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Round-Bale Silage Harvesting and Processing Effects on Overwintering Ability, Dry Matter Yield, Fermentation Quality, and Palatability of Dwarf Napiergrass (*Pennisetum purpureum* Schumach)

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Abstract: Round-bale silage harvesting and processing methods were assessed to evaluate overwintering ability and dry matter (DM) yield, fermentation quality and palatability of overwintered dwarf Napiergrass (*Pennisetum purpureum* Schumach) in the two years following establishment in Nagasaki, Japan, in May 2013 using rooted tillers with a density of 2 plants/m^2. In 2014, harvesting methods under no-wilting treatment were compared for flail-type harvesting with a round-baler (Flail/baler plot) and mower conditioning with a round-baler (Mower/baler plot), which is common for beef-calf–producing farmers in the region. In 2015, the effect of ensilage with wilting was investigated only in the Mower/baler plot. Dwarf Napiergrass was cut twice, in early August (summer) and late November (late autumn), each year. The winter survival rate was greater than 96% in May both years. The DM yield in the Mower/baler plot did not differ significantly for the first summer cutting or the annual total from the Flail/baler plot, but did show inferior yield for the second cutting. The fermentation quality of the second-cut plants, estimated using the V2-score, was higher in the Flail/baler plot than in the Mower/baler plot, possibly because of higher air-tightness, and the second-cut silage tended to have better fermentation quality than the first-cut silage in both harvesting plots. Wilting improved the fermentation quality of dwarf Napiergrass silage in summer, but not in autumn. The palatability of the silage, as estimated by alternative and voluntary intake trials using Japanese Black beef cattle, did not differ significantly between plots. The results suggest that dwarf Napiergrass can be better harvested using a mower conditioner with processing by a round-baler, an approach common to beef-calf–producing farmers, than with the flail/baler system, without reducing the persistence, yield, or palatability of the silage. Moreover, wilting treatment improved the fermentation quality of the dwarf Napiergrass silage when processed in summer.

Keywords: harvesting; silage processing; wintering ability; fermentation quality; dwarf Napiergrass

1. Introduction

Relative to the average for tropical grasses, the dwarf variety of late-heading-type Napiergrass (*Pennisetum purpureum* Schumach) has a high nutritive value as estimated by its crude protein (CP) concentration and in vitro dry matter (DM) digestibility (IVDMD) [1,2]. Dwarf Napiergrass shows high winter survival when receiving a mid-November to late November closing cut in the northern Kyushu including Nagasaki Prefecture, where the average daily temperature drops below 15 °C [2], and thus, the grass can be used as a perennial.

Dwarf Napiergrass has better silage quality in terms of palatability than sorghum (*Sorghum bicolor* Moench) and Sudangrass (*Sorghum sudanense* (Piper) Stapf.) [3]. Dwarf Napiergrass silage was able to be substituted for corn silage with only a small decrease in the milk yield of dairy cows [4]. Furthermore, the total digestible nutrient (TDN) concentration in the grass species is high at 550–600 mg/g, as estimated by digestion trials with Japanese Black breeding cattle [3]. Therefore, dwarf Napiergrass has been verified as a promising forage species for beef cow production in the region [2,3].

The fermentation quality of round-bale silage in dwarf Napiergrass was evaluated by cutting with a flail-type harvester equipped with a round-baler in our previous studies [2,5,6]. However, this is not the usual machinery for the silage processing of grasses by beef cow producers, who most often use a mower conditioner and round-baler. In the present study, we investigated ensiling methods, comparing the effects of the previous flail-type harvester with the current mower conditioner on DM yield, overwintering ability, palatability, and fermentation quality of dwarf Napiergrass.

Since the fermentation quality of the round-bale silage of dwarf Napiergrass produced in summer is considered inconsistent [3,5], we have had success in improving the amount of satisfactory quality silage by adding lactic acid bacteria with *Acremonium* cellulose or fermented juice of epiphytic lactic acid bacteria [6]. Wilting is an effective method to improve the fermentation quality of tropical grass silage [7], though in the previous study [6], a no-wilting ensilage method was examined, and only for dwarf Napiergrass. Thus, we also investigated the effect of wilting on the fermentation quality of dwarf Napiergrass silage under processing by a mower conditioner and round-baler.

2. Materials and Methods

2.1. Cultivation of the Plants

The Napiergrass (*Pennisetum purpureum* Schumach) genotype was a dwarf variety of a late heading type [8,9]. Experiments were conducted at the Livestock Research Division, Nagasaki Agricultural and Forestry Technical Development Center in Shimabara, Nagasaki (32°14′ N, 130°20′ E) in 2014–2015. The dwarf Napiergrass pasture (500 m^2) examined was established by transplanting rooted tillers at 2 plants/m^2 with 1 m inter-row and 0.5 m intra-row spacing on 24 May 2013, as described in our previous study [6]. Additional fertilizer at 10 g/m^2 of N and K_2O were applied immediately after harvest in mid-June and in each experiment of both years.

2.2. Experimental Design

2.2.1. Ensiling Methods in 2014 (Experiment 1)

Overwintering plants, established in May 2013, were used after cutting on 11 June 2014. Experimental plots were set at two ensiling methods without wilting before ensilage, specifically, harvested using a flail-type harvester equipped with a round-baler (JCB1420 Combination Baler; IHI Corp., Sapporo, Japan), designated as the Flail/baler plot, and harvested using a mower conditioner (John Deere 1340 Mower Conditioner; Deere & Company, Moline, IL, USA) with subsequent processing using a round-baler (TCR0930WT; IHI Corp., Sapporo, Japan), as for the Mower/baler plot, which is common in beef cattle production in the region. The bales were wrapped with six layers of polyethylene film (KS Wrap, Kaneko Seeds Co. Ltd., Maebashi, Japan). Dwarf Napiergrass was harvested in the first summer cut on 11 August at 61 days' regrowth and in the second autumn cut on 21 November at 102 days' regrowth.

2.2.2. Wilting Effect in 2015 (Experiment 2)

The experiment used overwintering plants after cutting on 10 June 2015. Plants were harvested by a mower conditioner, followed by wilting treatments (with wilting for one day under sunshine or without wilting) and processed with a round-baler. The machinery was the same as in Experiment 1.

Dwarf Napiergrass was harvested twice, with the first cut in summer on 3 August at 54 days' regrowth and the second cut in autumn on 19 November at 108 days' regrowth.

2.3. Measurements

Plant growth was evaluated by plant length at harvest. Plant samples cut at 10 cm above the ground surface were divided into leaf blade, stem (inclusive of leaf sheath), and dead parts. The DM weight of each plant part was determined after oven-drying at 70 °C for 72 h. Crude protein (CP) concentrations and in vitro DM digestibility (IVDMD) of the samples in Experiment 1 were analyzed using a Kjeltec analyzer (FOSS, Hillerod, Denmark) and pepsin-cellulase assay [10].

The palatability of the silages in Experiment 1 was evaluated using alternative and voluntary intake methods for the first-cut and second-cut samples, respectively. Relative consumption of the silages in both Mower/baler plot and Flail/baler plot was measured at a four-day interval by an alternative method where two materials were fed to two paired Japanese Black breeding beef cows, or four head in total (live weight averaged at 475 kg and 419 kg for the high and low groups, respectively) over 2 h. The four-day term for this measurement consisted of a one-day preliminary period, followed by a three-day examination period to evaluate the consumption rate, expressed as a percentage of whole intake of fed materials. The voluntary intake was measured with four Japanese Black breeding beef cows (live weight averaged at 485.5 kg) penned individually in a two-treatment changeover design. Each trial consisted of a two-day preliminary period followed by a three-day examination period. The silages without concentrates were fed to beef cows ad libitum in sufficient quantities to evaluate dry matter intake per day in each term. Fukagawa et al. [3] reported that the palatability of Napiergrass silages was successfully evaluated by the alternative and voluntary intake methods for the short and long periods, respectively.

Silage extraction methods were the same as reported in previous research [6]. Samples (25 g) of silage, which were taken from three round bales per plot 60 days after ensiling, were mixed with 200 mL distilled water and stored in a refrigerator at 5 °C overnight. The pH values of the extracts of the silage samples were measured using a pH meter (S20 SevenEasy pH, Mettler-Toledo AG, Schwerzenbach, Switzerland), ammoniacal nitrogen (NH_3-N) was measured using a Kjeltec analyzer (Kjeltec system 1035, FOSS A/S Co. Ltd., Hillerod, Denmark), and organic acids were measured with a bromothymol blue (**BTB**) post-labeling method using an high performance liquid chromatography (HPLC) system with an RI-2031 Plus refractive index detector (JASCO Corporation, Tokyo, Japan) and a Shodex RS Pak KC-811 column (Showa Denko K.K., Tokyo, Japan), as described previously [11]. The V2-score values for assessing the silage fermentation quality were determined from the concentrations of acetic, propionic, butyric, caproic, and valeric acids, and NH_3-N [12], based on the calculation method listed in Table 1. CP concentration and IVDMD of the silage samples in Experiment 1 were analyzed by a Kjeltec analyzer and pepsin-cellulase assay, respectively.

Table 1. Calculation of V2-score evaluation (Y) for silage (% Fresh Weight, FW).

NH_3-N [1]	Evaluation	$C_2 + C_3$ [2]	Evaluation	$C_4 + C_5 + C_6$ [3]	Evaluation	V2-Score Evaluation [4]
Xa	Ya	Xb	Yb	Xc	Yc	Y
≤20	Ya = 50	≤0.2	Yb = 10	0	Yc = 40	
20–200	Ya = (1000 − 5Xa)/18	0.2–1.5	Yb = (150 − 100Xa)/13	0–0.5	Yc = 40 − 80Xc	Y = Ya + Yb + Yc
>200	Ya = 0	>1.5	Yb = 0	>0.5	Yc = 0	

[1] ammoniacal nitrogen, [2] Sum of acetic and propionic acids; [3] Sum of butyric, caproic and valeric acids containing each isomer; [4] V2-score indicates fermentation quality of silages with judging by the score of good (above 80), fair (60–80) and poor (below 60).

2.4. Statistical Analysis

Independent Student's *t*-tests were conducted using StatView for Windows software ver. 5.0 (SAS Institute Inc., Cary, NC, USA) for the differences between two pairs at the 5% probability level.

3. Results

Overwintering ability and growth, yield, and quality attributes of dwarf Napiergrass plants before ensiling are presented in Table 2 for Experiment 1. The winter survival rate was above 96% in both plots for the two-year experiment. No significant differences were detected between plots in the attributes of plant length or DM ratio of leaf blade per stem with leaf sheath (LB/ST) in the first or second cut, or in the CP concentration or IVDMD of the second-cut samples. Neither the DM yield of the first-cut samples nor the annual total differed significantly in the Mower/baler plot from the Flail/baler plot, though the Flail/baler plot had a superior second-cut yield.

Table 2. Plant length, ratio of leaf blade to stem with leaf sheath (LB/ST), dry matter yield, crude protein (CP) concentration and in vitro dry matter (DM) digestibility (IVDMD) at ensiling in the first (1st)- and second (2nd)-cut samples and winter survival rate of dwarf Napiergrass.

Experiment (Exp.)	Plot	Plant Length (cm)		LB/ST		DM Yield (Mg/ha)			CP (% DM)		IVDMD (%)		Winter Survival Rate (%)
		1st	2nd	1st	2nd	1st	2nd	Annual	1st	2nd	1st	2nd	
Exp. 1 [1]	Mower/baler [3]	160.6 ^{ns} [6]	157.7 ^{ns}	1.18 ^{ns}	1.06 ^{ns}	9.8 ^{ns}	9.6 ^{b}	19.4 ^{ns}	10.6 ^{ns}	9.56 ^{a}	66.1 ^{ns}	58.0 ^{a}	99.5 ^{ns}
	Flail/baler [4]	155.9	162.1	1.31	0.93	10.3	12.2 ^{a}	22.5	10.6	8.87 ^{b}	64.7	56.1 ^{b}	97.5
Exp. 2 [2]	Wilting [5]	136.9	146.7	1.66	0.81	6.8	10.6	17.4					96.1 ^{ns}
	Unwilting	137.6	145.4	1.4	0.91	7.8	9.8	17.6					97.4

[1] Dates of establishment, the first and second cuttings were 24 May 2013, 11 August 2014 and 21 November 2014, respectively. [2] Dates of establishment, the first and second cutting were 24 May 2013, 3 August 2015 and 19 November 2015, respectively. [3] Cutting and ensiling methods were mower conditoner and round baler, of which bale was sized at 90 cm diameter and 86 cm height. [4] Cutting and ensiling methods were combination-baler, of which bale was sized at 90 cm diameter and 86 cm height. [5] Cutting, ensiling methods and bale size were the same as in the Mower/baler plot in Experiment 1, except for wilting at 1 day under sunshine after cutting (wilting) or unwilting imposed. [6] The values with different small letters (a, b) within the same column are significantly different at 5 % level by student t-test. ns: Non-significant.

The moisture, bale density, organic acid composition, and fermentation quality of the silages are shown in Table 3. Bale density was only examined for the second autumn-cut samples in Experiment 1, where a significantly higher density in the Flail/baler plot was obtained compared with the Mower/baler plot. In Experiment 1, lower pH and higher lactic acid, combined with a tendency for lower acetic and propionic acid concentrations, were obtained in the Flail/baler plot compared to the Mower/baler plot, which corresponded with a significantly higher fermentation quality in the Flail/baler plot based on the V2-score. However, samples in the first summer-cut plants tended to have lower lactic acid and higher pH in both harvesting plots compared with the second-cut samples. The fermentation quality estimated using the V2-score did not differ significantly between harvesting plots for the first summer-cut samples, while it was higher quality in the Flail/baler plot than in the Mower/baler plot for the second-cut samples.

Table 3. Moisture and fermentation quality of silage and density of bale in dwarf Napiergrass, as affected by ensiling methods (Exp.1) and wilting treatment (Exp.2).

Experiment (Exp.)	Time of Cut (Season)	Plot	Moisture (%)	Organic Acid Composition			Fermentation Quality		Density of Bale (g/cm^3)
				Lactic (% FW)	$C_2 + C_3$ [1] (% FW)	$C_4 + C_5 + C_6$ [2] (% FW)	pH	V2-Score [3]	
Exp. 1 [1]	1st (Summer)	Mower/baler	84.5 ^{ns}	0.02	4.14 ^{a} [4]	1.57 ^{ns}	4.84 ^{b}	33 ^{ns}	-
		Flail/baler	84.0	nd	3.81 ^{b}	1.49	5.06 ^{a}	30 ^{bb}	-
	2nd (Autumn)	Mower/baler	83.7 ^{ns}	0.60 ^{b}	1.15 ^{ns}	0.20	5.02 ^{a}	77 ^{b}	0.443 ^{b}
		Flail/baler	83.2	1.72 ^{a}	0.86	nd [5]	3.96 ^{b}	95 ^{a}	0.557 ^{a}
Exp. 2 [2]	1st (Summer)	Wilting	55.4 ^{b}	2.48 ^{a}	0.57 ^{b}	nd	5.11	84 ^{a}	-
		Unwilting	84.7 ^{a}	1.09 ^{b}	1.01 ^{a}	1.16	4.81	45 ^{b}	-
	2nd (Autumn)	Wilting	74.1 ^{b}	0.12 ^{ns}	0.86 ^{ns}	0.15	5.94	75 ^{ns}	-
		Unwilting	81.1 ^{a}	0.18	0.78	0.24	5.60	70 ^{bb}	-

[1] Sum of acetic and propionic acids. [2] Sum of butric, capronic and valeric acids containing each isomer. [3] V2-score indicates fermentation quality of silages with judging by the score of good (above 80), fair (60-80) and poor (below 60). [4] The values with different small letter (a, b) within the same column on each time of cut in the same experiment are significantly different at 5% level by student-t test. ns: Not-significant. [5] nd = Not ditected.

In Experiment 2, the wilting treatment did not affect pH, while it increased the lactic acid concentration significantly, corresponding with no detection of butyric, caproic or valeric acid in the summer samples. On the other hand, the decline of the moisture concentration with wilting occurred to a lesser extent in the second-cut samples in Experiment 2, compared with the greater decline of nearly 30 points in the summer samples.

Figure 1 presents the palatability of the silages, as assessed by the alternative and voluntary intake trials using Japanese Black beef cows. The relative DM intake of the dwarf Napiergrass silage increased with the increase in the tester live weight (LW), which showed a similar tendency for the alternative and voluntary intake trials. Concentrations of structural carbohydrates such as neutral detergent fiber (NDF) and acid detergent fiber (ADF) of the silages did not differ between the plots, as shown in Table 4.

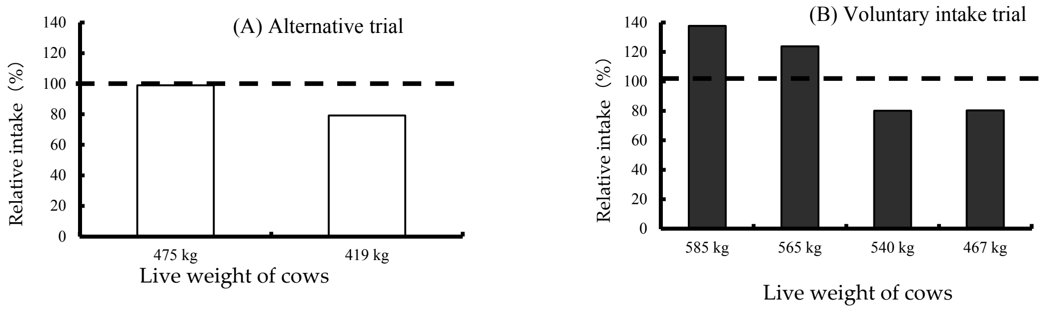

Figure 1. Relative dry matter (DM) intake in Mower/baler plot to Flail/baler plot (as a percentage) in the two palatability tests from dwarf Napiergrass silages in Experiment 2. (**A**) The DM intake over 2 h was determined using two paired Japanese Black breeding cows (mean live weight (LW): high live weight (HLW) plot = 475 kg, low live weight (LLW) plot = 419 kg) with a one-day preliminary period followed by a three-day examination period; (**B**) The DM intake per day, determined using four Japanese Black breeding cows (mean LW = 485.5 kg) with a two-day preliminary period followed by a three-day examination period.

Table 4. Nutritive values of crude protein (CP), neutral detergent fiber (NDF) and acid detergent fiber (ADF) concentrations in dwarf Napiergrass silages of the first (1st)- and second (2nd)-cut samples in Experiment 1.

Experiment (Exp.)	Time of cut (Season)	Plot	CP (% DM [1])	NDF (% DM)	ADF (% DM)
Exp. 1 [2]	1st (Summer)	Mower/baler	7.1 [a 1]	61.1 [ns]	44.8 [ns]
		Flail/baler	6.5 [b]	60.3	41.8
	2nd (Autumn)	Mower/baler	9.0 [ns]	58.4 [ns]	39.7 [ns]
		Flail/baler	9.1	56.4	39.2

[1] Dry matter. [2] The values with different small letter (a, b) within the same column on each time of cut are significantly different at 5 % level by student t-test. ns: Non-significant.

4. Discussion

The persistence of dwarf Napiergrass must be maintained after machine harvest. We found that the machinery ensiling methods did not affect the overwintering ability, which showed a nearly perfect (≥96%) winter survival rate when the closing cut was conducted in mid- to late November.

The bale density was significantly higher in the Flail/baler plot (0.557 g/cm^3) than in the Mower/baler plot (0.443 g/cm^3), possibly due to the operation of the flail-type harvester, an effect also observed by Shao et al. [13]. Therefore, the fermentation quality of Napiergrass, as assessed by the V2-score, was superior in the Flail/baler plot to the Mower/baler plot. The V2-scores of both plots of dwarf Napiergrass tended to be higher in silages processed in autumn than in summer, corresponding to our earlier research findings [5], which were affected by higher concentrations of monosaccharides and oligosaccharides in the plants [5].

Good fermentation quality of five Napiergrass clones including dwarf types was reported to lead to a silage with a pH above 4.2, which was related to the low DM concentration of the plants, below 20% [14]. Since a wilting treatment should increase the DM percentage of Napiergrass by at least 30% DM in order to get a satisfactory fermentation quality of the silage [15], the wilting treatment for the first summer cut in Experiment 2 was successful because it decreased the moisture to 55.4%, leading to an improved silage fermentation quality.

The results of ensiling and the wilting effects suggested that the fermentation quality of dwarf Napiergrass silage in summer can be improved by wilting treatment without additives, due to the faster decline of the moisture concentration that was observed after treatment in summer, compared with no positive effects when treated in autumn.

In our previous research [6], ensilage of dwarf Napiergrass covered by plastic bags without additives after harvest by a flail-type harvester in autumn proved to lead to a satisfactory silage quality of the grass species, which may be applicable to some small-holder beef cow and calf–producing farmers in the region as 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 ordinary cow-calf farmers.

In our previous research [3], the palatability of the dwarf Napiergrass silage fed to Japanese Black beef cattle, assessed by alternative trials, was superior to that of Sudangrass silage, because of the lower NDF and ADF concentration in Napiergrass. In the present study, no difference in palatability was apparent between the two harvesting and processing plots, as reflected by the absence of any significant ensilage effects on the NDF and ADF concentrations.

5. Conclusions

A flail-type harvester equipped with a round-baler had no significant effects on the overwintering ability, total DM yield or palatability of silage of dwarf Napiergrass compared with conventional harvesting equipment. Thus, we recommend that breeding beef cow producers ensile dwarf Napiergrass using a mower conditioner, followed by a round-baler, using the normal ensiling processes used in the region. As a pretreatment, wilting effectively improves the fermentation quality of silage when dwarf Napiergrass is ensiled in summer.

Author Contributions: Satoru Fukagawa and Yasuyuki Ishii conceived and designed the experiments; Satoru Fukagawa performed the experiments, analyzed the data and Kenichi Kataoka contributed materials and analysis tools; Satoru Fukagawa and Yasuyuki Ishii wrote the paper.

Conflicts of Interest: The authors declare no conflict of interest.

Nomenclature

Napiergrass	*Pennisetum purpureum* Schumach
DM	dry matter
CP	crude protein
IVDMD	in vitro dry matter digestibility
LB/ST	ratio of leaf blade to stem with leaf sheath
NH_3-N	ammoniacal nitrogen
FW	fresh weight
C_2	acetic acid
C_3	propionic acid
C_4	butyric acid
C_5	caproic acid
C_6	valelic acid
NDF	neutral detergent fiber
ADF	acid detergent fiber
HPLC	high performance liquid chromatography

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