the maturity progresses in tropical grasses. Digestibility in Napiergrass tends to be higher in the juvenile stage than in the matured stage (Ishii *et al.,* 1993; Fukagawa *et al*., 2000). Several studies have reported the high forage quality of dwarf Napiergrass in Florida, USA (Woodard and Prine, 1991; Sollenberger *et al.,* 1993; Williams and Hanna, 1995).

2.4. Processing and utilization of Napiergrass

Napiergrass can be processed into high quality silage. Its high cell wall content and lower concentration in water soluble carbohydrates, however, weaken the ensiling process. It was determined in Zimbabwe that Napiergrass should be harvested for ensiling between weeks 6 and 7, at the peak of water soluble carbohydrate concentrations, to increase DM content and enhance herbage production without affecting nutritive value. The high moisture of Napiergrass when its nutritive value is highest is a problem for using it as silage, because it results in undesirable fermentation with considerable nutrient losses. Therefore, Napiergrass is regularly ensiled with materials to improve the quality of the silage and its nutritional value as protein or energy (Manyawu *et al.,* 2003a).

Fukagawa *et al.* (2017) reported the results of ensiling and the effects of wilting recommending for the fermentation quality of dwarf Napiergrass silage in summer, which can be improved by wilting treatment without additives. It is because that the faster drop of the moisture concentration was observed after treatment in the summer season, compared with no positive effects when treated in autumn. In another study reported by Fukagawa *et al.* (2016), the ensilage of dwarf Napiergrass that covered by plastic bags without additives after harvest by a flail-type harvester in the autumn season proved to lead to a satisfactory silage quality of the grass species, that might be applicable to some small-holder beef cow-calf producing farmers in the region as a winter-stored forage. In this research, a satisfactory fermentation quality of the silage was confirmed when adopting the practical apparatus of a mower and round baler-system for the ordinary cow-calf farmers.

Napiergrass due to its high productivity is a very important forage in the tropical regions. It is a particularly suitable feed to cattle and buffaloes. Napiergrass is mostly used in cut-and-carry systems that fed in stalls as indoor-feeding, or made into silage or hay. Napiergrass can be grazed, or it can be kept at the vegetative stage: livestock have a tendency to feed only the younger leaves. This grass is also called as elephant grass, and is an important source of forage for elephants in Africa (Cook *et al.,* 2005). Napiergrass has the ability to exchange its alleles with other *Pennisetum* species to develop several hybrids. Hybrids of pearl millet (*Pennisetum glaucum*) and elephant grass (Kinggrass, Pusa Giant, Banagrass, Florida and others) brought the benefit from the desirable characteristics of pearl millet, for example, plant vigor, drought resistance, tolerance to diseases, forage quality and seed size, whereas Napiergrass provides, aggressiveness, perennially, palatability and high DMY (Timb *et al.,* 2010).

Napiergrass is often fed fresh in cut-and-carry systems. It can be physically or mechanically chopped prior to feeding to reduce the selection of leaves and stems by the animal. Chopping and then wilting in the sun for several hours to reduce moisture stimulates appetite, facilitates rumination and therefore improves forage utilization (Moran, 2011).

2.5. Animal production under indoor-feeding of Napiergrass

Grazing adaptability of beef cattle on DL Napiergrass (*Pennisetum purpureum* Schumach) pasture was observed in summer season at Miyazaki, Japan in the year 2005. Six paddocks of DL Napiergrass pasture with an allocated area of 3000 m^2 (500 m^2 per paddock) were established since May 2002. Three heads of raising beef cows (JB cows) were rotationally grazed in a week that had 4 weeks resting period started from June to October. Forage dry yield at pre and post grazing averaged 238.6–582.6 g/m^2 and 152.8–309.5 g/m^2, respectively with percentage consumption averaging 42.5–71.6%. Forage consumption and DMI averaged 14.5–50.9 g DM/m^2/day and 2.42–8.48 kg DM/IU/day, respectively with ADG at 0. 56 kg/day. Grazing adaptability of beef cattle on DL Napiergrass needed time for about one week. Therefore, the DL Napiergrass pasture can be utilized under the rotational grazing at stocking rate of 12 head/ha (calculated 3600 kg LW/ha/day) in the subtropical area in the summer season (Ako, 2010).

LW changes in breeding beef cows and the relationship between DMI and ADG reported by (Mukhtar and Ishii, 2007) that there were increasing tendencies in LW with the grazing at the first and second cycles, and cow LW almost maintained at the third cycle for three head beef cows. Therefore, cow LW at least maintained under the rotational grazing system without any concentrate intake for this experiment. ADG was highest at 0.54 kg/day during cycle 1, whereas ADG was negative during cycles 2 and 3 and there were no significant correlations between DMI and ADG. So, the LW of the breeding beef cows was at least maintained under this rotational grazing system without any concentrate or other supplied roughage. Although the grazing period was decreased, plant height at the post-grazing may be caused by the high palatability of Napiergrass for grazing cows.

Sollenberger and Jones (1989) highlighted Mott dwarf Napiergrass potential in forage livestock systems, where maintaining high LW gains is critical during the growing season. The only periods throughout the trial when LW gains on Mott dwarf Napiergrass were low (0.55kg) happened in the first grazing period of both years of

1984 and 1985. The grass had not been grazed previously by steers in those years, and animals were reluctant to graze it for the first several days to one week. It is concluded that Mott dwarf Napiergrass is persistent, high quality, and perennial forage grass which is capable to support the average of four yearling steers/ha in the growing season. DGs on Mott dwarf Napiergrass approached 1.0 kg/day, which was higher than those reported for other tropical grasses in Florida. Consistently high IVOMD and CP levels were related with excellent animal performance. The principle limitation for using Mott in the USA is the vegetatively propagation using stem cutting (Sollenberger *et al.,* 1988b)

Gitau *et al.* (1994) assumed that heifers can gain at least 0.5 kg/day but less than 0.25 kg is observed in practice on small-holder farms and hence puberty is not attained until after 24 months. It is attributed to the lower quality of Napiergrass fed to farm animals and the absence of concentrate feeding (Wouters, 1987). The potential of Napiergrass in cattle for LW gain has been examined with or without protein or energy supplements. The results obtained differed widely depending on quality of grass, cattle species and the level and the kind of supplement used. Friesian heifers achieved DG among 0.13 and 0.8 kg/day when fed on Napiergrass changing in maturity from flowering to early vegetative stage (CP 63 to 96 g/kg DM) and achieved a daily DMI of 2.1 to 3.1 kg per 100 kg LW (Arias, 1980). In another experiment conducted by Dixon (1984), it is obtained for the LW gain of +0.72/-0.21 kg/day from Holstein heifers fed with 60 to 85 day-old Napiergrass of unspecified CP content supplement with 0.2, 0.4 and 0.8% molasses on LW basis.

Ten Friesian cows with 4 years of age, almost 7 months into the first lactation were used to determine the potential of milk production of Napiergrass as sole forage fed for lactating cows in the indoor-feeding system. The cows were separated into two groups of five animals each offered chopped Napiergrass *ad libitum.* One group was offered 8 kg of dairy concentrate in addition with Napiergrass. DMI and milk yield were recorded daily while animals were weighed on weekly bases. Daily DMI for animals on Napiergrass alone was 3.3 kg DM/100 kg LW, equivalent to about 66 kg per day of fresh forage per animal. This was significantly ($P<0.05$) less than the total feed intake for the supplemented group of 4.3 kg DM/100 kg LW, equivalent to about 53 kg of fresh forage and 7 kg of concentrate per day. Average daily milk production was 10.5 kg and 15 kg for the un-supplemented and supplemented group, respectively. Anindo and Potter (1986) indicated that feeding Napiergrass lonely can support milk production above 10 kg/day, although from a very high level of forage intake. Since 10.5 kg of milk production obtained from the diet with forage only was twice the reported national average from grade cows in Kenya. An increase in the quantity of good-quality forage supplied might raise the level of milk production per cow on the farm.

2.6. Pasture management in Napiergrass

Ishii *et al.* (2013) reported that a DL Napiergrass had superior sustainability for more than five years in Miyazaki, Japan, and in cooperation with local communities the cultivation areas has been gradually increased for both cut-and-carry and grazing herbage production. However, the extension in several areas of Kyushu, DL Napiergrass required temperature above -6.2°C for its sustainability in winter season, on the base of its threshold response to the lethal minimum temperature. DL Napiergrass pasture can be utilized by grazing beef cows even in the early stage of spring season along with temperate Italian ryegrass inter-sown into the inter-row spaces. To reduce energy consumption and allow comparable productivity, organic digested animal manure or sun-dried leguminous leaves as green manure can replace chemical fertilizers for Napiergrass pasture.

Ishii *et al*. (2005) reported that DL Napiergrass pasture can adapt for the intensive rotational grazing by beef cows and is getting to expand cultivation areas in southern Kyushu. In another study (Utamy *et al*., 2011; Ishii *et al*., 2013), it is reported that grazed perennial DL Napiergrass pasture produces a high herbage mass and quality, and hence provides herbages cheaper than imported hay feeding. Mukhtar *et al.* (2004b) reported that plant height of DL Napiergrass pasture decreased continuously with the grazing progressed, suggesting that HC by grazing beef cows was more frequent in LB than in ST.

Mukhtar *et al.* (2004b) examined that DL Napiergrass, which was allocated for a paddock with almost 500 m^2, was transplanted by rooted tillers regrown from the overwintered stubble on 30 April, 2001. Plant space and density were 1 m × 0.5 and 2 plants/m^2, being totally 1,000 plants/paddock. DL stubbles after overwintering were cut at the ground level on 26 March to activate the regrowth of emerged tillers from tiller bud on the ground stem. The paddock field was fertilized with 30 g N/m^2 of chemical compound fertilizer with 6 times of split application before the start of grazing on 16 May and 14 June and after every grazing each month in 2001, and with 5 times before the start of grazing on 8 May and after every grazing nearly each month in 2002. Before the start of the rotational grazing, weeding was conducted by hand.

Dwarf Napiergrass (*Pennisetum purpureum*) pasture is suitable for beef-cow grazing in warm regions of Japan, the suitability using a herd of dairy cows has not yet assessed in the region. This study determined the effects of digested effluent (DE) application on herbage yield and quality, HC and DMI under rotational grazing by a herd of dairy cows on dwarf napiergrass pasture in southern Kyushu for the years 2007 and 2008. Plant height, tiller number, herbage mass and HC increased consistently from the first to the second or to the third grazing cycle in the two years. Pre-grazing herbage mass was averaged at 176 and 193 g/m^2 in chemical fertilizer (CF) and DE treatments, respectively. Overwintering ability was almost perfect in Miyazaki, judged by 97.1% of regrown plants in May 2008. Therefore, pasture of Dwarf Napiergrass fertilized with liquid DE treatment can be utilized by dairy-cow grazing as the same with CF fertilization, where DMI was averaged at 4.4 kg DM/head/day for 3 summer months in the two years (Hasyim *et al.,* 2014).

The grazing study was conducted in Sumiyoshi Livestock Experimental Station, University of Miyazaki, Japan (131.46°E, 31.99°N) from 23 July 2007 to 31 October 2008. One-ha of DL Napiergrass pasture was established by rooted tillers on 18-20 May 2005, and was divided into 5 paddocks (40 × 50 m, 0.2 ha each). The spacing and density of DL Napiergrass were 1 m grid and 1 plant/m^2. Each paddock was linked to the watering facility under shelter woods. Paddocks 1-3 were equally subdivided into 0.1-ha areas with DE and CF plots and paddocks 4 and 5 were subjected to CF plot. Liquid DE was applied to DE plots at 46 KL/ha/year (112 kg of $NH_4{}^+$-N) with 4 times using split application in 2007 and at 58 KL/ha/year (141 kg of NH_4 +-N) with 5 times using split applications by additionally fertilized with chemical compound fertilizer at 93 kg N/ha in 2008. CF plots were fertilized with 112 kg N and 234 kg N/ha/year of chemical compound fertilizer with 4 times and 5 times using split applications in 2007 and 2008, respectively in Hasyim *et al.* (2016).

Hasyim *et al*. (2014) reported that liquid DE was applied to DL Napiergrass pasture two times before the start of grazing on DL Napiergrass pasture and at each cycle after the grazing ended in each paddock. Almost 1,200 L (1.2 m^3) of liquid DE required to be transported from the bio-gas plant to 0.2-ha for post-grazing pasture and was applied by vacuumed sprayer. This fertilization method has several qualities that DL Napiergrass pasture needed high rate of liquid DE at more than 200 kg N/ha during the growing season, that was a suitable condition for the high density of livestock producers in southern Kyushu and that the pasture managers can replace purchase of chemical fertilizer by the application of liquid DE to decrease the fertilization cost.

The annual total yields of Napiergrass based on common features increased from the year of establishment to the following year when the spring regrowth began from the overwintered stubbles (Ishii *et al*., 1995; Sunusi *et al*., 1999; Wadi *et al*., 2004) along with other perennial tropical grasses, if management for pasture was suitable for the grass species. In case of the establishment of IR, the method of digested effluent of manure (DEM) application was changed from the first to the second year; DEM was applied two times in the first year just at pre-and post-sowing of IR, which might delay the emergence of over-sown IR to produce poorer establishment, resulting in lowering DMY. However, in the second year, the first DEM application was conducted one month after the sowing of IR to improve the establishment of the species without disturbing the early growth by DEM solution.

2.7. General grazing behaviors

Mukhtar *et al*. (2004a) reported that percentage utilization (PU) was highest in DL, followed by dwarf-early and lowest in Wruk wona (WK) and bahiagrass in both years of the experiment. Animals were grazed more than half of herbage in dwarf Napiergrass, whereas they left more than half of uneaten herbage in WK, particularly at the final 2 grazing practices in both years. Among 4 grazing times, grazing time on bahiagrass was the highest while the difference between time on varieties of Napiergrass and that on bahiagrass tended to be decreased as the grazing season proceeded. Grazing time on bahiagrass in 2002 was reduced faster than in 2001, while that on DL was highest from the 2nd to the fifth grazing, followed by WK and dwarf-early. Compared with HC, grazing on WK and DL was generally more efficient in grazing herbage than that on dwarf-early and bahiagrass, based on HC per percentage grazing time. Grazing time was shorter on the sunny and hot days in June and August of 2001, and in June, July and August, 2002 than that on the cloudy days in July 2001 and in September 2002 and that on the cold days in November both years.

While the quantity and quality of herbages are good, grazing patterns follow carefully the periods of daylight and cattle extend their grazing into dark period under adverse conditions (Stobbs, 1970). Highly productive cows can be recognized through the amount of forages in the night, meanwhile more than 50% of grazing time can happens between 6 pm and 6 am. To get the optimum production, it is highly needed to have good night paddocks (Rees *et al.*, 1972). For the most grazing animals as leaf is the main component of the diet and has a higher nutritional value, it is recommended to pay more attention to leaf component of the sward instead of total DMY. Studies in relation to the net assimilation and senescence of leaves in grazed tropical pasture swards might lead to better understanding of pasture and animal relationships. The final test of any index related to the nutritional value of herbages is its association to animal performance and further testing of the grazing behavior effects upon animal productivity is needed.

Grazing livestock are maintained for one purpose in many cases, to provide profit (food supply and economic aspect) to the owners. Therefore, the objectives for grazing management might place greater emphasis on the manipulation of plant communities in the future (Walker, 1995). Consequently, sustained research on the application of grazing behavior to management at the landscape level will remain serious (Bailey *et al.*, 1996). Combining grazing behavioral features with grazing management strategies gives us the chance to manipulate utilization patterns or diet selection to achieve particular management goals. Utilization is the percentage of consumed herbage production or that grazed by herbivores. Physical features, for example the distance to water, slope, and the presence of overlying canopy affect the quantity of forage consumed and hence, utilization of a specified area of a pasture. Several aspects of grazing behavior can also affect utilization and provide suggestions for pasture management.

Walker (1962) reported that after 11 November, once the herd was complete, observations on the grazing behavior of the dams were noted for the numbers of heifers grazing, lying, or loafing. Any animals which happened to be suckling were categorized as loafing. The main grazing periods happened after sunrise for about two hours and in the late afternoon from approximately 3 p.m. until after sunset. During the middle of the night, most of the herd preferred in a short grazing period but some continued settled once they had camped down for the night. In general there seemed to be 5 to 6 grazing cycles, in which the midnight and early morning ones were most clearly defined and the late-afternoon and evening grazing cycles tended to overlap. The grazing periods from mid-morning to mid-afternoon were not well-described. Most of the loafing happened throughout this period, to certain extent caused by heat, flies, rainstorms, or inessential excitements, and therefore, grazing tended to be short-term and strong.

2.8. Grazing behaviors on Napiergrass pasture

Mukhtar and Ishii (2007) reported that the percentage time of grazing behavior at the start and the end of the cloudy day on 24 August, 2004 or at the cold day on 27 October, 2003 and on 7 December, 2004 similarly tended to be larger than at the sunny and hot day on the other dates. Regardless of seasons, beef cows grazed DL Napiergrass at 50–60% and 60–70% of daytime in 2003 and 2004, respectively. Grazing time on DL Napiergrass at the start of grazing tended to be stable between 4-5 grazing times at about 50% and 60% in 2003 and 2004, respectively. However, grazing time on DL Napiergrass tended to increase with grazing cycles to reach 70% at the last grazing both years.

Length of grazing on DL Napiergrass was decreased by several factors, for example, large amount of leafage, which was associated with bite size and hot climate. Length of grazing on DL Napiergrass tended to decline when HC was the highest at the third and fourth grazing periods in 2003 and 2004, respectively. On the last day of each grazing on DL Napiergrass pasture, length of grazing in day time increased to 70% of the day, which was the similar tendency to the low-yielding swards of Setaria and pangola grass, where cows extended the grazing time to compensate for the small bites pretended (up to 707 minutes in 24 hrs), reported by Chacon *et al*. (1978).

Grazing management provides sufficient quantity and quality of herbages to satisfy animal needs under the sustaining pasture. During a grazing system, animals frequently face a choice between patches in vegetation structure or quality and cows are shown to choose the herbages that provided the highest intake rate (Distel *et al.,* 1995). Mukhtar *et al.* (2004b) reported that plant height of DL Napiergrass pasture decreased continuously with the grazing progressed, suggesting that HC by grazing beef cows was more frequent in LB than in ST.

HC increased from the 1st cycle to the 3rd cycle and then declined severely at the last paddock 1 or 4 in CF treatment in the 2 years. The DMI by dairy cows increased from the 1st to the 3rd cycle and was closely correlated with HC from the 1st to the 3rd cycle. DMIs in CF and DE treatment averaged across 4 cycles were 4.1 and 7.0 kg DM/head/day, respectively, in 2007 and 2.8 and 3.6 kg DM/head/day, respectively, in 2008. The increase of DMI in paddocks 1-3 at the last cycle in 2007 was brought about by the only one-day of grazing practice because of poor regrowth and shortage in herbage, reported by Hasyim *et al*. (2016).

Cattle grazing behavior should be related with the highest quality forage species which is available at any point in time. However, the determination of plant species will be chosen on the base of tradeoff between availability and nutritional quality, which might interact with or be determined by the current behavior of grazing. Wallis De Vries *et al*. (1999) suggested that sites with shorter herbage and probably higher nutritive value or digestibility will be selected over sites with taller and more fibrous herbage. Other experimental and theoretical work on animal behaviors suggest that animals may graze cyclically on preferred sites, based on forage availability from plant regrowth (Wilmshurt *et al*., 2000), that might enhance selection for forage quality.

CHAPTER 3

GENOTYPIC DIFFERENCES IN FORAGE QUANTITY AND QUALITY OFCANOPY STRATA IN NAPIERGRASS (*Pennisetum purpureum* SCHUMACH)

3.1. Abstract

To assess grazing suitability of Napiergrass genotypes across real dwarf Taiwan 7734 (7734), DL and normal-tall 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, DMY, and leaf area index than DL and ME at both cuttings. Canopy RLI in 7734 tended to decrease more steeply with strata than in DL and ME, which was corresponded with steeper decrease in RLI however, lower K was due to higher leaf area and steeper decrease in RLI can be linked to higher K. The lowest canopy extinction coefficient (K) was 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.

3.2 Introduction

Napiergrass (*Pennisetum purpureum* Schumach) is used extensively in Japan as a forage crop for cattle, has a quick growth and produces a high amount of DM (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 (DL) originated from Florida, in the United States (Sollenberger *et al.,* 1988a), was then brought to the 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). IVDMD, CP concentration, and overwintering ability of DL Napiergrass were superior to the normal Napiergrass genotype in various tropical and sub-tropical areas in the world (Tudsri *et al.,* 2002a). It is important to examine growth attributes along with forage quality of dwarf types in comparison with normal-tall ME in the region.

DMY 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 herbages (Woodard & Prine, 1991; Ishii *et al.,* 1998). High leaf expansion, vigorous tillering, and rapid DM production in tall canopy are categorized as important factors to attain high production of napiergrass (Ferraris *et al.,* 1986; Matsuda *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.

3.3 Materials and Methods

3.3.1 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 m^2 (2 m × 3 m) for both DL and 7734, while for ME, plot size was fixed at 20 m^2 (4 m × 5 m), which had 12, 24, and 20 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 22 April, 2015. Rooted tillers of 7734, DL, and ME were transplanted at the density of 4, 2, and 1 plants/m^2, respectively, on 26-27 May, 2015. Chemical compound fertilizer at 5 g each of N, P_2O_5, and K_2O/m^2 was supplied twice before the first cutting and just after the first cutting on 4 September for an annual total of 15 g each of N, P_2O_5, and K_2O/m^2. Weeds were removed by hand as required.

3.3.2 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 15 June, 24 July, 4 September, 15 October, and 28 November, 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 LB, ST, and dead part (D) and then oven-dried at 70ºC using the ventilation oven (model DKM 600, Yamato Scientific Co. Ltd, Tokyo, Japan) for 3 days (72 hrs) to determine the percentage of DM in each plant fraction. Plants were measured for 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 4 September for all genotypes at the first cutting and on 28 November 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.

3.3.3 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 IVDMD, CP, and structural carbohydrates such as NDF, 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 and Minson, 1977) using the *in vitro* incubator (Model: ANKOM DAISY II, ANKOM Technology, New York, USA).

3.3.4 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.

3.4. Results and Discussion

3.4.1 Climatic conditions

Monthly mean temperature and precipitation in 2015 are shown in Figure 3.1, compared with those in the normal year (NY) averaged from 1981 to 2010 data determined at Miyazaki Meteorological Observatory in Japan Meteorological Agency (Japan Meteorological Agency). The mean temperatures in June and July 2015, respectively, were lower at 21.8ºC and 25.7ºC than those in the NY at 23.1ºC and 27.3ºC. 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. 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.

3.4.2 Changes in growth attributes

Changes in plant height per month across the 3 genotypes 7734, DL, and ME are shown in Figure 3.2. 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 3.3. 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.

Changes in DMY in the 3 genotypes across the growing season are shown in Figure 4. DMY 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 DMY at 830 g/m^2, followed by ME at 640 g/m^2, and DL at 590 g/m^2. In the second cutting, DMY was not significantly different among cultivars. Therefore, annual total DMY 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 15 October 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 and

Fribourg, 1958; Boonman, 1993) as well as in dwarf genotypes (Mohammad *et al.,* 1988; Wadi *et al.,* 2004). Utamy *et al.* (2011) reported that DMY in DL was so variable across the observed sites in southern Kyushu, ranging from 70–1360 and 20–1580 g/m^2/year in 2007 and 2008, respectively. It is clear that significantly positive correlation was obtained from the study between DMY 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 DM partitioning of plant fractions (LB, ST, and D) in the 3 genotypes are shown from 15 June to 28 November in Figure 3.5. 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 15 June when the highest LB (100%) in both DL and ME occurred, showing a simple index for CP concentration of herbages. 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 LB to ST (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 digested effluent of manure (DEM) application across the seasons. In the first defoliation of DL napiergrass, when the plant height reached 111–132 cm, DMY 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.

3.4.3 Canopy structure

Changes in the RLI of the canopy and canopy architecture were observed in the first and second cuttings on 4 September and 28 November, respectively, across the 3 genotypes (Figure 3.6). Canopy RLI decreased with strata, and the decreased percentage tended to be more severe in 7734 than in DL and ME because of steeper decrease in RLI however, lower K was due to higher leaf area. 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 28 November, the amount of leafages was lower in the second cutting on 28 November than in the first cutting on 4 September.

Canopy K was the lowest in 7734 at 0.36 and 0.61 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.

3.4.4 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 4 September and 28 November, respectively (Table 3.1). 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 DM for LB and 91 to 102 mg/g DM for ST in the first cutting and was increased to 114 to 206 and 91 to 181 mg/g 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 DM in LB and ST, respectively, and LB tended to have higher CP concentration than ST (Fukagawa *et al.,* 2000). The dwarf genotypes of napiegrass tended to have higher CP concentration than the normal genotypes (Sollenberger *et al.,* 1988a; Muinga *et al.,* 1993; Silva *et al.,* 1994; Chaparro and Sollenberger, 1997; Tudsri *et al.,* 2002a), 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 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 3.7). 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.

It is reported that IVDMD in ME was variable from 567–772 and 619–786 mg/g 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 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 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 3.2). 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 DM, and ADF concentration ranged from 383 to 439 ± 2.9 mg/g DM, with the highest values generally found in the summer. Similar fiber contents were reported for the dwarf genotype (Silva *et al.,* 1994).

3.5 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.

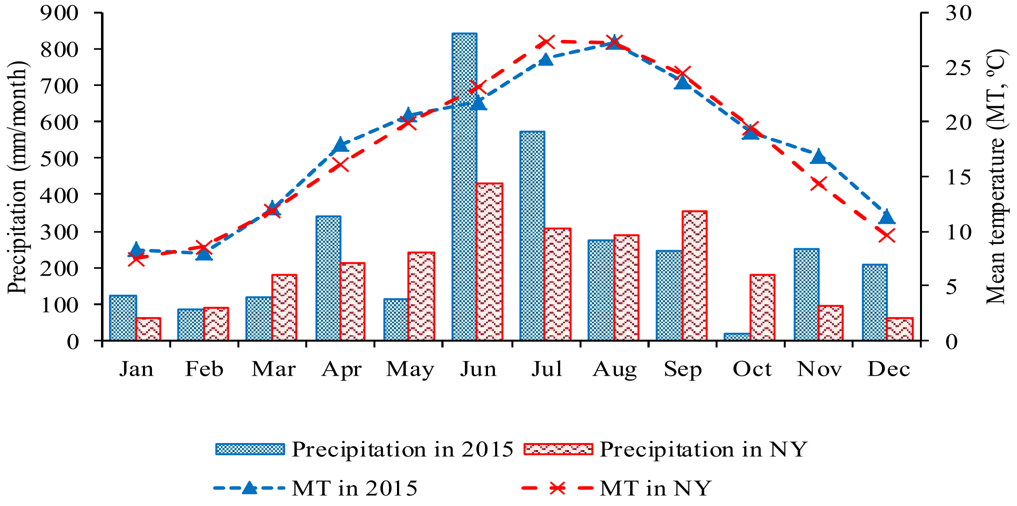


Figure 3.1. Changes in climatic conditions in 2015 compared with the normal year (NY), averaged in 1980-2010.

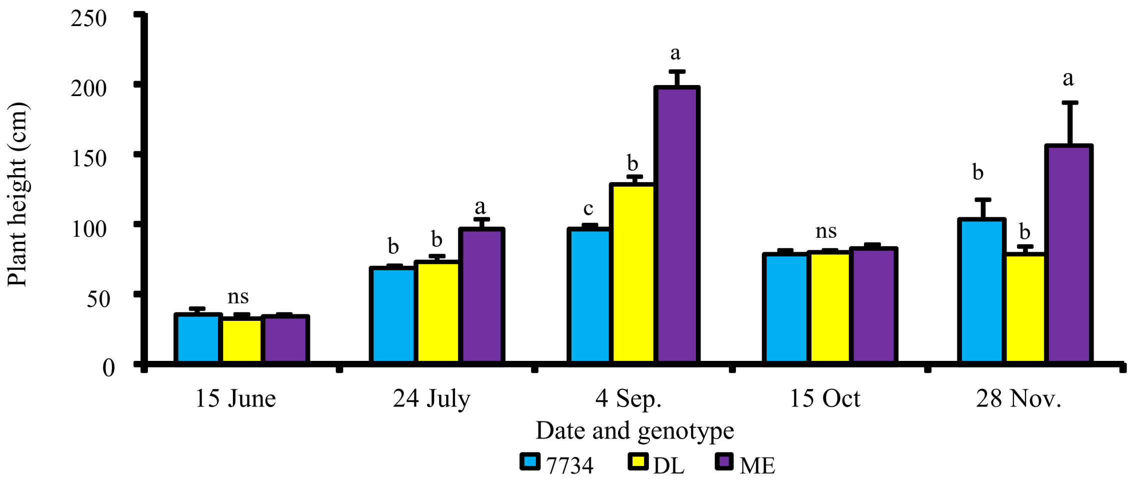


Figure 3.2. Changes in plant height for the 3 genotypes in 2015. The symbol shows mean values ±standards deviation (n=3). Symbols with different letters denote significant difference at the 5% level by LSD test.

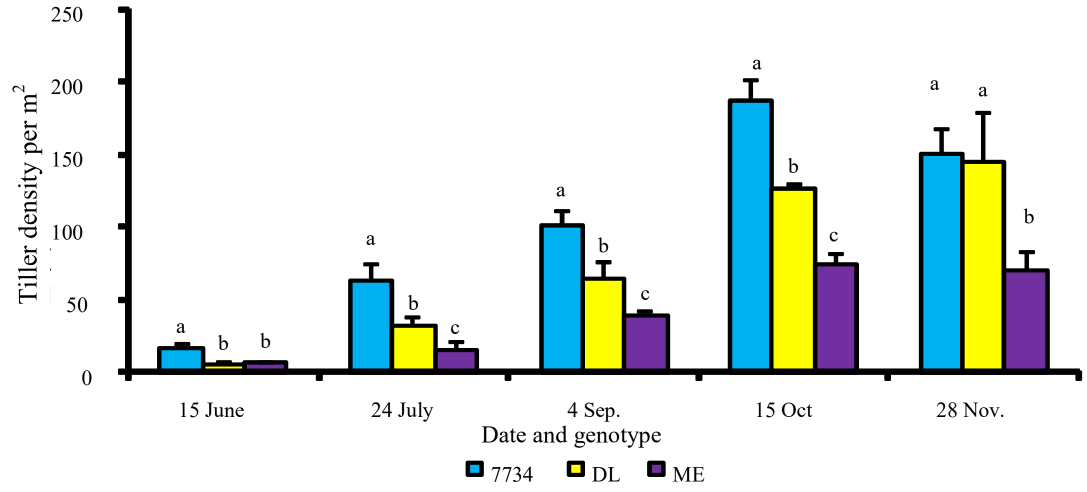


Figure 3.3. Changes in tiller density of the 3 genotypes in 2015. The symbol shows mean values±stabdards deviation (n=3). Symbols with different letters denote significant difference at the 5% level by LSD test.

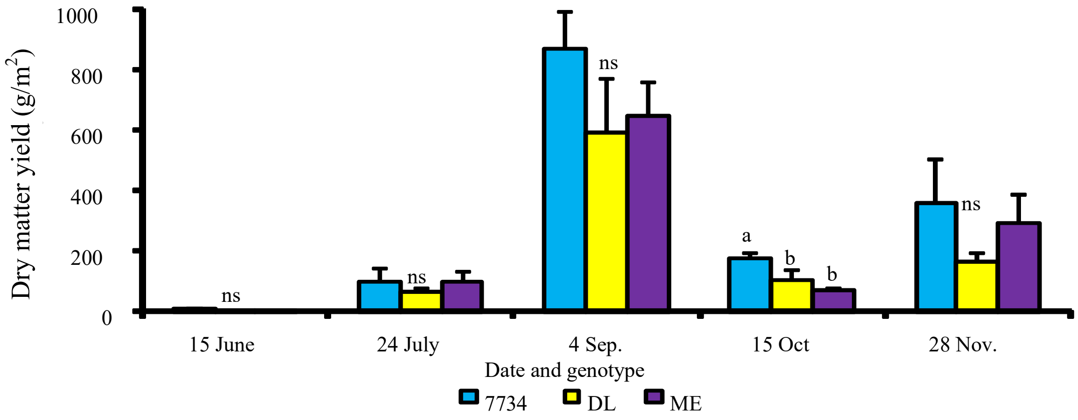


Figure 3.4. Changes in dry matter yield of the 3 genotypes in 2015. The symbol shows mean values±stabdards deviation (n=3). Symbols with different letters denote significant difference at the 5% level by LSD test.

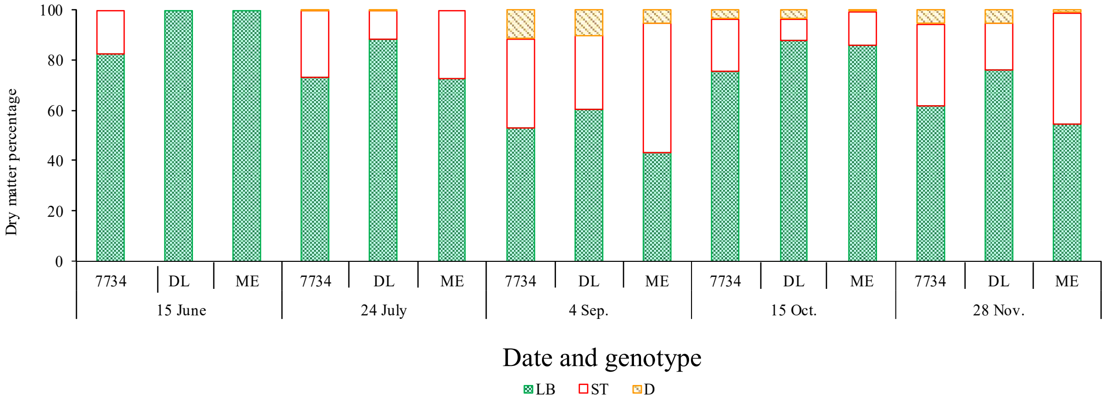
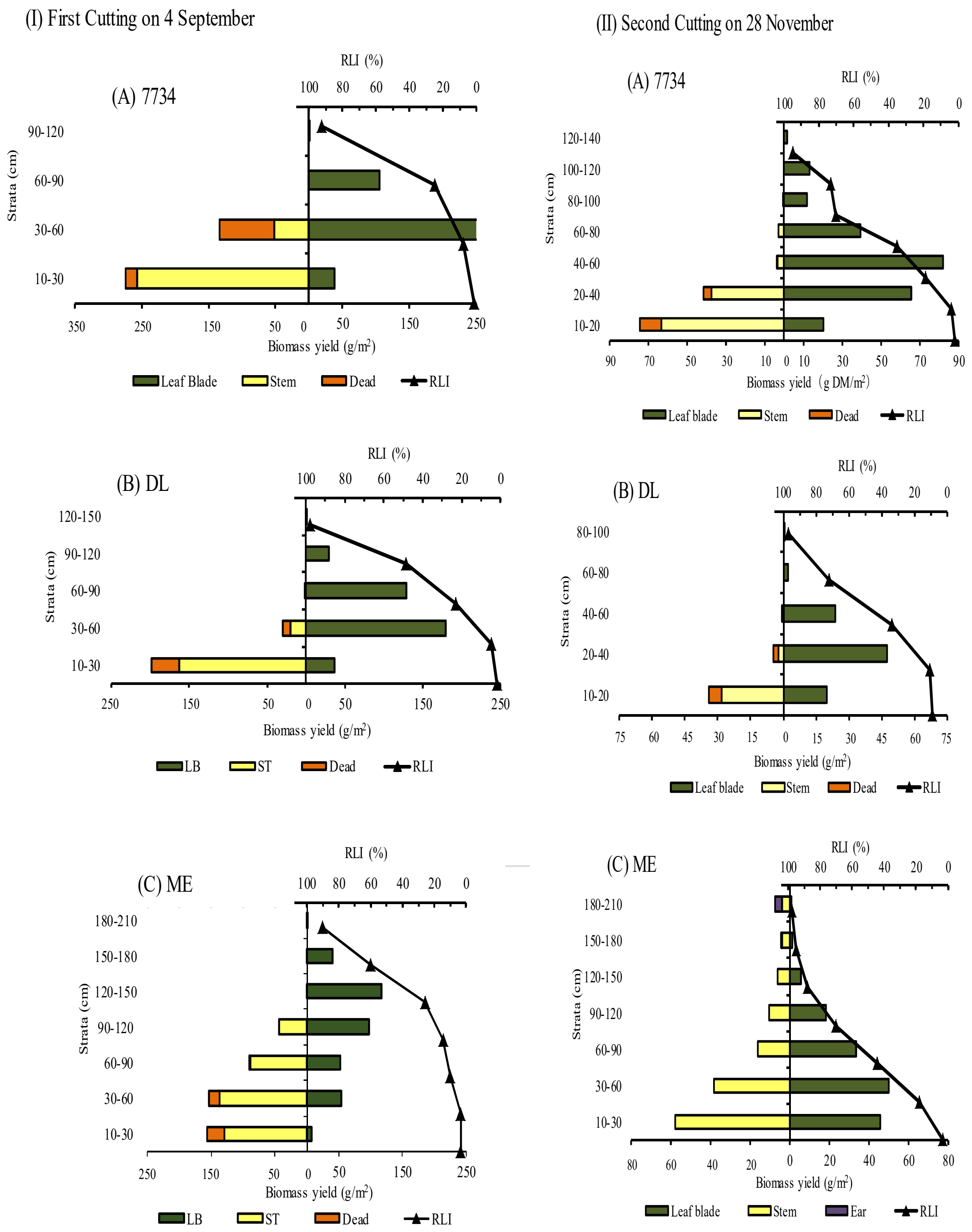


Figure 3.5. Changes in percentage of dry matter of plant fractions in leaf blade (LB), stem inclusive of leaf sheath (ST), and dead leaves (D) in the 3 genotypes. The symbol shows mean values (n=3).

Table 3.1. Crude protein concentration (mg/g DM) of plant fractions in Napiergrass genotypes.

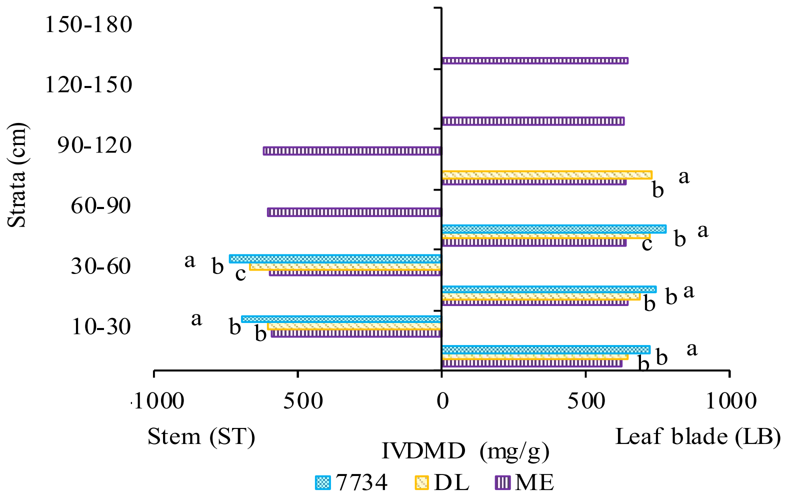
	September						November					
	LB			ST			LB			ST		
S	7734	DL	ME	7734	DL	ME	7734	DL	ME	7734	DL	ME
1			138				206					
2			117				208					
3			100				151			159		
4		129a	102b			91	144a	132a	137a	181		
5	145a	116b	92b			69	129a	127a	129a	112a		64a
6	111a	81b	77b	102a	82a	39b	112a	104a	115a	103a	47a	57a
7	82a	58b	94a	91a	70a	31b	114a	87a	114a	91a	52a	45a

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.



Figures 3.6. Changes in relative light intensity (RLI) in the canopy and canopy architecture at the first cutting on September 4 (I) and at the second cuttimg on Novevember 28 (II). The symbol shows mean values (n=3).

(A) First cutting on 4 September



(B) Second cutting on 28 November

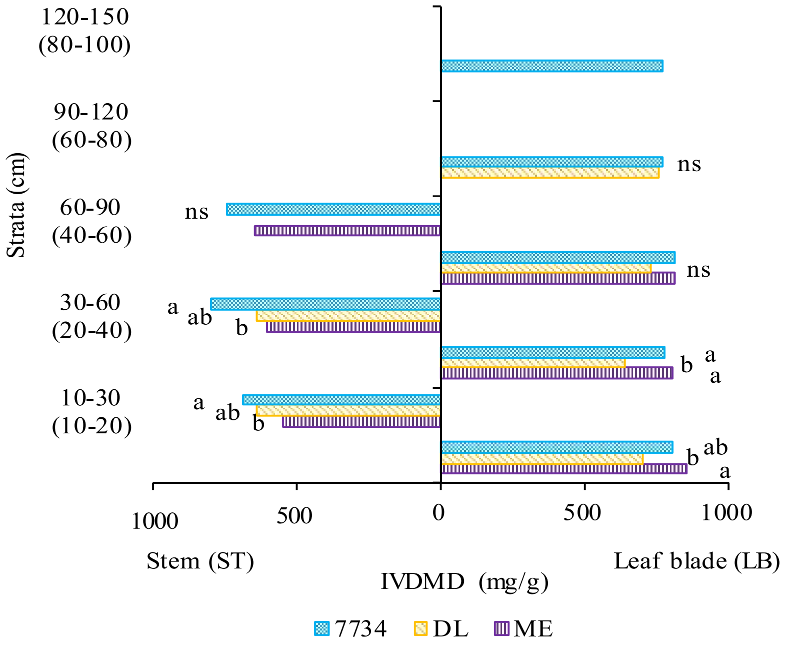


Figure 3.7. Changes in *in vitro* dry matter digestibility (IVDMD) amomg canopy strata at the first cutting on September 4 (A) and at the second cutting on Novemver 28 (B), for stem (ST) and leaf blade (LB) fractions. Symbols with different letters denote significant difference at the 5% level by LSD test.

Table 3.2. Structural carbohydrate concentration (mg/g DM) of plant fractions in NDF (A), ADF (B) and ADL (C) for the 3 Napiergrass genotypes.

(A) NDF

	4 September						28 November					
	LB			ST			LB			ST		
Strata	7734	DL	ME	7734	DL	ME	7734	DL	ME	7734	DL	ME
2			657				608					
3			676				590					
4		635a	664a			667	632a	551a				
5	629b	646ab	683a			677	607a	579a	595a	592a		633a
6	647a	659a	692a	608b	665a	694a	633a	601ab	564b	645a	667a	644a
7	659b	698ab	704a	630b	666a	701a	642a	630a	545b	639a	652a	693a

(B) ADF

	4 September						28 November					
	LB			ST			LB			ST		
Strata	7734	DL	ME	7734	DL	ME	7734	DL	ME	7734	DL	ME
2			410									
3			426				396					
4		423a	430a			430	418					
5	393a	432a	425a			431	428a	432a	422a	386a		472a
6	403b	444a	433a	399c	436b	441a	424a	447a	423a	393b		495a
7	426b	457a	424b	415b	443ab	456a	434a	441a	433a	412b	437b	529a

C) ADL

	4 September						28 November					
	LB			ST			LB			ST		
Strata	7734	DL	ME	7734	DL	ME	7734	DL	ME	7734	DL	ME
2			106									
3			117				129					
4		101a	125a			122	128					
5	84b	104ab	117a			128	140b	208a	126b	63a		133a
6	92a	101a	122a	94a	90a	111a	129a	137a	123a	68b		145a
7	91b	103ab	119a	89b	108a	130a	147a	112a	133a	81b	92b	136a

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

CHAPTER 4

GRAZING POTENTIAL OF FOGGAGE AND FRESH DWARF NAPIERGRASS PASTURE BY BREEDING BEEF COWS IN SOUTHERN KYUSHU, JAPAN

4.1. Abstract

Two Napiergrass genotypes, a semi-dwarf late-heading, DL, and a true dwarf (Taiwan Line 7734), were examined for grazing potential on foggage pasture with an area of 2000 m^2 in winter and for rotational grazing on fresh grass pasture with an area of 3500 m^2 by the three replication per genotype in addition with the fourth replication for 7734 in summer in southern Kyushu, Japan. In one-day intermittent grazing on foggage pasture by 24 JB breeding beef cows from December to March, 2017, grazing time on Napiergrass increased up to late February, and pasture height and herbage mass decreased consistently with grazing. In the rotational grazing by three JB breeding beef cows during pregnancy over two cycles from mid-July to early September 2017, pre- and post-grazing plant height was higher for DL than 7734. Herbage mass was roughly comparable between the two genotypes in the first cycle, while it decreased considerably for 7734 in the second cycle. However, the herbage consumption (HC) tended to be similar between genotypes, and moreover, dry matter intake (DMI) tended to be higher for 7734 than for DL in the first cycle. LW gain increased with grazing, averaging 0.79 kg/head/day under an average stocking rate of 8.6 cows/ha with 19.42 g DM/kg LW/day of DMI. Therefore, the LW of breeding beef cows was at least maintained under rotational grazing without additional feed supply for 56 days in summer.

4.2. Introduction

Phenotypic variation in Napiergrass (*Pennisetum purpureum* Schumach) includes normal, semi-dwarf (DL), and dwarf (Taiwan Line 7734) types (Negawo *et al.*, 2017). It is previously shown that dwarf and semi-dwarf genotypes have a contrasting canopy structure to normal Napiergrass, cv. ME (Kadwal *et al.*, 2016) in chapter 3, and the dwarf types were better suited for grazing than the normal type (Mukhtar *et al.*, 2004b), since they had a higher tiller number and percentage of LB. Napiergrass is a C_4 tropical grass that produces plentiful, nutritious green forage and is considered an excellent feeding source for livestock raised under grazing systems and green chopping in tropical regions (Vicente-Chandler *et al.*, 1959; Woodard and Prine, 1993) and in temperate Kyushu, Japan (Sunusi *et al.*, 1999; Wadi *et al.*, 2004; Ishii *et al.*, 2005; Utamy *et al.*, 2011). Leaves of tropical grasses, including Napiergrass, are susceptible to frost damage and growth of plants ceases when faced with frost. However, frost-damaged leaves form foggage, which should have the potential to be used as stored herbage over winter in the same way as hay and silage are used during the summer. However, no research findings are available for grazing of beef cows on Napiergrass foggage as autumn-saved pasture (Daly and Allan, 1985).

Rotational grazing is a method to enable an intensive grazing management, which allows livestock a continuous opportunity to consume fresh grass at an active growth stage (Chacon *et al.*, 1978). In order to maximize livestock production, sustainability and longevity of the pasture, the impact of grazing animals on community structure, and maintaining a functional ecosystem in the pasture are key issues in rotational grazing management (Krysl and Hess, 1993). Therefore, a grazing system is a management tool that allows pasture managers to control the frequency and duration of grazing and rest periods to optimize livestock and plant performance (Savory and Parsons, 1980). DL Napiergrass can adapt to intensive rotational grazing by beef cows (Ishii *et al.*, 2005) and is allowing expansion of cultivation areas in southern Kyushu (Utamy *et al.*, 2011; Ishii *et al.*, 2013). Grazed DL Napiergrass produces a high herbage mass and quality and provides herbage more cheaply than imported hay. However, no grazing management on 7734 Napiergrass pasture has been previously examined in southern Kyushu, Japan. A tropical legume, lablab bean (*Dolichos lablab* L.) was found suitable for mixed cropping with a tropical grass, ruzigrass (*Brachiaria ruziziensis*), to increase crude protein (CP) in herbage and milk production by grazing dairy cows in Thailand (Tudsri *et al*., 1997). Napiergrass was found suitable for intercropping with tropical legume species such as leucaena (*Leucaena leucocephala*) in Tudsri and Kaewkunya (2002), stylo (*Stylosanthes scabra* cv. Seca) and siratro (*Macroptilium atropurpureum* cv. Siratro) by Njoka-Njiru *et al.* (2006).

The present study was conducted to examine the grazing potential on foggage and fresh grass of two genotypes of Napiergrass, a semi-dwarf and a true dwarf. In the first trial, Napiergrass was used as frosted fodder for breeding beef cows for 1-4 months after frost in southern Kyushu. In the second trial, the rotational grazing potential of two Napiergrass genotypes was determined in mixed cropping with lablab bean and the LW gain of three JB breeding beef cows was determined during the summer season in southern Kyushu.

4.3. Materials and Methods

4.3.1. Experimental site and plant species examined

The experiments were conducted at the Sumiyoshi Livestock Experimental Station of the University of Miyazaki, located on sandy soils (131°25′ E, 31°54′ N), combining two trials on foggage pasture from December 2016 to March 2017 and on fresh grass pasture from July 2017 to September 2017. Plant species examined in 2016 were two Napiergrass genotypes, semi-dwarf type DL, which was derived from Kasetsart University, Thailand in 1996 (Mukhtar *et al*., 2003), and true dwarf type, Taiwan Line 7734, abbreviated as 7734, from the Okinawa Livestock Experimental Station in 2010. The species examined in 2017 were DL and 7734 Napiergrass genotypes and the tropical herbaceous legume lablab bean.

4.3.2. Grazing trials on foggage pasture in the winter season

In 2016, two Napiergrass genotypes, DL and 7734, were used to establish pastures at 500 m^2 per paddock by transplanting rooted tillers at 1 plant/m^2 with two replications per genotype, one on 18 June and the other on 27 June 2016 (Figure 4.1). Pastures were fertilized with 112 kg N, P_2O_5 and K_2O/ha/yr by twice-split application. Napiergrass was killed by the first frost on 25 November 2016. The first monitoring session of grazing behavior, classified as grazing on Napiergrass and other plants, standing or lying, or drinking water, was conducted on three breeding JB beef cows for 1 hr per paddock with two replications on 29 December 2016. The second, third, fourth and fifth grazing sessions were conducted over 6 hr on 5 January, 13 January, 24 February and 16 March 2017, respectively, when four paddocks of the two Napiergrass genotypes were grazed by the same 24 JB cows and 5-8 calves. Grazing behavior of two selected animals, the same as in the first monitoring session, was monitored using the same classification of behavior. Pre-grazing herbage mass was determined by defoliating two plants/paddock 10 cm above the soil, and pre-grazing pasture height by measuring 20 plants/paddock in each of the monitoring sessions. After winter, the percentage of overwintering Napiergrass plants was determined for four paddocks of both genotypes on 3 May 2017. Pastures were not defoliated after wintering, but were fertilized at 56 kg N, P_2O_5 and K_2O/ha on 6 May 2017.

4.3.3. Grazing trials on fresh grass pasture in the summer season

In 2017, DL and 7734 paddocks were extended by transplanting rooted tillers at 1 plant/m^2 for 500 m^2 per paddock on 27 May as the third replication. Another 7734 paddock was established as the fourth replication on 29 June using the same procedure used for the third replication (Figure 4.1). In this year, lablab bean was sown to the intra-row spaces of Napiergrass at 2 m intervals (0.5 plants/m^2). Pastures were fertilized with four split applications, one of 28 kg N, P_2O_5 and K_2O/ha at establishment, and 56 kg N, P_2O_5 and K_2O/ha three times, one on 14 June and again at the end of the first and second grazing practices in each paddock. Annual total fertilizer supply was thus 168 kg N, P_2O_5 and K_2O/ha/yr for the first and second replications, established in 2016, and 196 kg N, P_2O_5 and K_2O/ha/yr for the third and fourth replications, established in 2017. Weeds were controlled by hand as required.

Three head of pregnant JB beef heifers with an initial mean LW of 417 kg were used for the rotational grazing, conducted from 12 July to 6 September in two cycles. In the first cycle, the grazing period was almost one week (5-8 days) for the first and second replicated paddocks of both genotypes, while the period was reduced to 2-3 days for the third replicated plot and no grazing was imposed on the fourth plot. In the second cycle, the grazing period needed to be shortened to 3-6 days in the first and second replicated paddocks and was 2-3 days in the third and fourth paddocks.

Termination of grazing was judged by a pasture height of around 50 cm. No additional herbage was supplied, except for mineral supplements supplied ad libitum. Before the grazing started, the cows were raised with grazing on bahiagrass pasture with supplemental indoor feeding of IR silage. All paddocks were connected to the watering facility under sheltering woods.

4.3.4. Live weight of animals and plant measurement

Animal live weight was measured at 9:30-11:00 a.m. at the start of grazing and when the animals were switched to a different paddock. Plant height of Napiergrass was measured for 20 plants per paddock both pre- and post-grazing. Growth attributes of plant length, tiller density and FW of herbage were monitored for 6 plants per paddock. Sampled plants were randomly selected and defoliated 10 cm above the ground at both pre- and post-grazing. Subsamples of fresh grass or lablab bean plants of about 300-400 g FW were fractionated to LB, ST and D and then oven-dried at 70°C using a ventilation oven for three days to determine DM weight and percentage of DM in each plant fraction both pre- and post-grazing. HC was determined by the difference between pre- and post-grazing herbage mass in addition to the growth rate of herbage during the grazing period. DMI by grazing animals was calculated by HC divided by the sum of animal LWs and duration of the grazing period.

4*.3.5. Statistical analysis*

Student's *t*-test at the 5% level was applied to analyze the differences in growth and yield attributes of Napiergrass genotypes and lablab bean both pre- and post-grazing. Analysis of variance (ANOVA) was carried out using SPSS software (version 15.0) by one-way analysis procedures for growth and yield attributes in a randomized complete design at each cycle. Mean separation was tested using the Tukey-Kramer method at the 5% level.

4.4. Results

4.4.1. Grazing on foggage pasture in the winter season

In the first winter season, grazing on Napiergrass foggage was conducted five times during 1-4 months after the first frost (Table 4.1). Time of grazing on Napiergrass by monitored cows increased from the first to the fourth grazing, and Napiergrass grazing time tended to be a higher percentage for 7734 than for DL from the second to the fourth grazing, while it decreased during the fifth grazing for both genotypes. Pasture height and herbage mass decreased consistently with grazing from the first to fifth grazing, showing the almost complete consumption of Napiergrass foggage by grazing beef cows with calves. The percentage of overwintered plants (mean + standard error, n = 2) in DL and 7734 pastures was 99.3 + 0.35% and 100%, respectively, determined on 3 May 2017, showing that almost perfect overwintering ability could be maintained at the research site.

4.4.2. Grazing on fresh grass pasture in the summer season

4.4.2.1. Changes in growth attributes with grazing cycle

Changes in plant height are shown in Figure 4.2, and tiller and branch density of Napiergrass and lablab bean are shown in Figure 4.3 for both pre-and post-grazing averaged over 2-4 paddocks during two cycles of summer grazing in 2017. In Cycle 1, pre-grazing plant height was generally the highest for DL and lowest for lablab bean (Figure 4.2). In Cycle 2, the difference in the pre-grazing plant height among genotypes and species was the same as in Cycle 1, while the absolute values of height uniformly decreased between Cycle 1 and Cycle 2. Plant height post-grazing was more stable than at pre-grazing, and was highest for DL at 44-48 cm, followed by lablab bean at 36-39 cm, and lowest for 7734 at 33-37 cm in both the first and second cycles (Figure 4.2).

Comparing the two genotypes of Napiergrass, tiller density was fairly similar in both the first and second cycles, even though DL tended to have higher density (Figure 4.3). Tiller density increased from the first to the second cycle uniformly in both genotypes, and tended to increase during grazing, except for DL in the second cycle. Branch density of lablab bean was lower than tiller density of the two Napiergrass genotypes in both cycles but increased slightly between cycles (Figure 4.3).

4.4.2.2. Changes in herbage mass and percentage of plant fraction with grazing cycle

Changes in herbage mass are shown in Figure 4.4 for the two Napiergrass genotypes and lablab bean in the two cycles of summer grazing in 2017. In Cycle 1, pre-grazing herbage mass was the highest for DL and the lowest for lablab bean. Post-grazing herbage yield decreased considerably in DL and 7734, while it changed slightly in lablab bean (Figure 4.4). In Cycle 2, pre-grazing herbage mass almost fully recovered during the rest period. However, post-grazing herbage mass decreased to a larger extent in 7734 than DL. Herbage mass in lablab bean was lower than in the Napiergrass genotypes and decreased slightly during grazing (Figure 4.4).

Changes in the percentage of plant fractions are shown in Figure 4.5 for the two Napiergrass genotypes and lablab bean from pre- to post-grazing in two cycles of summer grazing in 2017. The percentage of LB in DL was higher in Cycle 1 than in Cycle 2, and decreased consistently during grazing. In 7734, the LB percentage tended to be lower than in DL at the first grazing, while the percentage was almost the same between the two genotypes at the second grazing. However, the post-grazing LB percentage tended to be lower in 7734 than in DL for both grazing practices. The percentage of D increased during grazing and between the first and second grazing practices in both genotypes of Napiergrass, while changes in the percentage of D tended to be larger in DL than in 7734. In lablab bean, the percentage of LB was slightly higher than ST at pre-grazing and decreased during both the first and second grazing practices, while the decrease in percentage of LB by grazing was limited to both the first and second grazing events (Figure 4.5).

4.4.2.3 Herbage consumption and dry matter intake

Changes in HC (A) and DMI (B) are shown in Figure 4.6 for both Napiergrass genotypes and lablab bean in two cycles of summer grazing in 2017. In Cycle 1, HC was lower in DL at 242 g DM/m^2 than in 7734 at 292 g DM/m^2, while it was severely limited for lablab bean at 5 g DM/m^2. In Cycle 2, HC tended to decrease from the first to the second cycle in both Napiergrass genotypes and lablab bean. In Cycle 1, DMI tended to be higher in 7734 at 20.5 g DM/kg LW/day than in DL at 17.2 g DM/kg LW/day, while the DMI at the second cycle was roughly comparable at 16.2 g DM/kg LW/day in both genotypes. DMI in lablab bean was quite limited at 0.5 and 0.2 g DM/kg LW/day in the first and second cycle, respectively.

4.4.2.4. Live weight gain of grazing animals

Changes in live weight gain in breeding beef heifers and the relationship between dry matter intake (DMI) and average daily gain (ADG) are shown in Table 4.2 for the two Napiergrass genotypes and lablab bean in two cycles of summer grazing in 2017. Live weight (LW) gain increased with grazing from the first to the second cycle. Therefore, cow LW was at least maintained under the rotational grazing system without any concentrate feeding during the two cycles for 56 days. Across two cycles, average daily gain was 0.79 kg per day and average dry matter intake was 19.4 g DM/kg LW/day.

4.5. Discussion

I used the same four paddocks that were used in the intermittent grazing trial on foggage Napiergrass in the winter season for five grazing trials as autumn-saved pasture, which was applied to temperate pasture (Daly and Allan, 1985) and tropical pasture (Schalkwyk and Gertenbach, 2000). After each grazing event, no regrowth is expected due to the cold winter temperatures. Therefore, herbage mass and pasture height decreased consistently from the first to the last grazing trial, as shown in Table 4.1. It is necessary to consider that the present grazing behavior might be affected by the change of foggage structure with grazing trials.

Changes in plant height with grazing in the summer show that the pre- and post-grazing plant height were higher in DL than in 7734, while the post-grazing height was maintained at around 40-50 cm for both genotypes over two cycles (Figure 4.2). The recovery of plant height between the first and second cycles was greater in DL than in 7734, showing an enhancement of the genotypic differences in pre-grazing height at the second cycle. I previously observed that in the year of establishment, plant height was greater in DL than 7734 at harvest of the first cutting in early September (Kadwal *et al.*, 2016) in Chapter 3. As a trend in grazing of breeding beef cows on DL Napiergrass pastures, Mukhtar *et al.* (2004) also found that post-grazing height was limited to 30-50 cm, generally determined by the position of the leaf junction. Hasyim *et al.* (2016) also found that post-grazing plant height remained similar across DL Napiergrass paddocks at around 40-50 cm above the ground, where the lamina junction was positioned. These observed trends likely result from the usual unwillingness of beef cows to graze stem parts of fresh grass. Relatively constant post-grazing plant height may be caused by the high palatability of leafage in Napiergrass for grazing cows (Hasyim *et al.*, 2016). In contrast, plant height of foggage Napiergrass decreased below 40 cm at the fifth grazing, suggesting high palatability of stem sections when affected by frost damage in both genotypes.

Tiller density in the summer season increased similarly from the first to the second grazing for both genotypes, even though DL tended to have higher density than 7734 at both the first and second cycles (Figure 4.3). As previously observed by Mukhtar *et al* (2004a), pre-grazing tiller density in DL Napiergrass increased uniformly from the first to the third grazing cycle, suggesting high tillering ability after defoliation of the mother tillers in this genotype. The lower recovery of tiller density of 7734 Napiergrass may be due to grazing in the paddocks established in 2017. An increase in tiller density with a concomitant decrease in mean tiller weight during the grazing cycle is a desirable tendency for a species intended for grazing beef cows, because Napiergrass genotypes had such a high mean tiller weight at the first cycle that consumption of the whole tiller mass was not easy. Under defoliation management (Mukhtar *et al.*, 2003), tiller density increased with an increase in cutting frequency in the two years following establishment, and the most frequent defoliation treatment was at almost the same frequency as in the present grazing management for one-month or smaller intervals. It is apparent that recovery of tiller density in both DL and 7734 Napiergrass genotypes requires at least a one-month rest period even in the hot summer month of August.

Changes in herbage mass with grazing cycle, as shown in Figure 4.4, demonstrated that pre-grazing herbage mass was roughly comparable between the two genotypes of Napiergrass, averaging 360-383 g DM/m^2 at the first cycle, while it decreased considerably in 7734 to 190 g DM/m^2 in the second cycle, compared with almost complete recovery in DL at 361 g DM/m^2. Ako (2010) reported that both pre- and post-grazing, herbage mass tended to increase with grazing cycle from the first to the eighth week, except for the post-grazing mass in the first week, and tended to be constant from the eighth to the fifteenth week. This suggested that DL Napiergrass pasture has the capacity to be grazed and supply enough herbage mass for beef cows for 4-7 days of grazing at monthly intervals in the second year from establishment, while recovery of herbage mass in 7734 Napiergrass was almost two-thirds of that at the first grazing under this grazing frequency. Ishii *et al.* (2005) also reported that pre-grazing herbage mass of DL Napiergrass pastures averaged 389 g DM/m^2 for the three grazing cycles in

2002 and 221 g DM/m^2 for the six grazing cycles in 2003, which supports the present results for herbage mass. During grazing on DL Napiergrass pasture by a standard herd (around 10 head) of breeding JB beef cows, pre-grazing herbage mass ranged from 389 to 703 g DM/m^2/yr (Ishii *et al.*, 2013).

Changes in the percentage of plant fractions as shown in Figure 4.5 under rotational grazing management were the opposite of a previous defoliation treatment on DL and 7734 Napiergrass genotypes (Kadwal *et al.*, 2016) in chapter 3, which found that the LB percentage increased from the first to the second defoliation, while in the present study, LB percentage decreased from the first to the second grazing cycle. The increase in LB percentage with defoliation management (Kadwal *et al.*, 2016) corresponded with a previous defoliation study in DL Napiergrass (Hasyim *et al.*, 2014), showing that the ratio of LB to ST (LB/ST) was lower at the first cutting in the year of establishment than at two later cutting stages. Under previous grazing management on DL Napiergrass pasture by dairy cows, Hasyim *et al.* (2016) reported that pre-grazing LB percentage decreased consistently from the first to the following cycles in the two years of grazing. Therefore, in the present study, frequent rotational grazing at monthly or shorter intervals would not be enough to allow recovery of the leaf canopy for consumption by grazing beef cows, and thus, the post-grazing LB percentage decreased significantly over all paddocks of both genotypes of Napiergrass.

HC decreased from the first to the second cycle, and the rate of decrease was larger in 7734 than in DL (Figure 4.6A), which correlated reasonably with the change in pre-grazing herbage mass, except for the largest HC of 7734 at Cycle 1 due to the largest drop of herbage mass from almost complete consumption by grazing beef cows. Mukhtar *et al.* (2004a) also reported that HC of DL Napiergrass pasture decreased from the first to the third cycle. DMI in the present study averaged 14.8-28.3 g/kg LW/day (Figure 4.6B), which was comparable to Mukhtar *et al.* (2004), in which DMI averaged 15.5-28.6 g/kg LW/day under rotational grazing on four paddocks of DL Napiergrass pasture. Additionally, grazing time on DL Napiergrass pasture was stable at 50–60% in the daytime on the first grazing day in both years of grazing trials. Under three stocking rates (7.5, 10 and 15 animals/ha) of yearling steers averaging 230–250 kg LW/head on three varieties of stargrass swards in Florida, USA, forage intake was calculated as 10.2, 9.3 and 7.6 kg DM/animal/day, respectively (Adjei *et al.*, 1980).

LW gain in breeding beef cows with grazing cycles as shown in Table 4.2 indicates that the ADG was 0.79 kg/day across all paddocks for 56 grazing days on two Napiergrass genotypes intercropped with lablab bean in only three paddocks in 2017. Sollenberger and Jones (1989) reported that the ADG over three seasons was 0.97 kg/head/day on Mott semi-dwarf type Napiergrass and 0.38 kg/head/day on Pensacola bahiagrass pastures under an average stocking rate of approximately 4 yearling steers/ha in Florida, USA. They concluded that since Mott Napiergrass persists well under optimum grazing management, Mott has great potential for improvement of animal production in the tropics and subtropics. Mukhtar *et al.* (2004) reported that the average DMI was 15.5-28.6 g DM/kg LW/day over the four paddocks studied and the ADG was 0.09 kg/head/day under intermittent grazing on DL Napiergrass pastures in Miyazaki, Japan. Thus, the LW of three beef cows was maintained during the second to the fourth grazing without concentrate feeding when DMI was above 20 g DM/LW/day. Arias (1980) reported that Friesian heifers achieved an ADG of 0.13-0.80 kg/day when fed on Napiergrass pasture varying in maturity from flowering to early vegetative stage. Dixon (1984) found that LW of Holstein heifers averaged weight gains of -0.21 to +0.72 kg/day when indoor-fed with 60 to 85-day-old Napiergrass in addition to 0.2, 0.4 and 0.8 percent molasses on an LW basis, even though the CP concentration was not specified with the supplements. Thus, the LW of breeding beef cows was at least maintained under rotational grazing of dwarf Napiergrass pastures in the summer without any supplied concentrates or roughage in southern Kyushu, Japan.

The present study revealed that foggage of dwarf Napiergrass genotypes had great palatability for breeding JB beef cows under intermittent winter grazing. The rotational grazing potential of dwarf Napiergrass foggage remains to be determined, as does estimating the change in ADG when it is used as autumn-saved pasture. These estimations would be the first step in utilization of dwarf-type Napiergrass pastures in year-round grazing management in the region.

Table 4.1. Grazing behavior of Japanese Black (JB) breeding beef cows on two genotypes of Napiergrass in the winter season from 29 December 2016 to 16 March 2017.

Date	Genotype	Grazing on Napiergrass (min)	Grazing on other plants (min)	Standing/ lying (min)	Drinking water (min)	Total (min)	Pre-grazing pasture height (cm)	Pre-grazing herbage mass (g DM/m^2)
29 Dec.	DL	67 (48)*	43 (31)	29 (21)	0 (0)	139 (100)	134.8	660.0
	7734	61 (46)	43 (32)	30 (22)	0 (0)	133 (100)	112.8	449.1
5 Jan.	DL	101 (51)	41 (21)	55 (28)	0 (0)	197 (100)	80.5	393.6
	7734	80 (95)	5 (5)	0 (0)	0 (0)	84 (100)	60.3	269.5
13 Jan.	DL	51 (38)	31 (23)	50 (37)	2 (2)	134 (100)	64.3	275.2
	7734	115 (80)	18 (13)	10 (7)	0 (0)	143 (100)	55.8	182.3
24 Feb.	DL	63 (28)	60 (26)	106 (46)	0.3 (2)	228 (100)	54.0	226.3
	7734	62 (80)	17 (13)	8 (7)	0 (0)	87 (100)	50.0	146.5
16 Mar.	DL	13 (19)	44 (64)	11 (16)	0.5 (1)	67 (100)	41.6 (39.3)$^+$	115.0
	7734	9 (30)	20 (67)	1 (3)	0 (0)	30 (100)	41.0 (38.3)$^+$	81.5

* Numbers in parentheses indicate duration of grazing as a percentage.

$^+$ Post-grazing height.

Table 4.2. Grazing on two genotypes of Napiergrass pastures by three Japanese Black (JB) breeding beef cows in the summer season from 12 July to 6 September, 2017.

Date of the start of grazing	Paddock (Genotype-Replication)	LW (kg)	Grazing period (Days)	DMI (g/kg LW/day)	DG (kg/day)
12 Jul	DL-Rep. 1	416.7	8	16.19	-0.46
20 Jul	7734-Rep. 1	413.0	6	29.87	0.89
26 Jul	DL-Rep. 2	418.3	7	13.29	0.19
2 Aug	7734-Rep. 2	419.7	5	26.71	-0.40
7 Aug	7734-Rep. 3 & DL-Rep. 3	417.7	5	20.86	1.67
12. Aug	DL-Rep. 1	426.0	6	23.90	-1.11
18 Aug	7734-Rep. 1	419.3	4	25.39	0.92
22 Aug	DL-Rep. 2	423.0	4	16.37	2.92
26 Aug	7734-Rep. 2	434.7	3	24.34	2.11
29 Aug	7734-Rep. 3	441.0	2	6.69	2.33
31 Aug	DL-Rep. 3	445.7	3	8.58	3.33
3 Sep	7734-Rep. 4 & DL-Rep. 3	455.7	3	8.53	1.78
6 Sep	End of grazing	461.0			
			Average	19.42	0.79

Notes: LW, live weight of beef cows; DMI, dry matter intake of cows; DG, daily LW gain of cows.

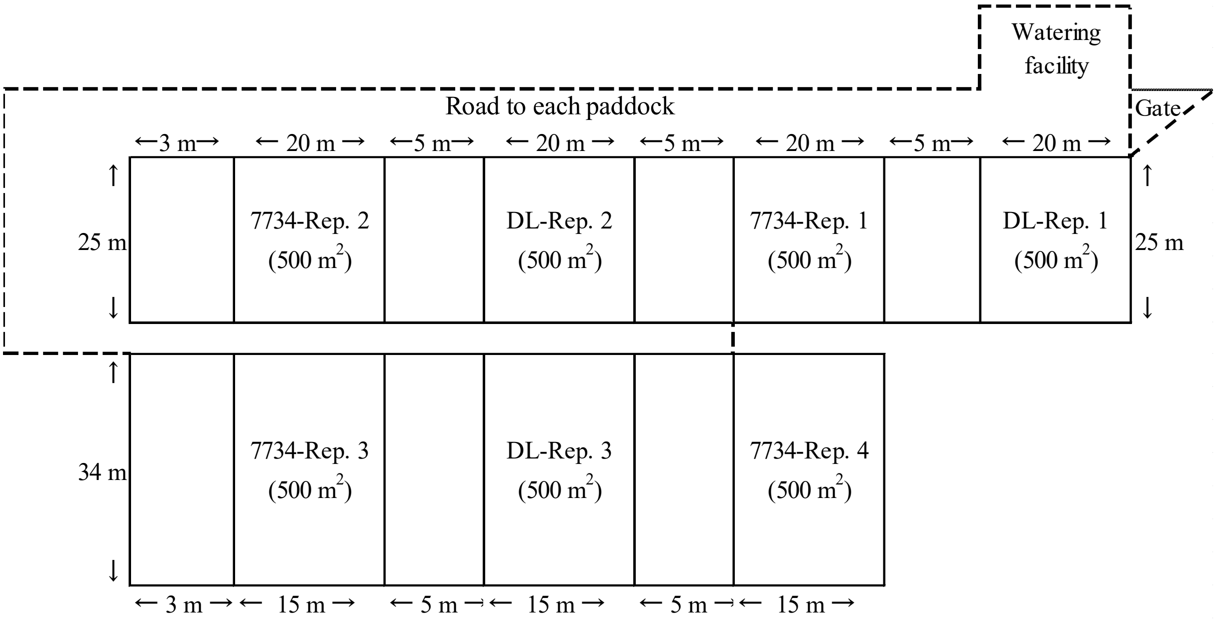


Figure 4.1. Field layout at Sumiyoshi Livestock Experimental Station in 2016 and 2017. Reps. 1-2 were established in 2016, and Reps. 3-4 were expanded in 2017. Dotted lines indicate wire fences.

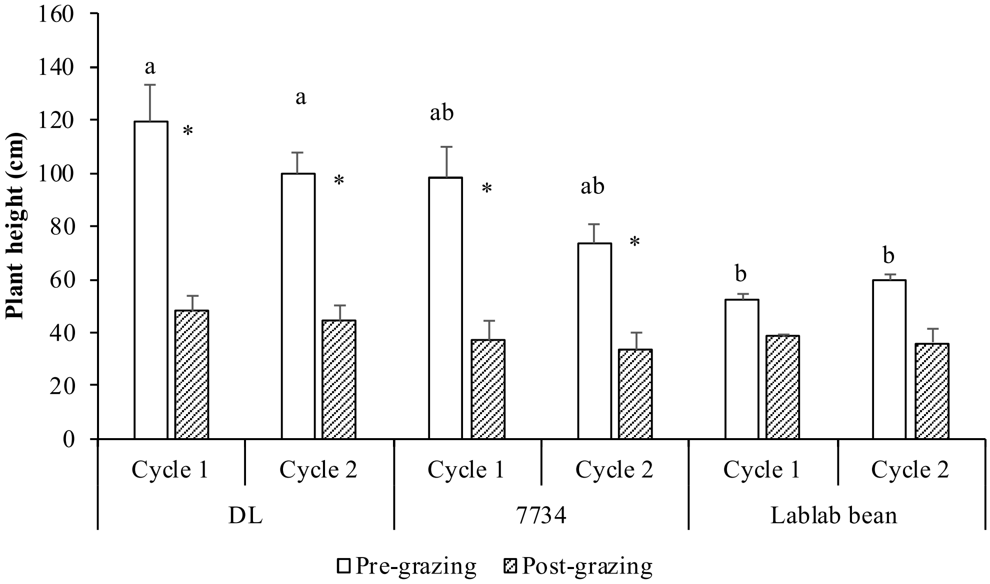


Figure 4.2. Changes in pre- and post-grazing plant height averaged for 2-4 paddocks of two Napiergrass genotypes (DL and 7734) and lablab bean in two cycles of summer grazing in 2017 (mean + SE).

Figures with different letters denote significant difference at the 5% level among species in the same cycle by Tukey-Kramer method. * denotes significant difference at the 5% level between pre- and post-grazing.

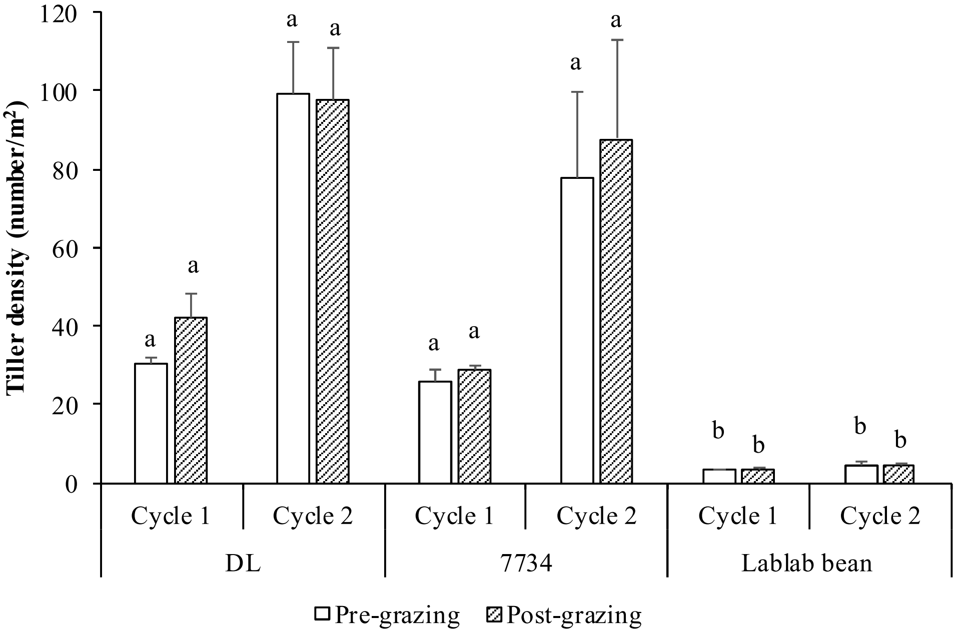


Figure 4.3. Changes in pre- and post-grazing tiller density of two genotypes of Napiergrass and branch density of lablab bean averaged over 2-4 paddocks in two cycles of summer grazing in 2017 (mean + SE).

Figures with different letters denote significant difference at the 5% level among species in the same cycle by Tukey-Kramer method.

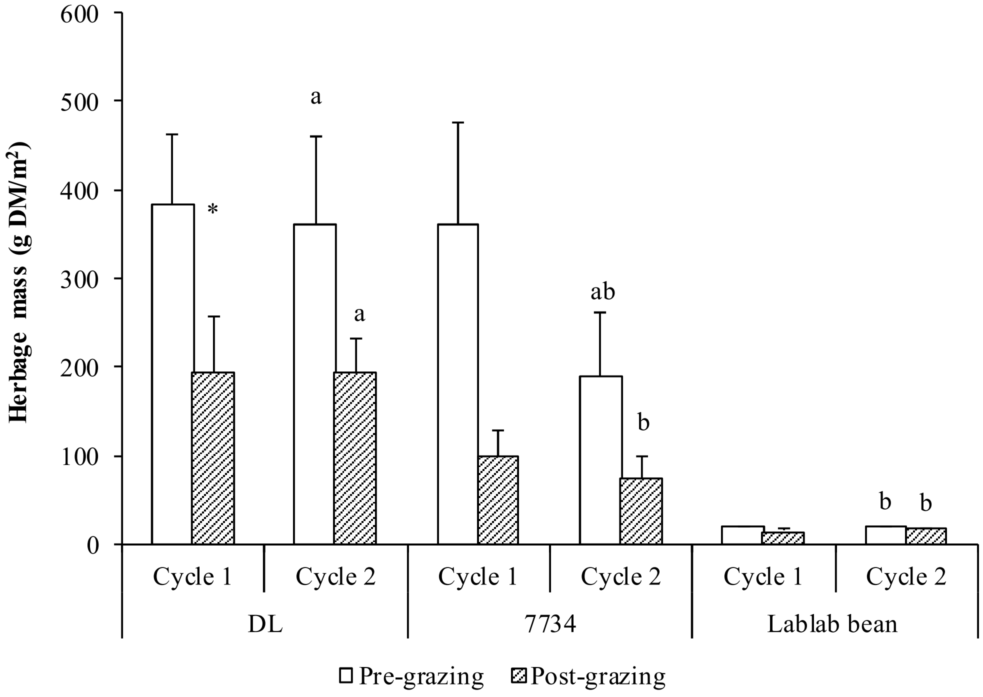


Figure 4.4. Changes in herbage mass of two Napiergrass genotypes and lablab bean at pre- and post-grazing in two cycles of summer grazing in 2017 (mean + SE).

Figures with different letters denote significant difference at the 5% level between genotypes or species in the same cycle by Tukey-Kramer method.

* denotes significant difference at the 5% level between pre- and post-grazing.

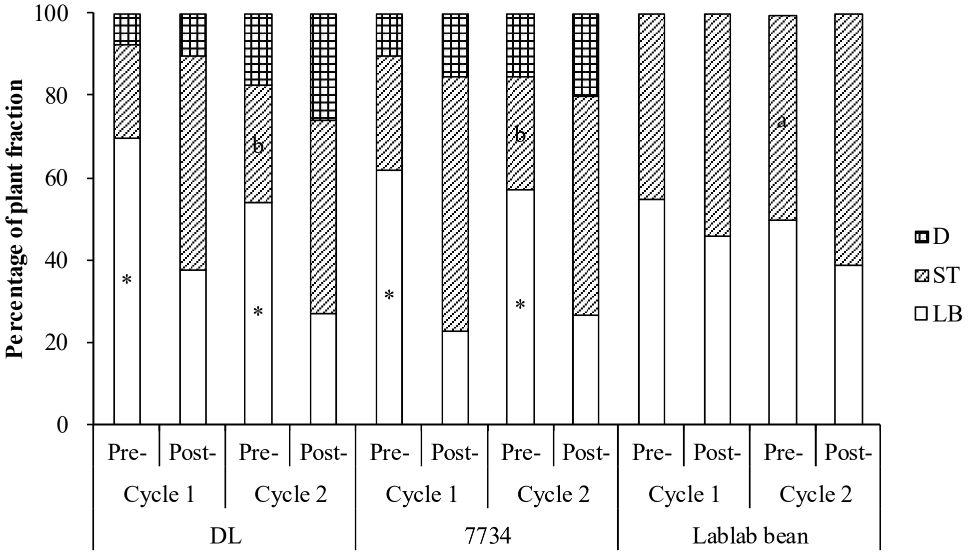


Figure 4.5. Changes in the percentage of plant fraction in leaf blade (LB), stem inclusive of leaf sheath (ST), and dead leaves (D) in two Napiergrass genotypes and lablab bean at pre- and post-grazing in two cycles of summer grazing in 2017.

Figures with different letters denote significant difference at the 5% level between genotypes or species in the same cycle by Tukey-Kramer method.
* denotes significant difference at the 5% level between pre- and post-grazing.

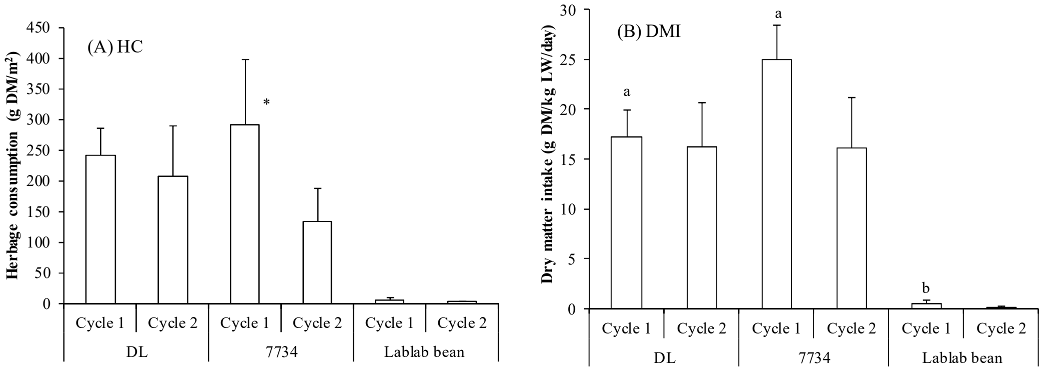


Figure 4.6. Changes in herbage consumption (HC, A) and dry matter intake (DMI, B) of two Napiergrass genotypes and lablab bean during the grazing period in two cycles of summer grazing in 2017 (mean + SE).

Figures with different letters denote significant difference at the 5% level between species in the same cycle by Tukey-Kramer method.

* denotes significant difference at the 5% level between pre- and post-grazing.

CHAPTER 5

GENERAL DISCUSSION

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 4 September, 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 28 November (Figure 3.2). 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.

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 (Figure 3.3). 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. DMY 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 4 September, 7734 had the highest DMY at 830 g/m^2, followed by ME at 640 g/m^2, and DL at 590 g/m^2. In the second cutting, DMY was not significantly different among cultivars. Therefore, annual total DMY 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 (Figure 3.4). The slow recovery on 15 October 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 and Fribourg, 1958; Boonman, 1993).

Utamy *et al.* (2011) reported that DMY in DL was so variable across the observed sites in southern Kyushu, ranging from 70–1360 and 20–1580 g/m^2/year in 2007 and 2008, respectively. It is clear that significantly positive correlation was obtained from the study between DMY 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.

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 (Figure 3.5). Percentage of LB was higher in DL than in 7734 and ME at both cuttings, except for 15 June when the highest LB (100%) in both DL and ME occurred, showing a simple index for CP concentration of herbages. 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 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 digested effluent of manure (DEM) application across the seasons. In the first defoliation of DL Napiergrass, when the plant height reached 111–132 cm, DMY 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 which was comparable to the present DL in the first cutting (Ishii *et al.,* 2013).

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 (Figure 3.6). 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 28 November, the amount of leafages was lower in the second cutting on 28 November than in the first cutting on 4 September.

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.

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 (Table 3.1). In general, CP concentration was the highest in 7734, ranging from 82 to 145 mg/g DM for LB and 91 to 102 mg/g DM for ST in the first cutting and was increased to 114 to 206 and 91 to 181 mg/g 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 DM in LB and ST, respectively, and LB tended to have higher CP concentration than ST (Fukagawa *et al.,* 2000). The dwarf genotypes of napiegrass tended to have higher CP concentration than the normal genotype (Sollenberger *et al.,* 1988; Muinga *et al.,* 1993; Silva *et al.,* 1994; Chaparro & Sollenberger, 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).

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 (Figure 3.7). 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. It is reported that IVDMD in ME was variable from 567–772 and 619–786 mg/g 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 (Fukagawa *et al.,* 2000). As for semi-dwarf DL, IVDMDs in LB ranged from 570–712 and 560–681 mg/g 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 DM in 2007 and 2008, respectively. (Utamy *et al.,* 2011). 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 (Table 3.2).

The pre- and post-grazing plant height were higher in DL than in 7734, while the post-grazing height was maintained at around 40-50 cm for both genotypes over two cycles (Figure 4.2). The recovery of plant height between the first and second cycles was greater in DL than in 7734, showing an enhancement of the genotypic differences in pre-grazing height at the second cycle. I previously observed that in the year of establishment, plant height was greater in DL than 7734 at harvest of the first cutting in early September (Kadwal *et al.,* 2016) in chapter 3. Relatively constant post-grazing plant height may be caused by the high palatability of leafage in Napiergrass for grazing cows (Hasyim *et al.,* 2016). In contrast, plant height of foggage Napiergrass decreased below 40 cm at the fifth grazing, suggesting high palatability of stem sections when affected by frost damage in both genotypes.

Tiller density in the summer season increased similarly from the first to the second grazing for both genotypes, even though DL tended to have higher density than 7734 at both the first and second cycles (Figure 4.3). In previous observation (Mukhtar *et al.,* 2004a), pre-grazing tiller density in DL Napiergrass increased uniformly from the first to the third grazing cycle, suggesting high tillering ability after defoliation of the mother tillers in this genotype. The lower recovery of tiller density of 7734 Napiergrass may be due to grazing in the paddocks established in 2017. An increase in tiller density with a concomitant decrease in mean tiller weight during the grazing cycle is a desirable tendency for a species intended for grazing beef cows, because Napiergrass genotypes had such a high mean tiller weight at the first cycle that consumption of the whole tiller mass was not easy. Under defoliation management (Mukhtar *et al.,* 2003), tiller density increased with an increase in cutting frequency in the two years following establishment, and the most frequent defoliation treatment was at almost the same frequency as in the present grazing management for one-month or smaller intervals. It is apparent that recovery of tiller density in both DL and 7734 Napiergrass genotypes requires at least a one-month rest period even in the hot summer month of August.

Pre-grazing herbage mass was roughly comparable between the two genotypes of Napiergrass, averaging 360-383 g DM/m^2 at the first cycle, while it decreased considerably in 7734 to 190 g DM/m^2 in the second cycle, compared with almost complete recovery in DL at 361 g DM/m^2 (Figure 4.4). This suggested that DL Napiergrass pasture has the capacity to be grazed and supply enough herbage mass for beef cows for 4-7 days of grazing at monthly intervals in the second year from establishment, while recovery of herbage mass in 7734 Napiergrass was almost two-thirds of that at the first grazing under this grazing frequency. Ishii *et al.* (2005) also reported that pre-grazing herbage mass of DL Napiergrass pastures averaged 389 g DM/m^2 for the three grazing cycles in 2002 and 221 g DM/m^2 for the six grazing cycles in 2003, which supports the present results for herbage mass.

Changes in the percentage of plant fractions under rotational grazing management were the opposite of a previous defoliation treatment on DL and 7734 Napiergrass genotypes (Kadwal *et al.,* 2016) in chapter 3, which found that the LB percentage increased from the first to the second defoliation, while in the present study, LB percentage decreased from the first to the second grazing cycle. The increase in LB percentage with defoliation management (Kadwal *et al.,* 2016) in Chapter 3 corresponded with a previous defoliation study in DL Napiergrass (Hasyim *et al.,* 2014), showing that the ratio of LB to ST (LB/ST) was lower at the first cutting in the year of establishment than at two later cutting stages (Figure 4.5). Under previous grazing management on DL Napiergrass pasture by dairy cows, pre-grazing LB percentage decreased consistently from the first to the following cycles in the two years of grazing (Hasyim *et al.,* 2016). Therefore, in the present study, frequent rotational grazing at monthly or shorter intervals would not be enough to allow recovery of the leaf canopy for consumption by grazing beef cows, and thus, the post-grazing LB percentage decreased significantly over all paddocks of both genotypes of Napiergrass.

HC decreased from the first to the second cycle, and the rate of decrease was larger in 7734 than in DL (Figure 4.6A), which correlated reasonably with the change in pre-grazing herbage mass, except for the largest HC of 7734 at Cycle 1 due to the largest drop of herbage mass from almost complete consumption by grazing beef cows (Mukhtar *et al.,* 2004). DMI in the present study averaged 14.8-28.3 g/kg LW/day (Figure 4.6B), which was comparable to the previous study, in which DMI averaged 15.5-28.6 g/kg LW/day under rotational grazing on four paddocks of DL Napiergrass pasture. Additionally, grazing time on DL Napiergrass pasture was stable at 50–60% in the daytime on the first grazing day in both years of grazing trials. Under three stocking rates (7.5, 10 and 15 animals/ha) of yearling steers averaging 230–250 kg LW/head on three varieties of stargrass swards in Florida, USA, forage intake was calculated as 10.2, 9.3 and 7.6 kg DM/animal/day, respectively

Live weight (LW) gain in breeding beef cows with grazing cycles (Table 4.2) indicates that the average daily gain (ADG) was 0.79 kg/day across all paddocks for 56 grazing days on two Napiergrass genotypes intercropped with lablab bean in only three paddocks in 2017. Previous study reported that the ADG over three seasons was 0.97 kg/head/day on Mott semi-dwarf type Napiergrass and 0.38 kg/head/day on Pensacola bahiagrass pastures under an average stocking rate of approximately 4 yearling steers/ha in Florida, USA (Sollenberger and Jones, 1989). They concluded that since Mott Napiergrass persists well under optimum grazing management, Mott has great potential for improvement of animal production in the tropics and subtropics. In previous study the average DMI was 15.5-28.6 g DM/kg LW/day over the four paddocks and the ADG was 0.09 kg/head/day under intermittent grazing on DL Napiergrass pastures in Miyazaki, Japan (Mukhtar *et al.,* 2004). Thus, the LW of three beef cows was maintained during the second to the fourth grazing without concentrate feeding when DMI was above 20 g DM/LW/day. The LW of breeding beef cows was at least maintained under rotational grazing of dwarf Napiergrass pastures in the summer without any supplied concentrates or roughage in southern Kyushu, Japan.

The present study revealed that foggage of dwarf Napiergrass genotypes had great palatability for breeding JB beef cows under intermittent winter grazing. The rotational grazing potential of dwarf Napiergrass foggage remains to be determined, as does estimating the change in ADG when it is used as autumn-saved pasture. These estimations would be the first step in utilization of dwarf-type Napiergrass pastures in year-round grazing management in the region.

CHAPTER 6

GENERAL SUMMARY

Napiergrass has a range of phenotypic variation from real-dwarf, semi-dwarf, to normal-tall genotypes. IVDMD, CP concentration, and overwintering ability of DL Napiergrass were superior to the normal Napiergrass genotypes in tropical and sub-tropical areas in the world. Three genotypes of real-dwarf (7734), semi-dwarf (DL), and normal-tall genotype, ME Napiergrass were used for field experiments fixed at 6 m^2 for both DL and 7734, while for ME, plot size was fixed at 20 m^2 which had 12, 24, and 20 plants/plot for DL, 7734, and ME, respectively. Density of plants were 1 plant/m^2 for ME, 2 plants/m^2 for DL, and 4 plants/m^2 for 7734.

Growth attributes as plant height, plant length, tiller density, and leaf area were measured for 2 plants/plot across the growing season in 2015. Subsamples approximately 300–400 g FW were divided into LB, ST, and D and oven-dried at 70ºC for 3 days (72 hrs) to determine the percentage of DM in each plant fraction. Plants were measured for RLI and used stratified clipping method of 30 cm strata to measure FW and percentage of DM on 4 September for all genotypes at the first cutting and on 28 November for ME at the second cutting.

Plant height was larger in ME than the semi-dwarf and the dwarf genotypes showing the highest in ME (199 cm), followed by DL (128 cm), and 7734 (88 cm) at the first cutting, 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. 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.

DMY was constantly higher in 7734, followed by ME and DL, except for the lowest weight in ME in October. In the first cutting, 7734 had the highest DMY at 830 g/m^2, followed by ME at 640 g/m^2, and DL at 590 g/m^2. Annual total DMY 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. CP concentration was the highest in 7734, ranging from 82 to 145 mg/g DM for LB and 91 to 102 mg/g DM for ST in the first cutting and increased to 114 to 206 and 91 to 181 mg/g DM for LB and ST, respectively, in the second cutting, followed by DL and ME.

IVDMDs of both LB and ST were higher in 7734 and 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.

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.

DL and 7734 pastures were established at 500 m^2/paddock on 18 and 27 June 2016. Pastures were fertilized with 112 kg N, P_2O_5 and K_2O/ha/yr by twice-split application. The first monitoring for grazing behaviors was conducted on three breeding JB beef cows for 1 hr/paddock on 29 December 2016. The second, third, fourth and fifth grazing practices were conducted over 6 hr across the wintering season in 2017. Napiergrass genotypes were grazed by the same 24 JB cows and 5-8 calves. Pre-grazing herbage mass was determined by defoliating 2plants/paddock, and pre-grazing pasture height by measuring 20 plants/paddock in each of the monitoring sessions.

DL and 7734 paddocks were extended on 27 May as the third replication. Another 7734 paddock was established as the fourth replication on 29 June 2017. Lablab bean was sown to the intra-row spaces of Napiergrass at 2 m intervals. Pastures were fertilized with four split applications, one of 28 kg N, P_2O_5 and K_2O/ha at the establishment, and 56 kg N, P_2O_5 and K_2O/ha three times, at 14 June and again at the end of the first and second grazing practices in each paddock. Annual total fertilizer supply was 168 kg N, P_2O_5 and K_2O/ha/yr for the first and second replications, established in 2016, and 196 kg N, P_2O_5 and K_2O/ha/yr for the third and fourth replications, established in 2017.

Pre-grazing plant height in Cycle 1 was the highest for DL and lowest for lablab bean. Pre-grazing plant height uniformly decreased between Cycle 1 and Cycle 2. Post-grazing plant height was more stable than that at pre-grazing, and was highest for DL at 44-48 cm, followed by lablab bean at 36-39 cm, and lowest for 7734 at 33-37 cm in both the first and second cycles. Tiller density was fairly similar in both the first and second cycles, even though DL tended to have higher density. Tiller density increased from the first to the second cycle uniformly in both genotypes, and tended to increase during grazing, except for DL in the second cycle. Branch density of lablab bean was lower than tiller density of the two Napiergrass genotypes in both cycles but increased slightly between cycles.

Pre-grazing herbage mass in Cycle 1 was the highest for DL and the lowest for lablab bean. Post-grazing herbage yield decreased considerably in DL and 7734, and changed slightly in lablab bean. Post-grazing herbage mass decreased to a larger extent in 7734 than DL. The percentage of LB in DL was higher in Cycle 1 than in Cycle 2. In 7734, the LB percentage tended to be lower than in DL at the first grazing, while the percentage was almost the same between the two genotypes at the second grazing. The post-grazing LB percentage tended to be lower in 7734 than in DL for both grazing practices. In lablab bean, the percentage of LB was slightly higher than ST at pre-grazing and decreased during the first and second grazing practices.

HC in Cycle 1 was lower in DL at 242 g DM/m^2 than in 7734 at 292 g DM/m^2, and severely limited for lablab bean at 5 g DM/m^2. HC in Cycle 2 tended to decrease from the first to the second cycle in both Napiergrass genotypes and lablab bean. In Cycle 1, DMI tended to be higher in 7734 at 20.5 g DM/kg LW/day than in DL at 17.2 g DM/kg LW/day. DMI at the second cycle was comparable at 16.2 g DM/kg LW/day in both genotypes. DMI in lablab bean was quite limited at 0.5 and 0.2 g DM/kg LW/day for both cycles, respectively.

LW gain increased with grazing from the first to the second cycle. Therefore, cow LW was at least maintained under the rotational grazing system without any concentrate feeding during the two cycles for 56 days. Across two cycles, ADG was 0.79 kg per day and average DMI was 19.4 g DM/kg LW/day.

These estimations would be the first step in utilization of dwarf-type Napiergrass pastures in year-round grazing management in the region.

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