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Research paper

Growth and nutritional evaluation of napier grass hybrids as forage for ruminants*

Producción y evaluación nutritiva de híbridos del pasto elefante como forraje para rumiantes

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Abstract

Napier grass is a perennial, tropical C-4 grass that can produce large amounts of forage. However, low temperatures and drought stress limit its productivity and nutritive value as a forage. To overcome these limitations, pearl millet × napier grass hybrids (PMN) were developed. It was hypothesized that PMN hybrids were more drought-tolerant, produced higher yields, and had higher nutritive value than napier grass varieties. The yield and nutritive value of 4 napier grass varieties (Bana grass, Mott, MB4 and N51) and 4 PMN hybrids (PMN2, PMN3, 5344 and 4604) were determined with or without irrigation in a strip plot design in Hawaii. Hybrid PMN3 outperformed napier grass varieties and the other hybrids for yield, while 5344 showed higher nutritional content and digestibility than most other grasses. Dry matter yields during the 110-day study period ranged from 10.3 to 32.1 t/ha without irrigation and 19.6 to 55.8 t/ha with irrigation, indicating that moisture stress was limiting performance in raingrown pastures. Only hybrids PMN3 and PMN2 and variety MB4 showed significant growth responses to irrigation. Further work is needed to evaluate the hybrids in a range of environments over much longer periods to determine if these preliminary results can be reproduced over the long term. Similarly, feeding studies with animals are needed to determine if the in vitro data for digestibility are reflected in superior performance for the promising hybrids.

Keywords: Biomass, cattle, in vitro digestion, nutrient content, *Pennisetum*, tropical grasses.

Resumen

Pasto elefante (*Pennisetum purpureum*) es una gramínea tropical C-4 que puede producir grandes cantidades de forraje. Sin embargo, temperaturas bajas y sequía limitan su productividad y valor nutritivo. Para superar estas limitaciones, se desarrollaron híbridos *P. glaucum* (sin. *P. americanum)* × *P. purpureum*, bajo la hipótesis que, en comparación con las variedades del pasto elefante, los híbridos son más tolerantes a la sequía y más productivos, y tienen mayor valor nutritivo. En este estudio se determinaron la producción de materia seca (MS) y el valor nutritivo de 4 variedades de pasto elefante (los cultivares Bana, Mott, MB4 y N51) y de 4 híbridos (PMN2, PMN3, 5344 y 4604), con o sin riego, en un diseño de parcelas divididas con tratamiento en franjas (*strip plot*) en Hawaii, USA. El híbrido PMN3 superó las variedades de pasto elefante y los otros híbridos respecto al rendimiento de MS, mientras que el híbrido 5344 mostró una mayor concentración de nutrientes y una digestibilidad más alta que la mayoría de las otras gramíneas.

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Las producciones de MS durante los 110 días del estudio oscilaron entre 10.3 y 32.1 t/ha sin riego y entre 19.6 y 55.8 t/ha con riego, lo que indica que la falta de humedad estaba limitando el rendimiento. Solo los híbridos PMN3 y PMN2 y la variedad MB4 respondieron al riego con producciones significativamente más altas. Se necesitan más estudios para evaluar los híbridos en una diversidad de ambientes y durante periodos mucho más largos para determinar si estos resultados preliminares pueden ser reproducidos a largo plazo. Del mismo modo, se necesitan estudios de alimentación con diferentes clases de animales para determinar si las digestibilidades in vitro más altas de los híbridos promisorios se reflejan en superiores producciones animal.

Keywords: Biomasa, calidad nutritiva, contenido de nutrientes, digestibilidad in vitro, gramíneas tropicales, *Pennisetum*.

Introduction

Forages are a necessary component of diets for ruminants, as they provide the fiber needed to optimize rumen function. Napier grass, *Pennisetum purpureum* Schumach. (2n=28), is a robust perennial grass that has been widely used as a tropical forage, producing greater dry matter (DM) yield than other tropical grasses (Boonman 1997; Hanna et al. 2004). Although it has low protein concentration, it can provide a satisfactory forage source for dairy cows, if supplemented with legumes and protein concentrates (Nyambati et al. 2003). Napier grass is an outcrossing species with a low self-fertilization rate. It is replicated vegetatively due to its low seed set and low seed viability. Pearl millet, *Pennisetum glaucum* (L.) R.Br. (2n=14), a major warm-season cereal and an annual bunchgrass grown in arid and semi-arid regions of the world, is a crop with an outcrossing rate of more than 85%. Pearl millet crosses easily with napier grass to produce sterile interspecific hybrids (3n=21), which are more vigorous than the parent species (Burton 1944) and have high biomass potential (Hanna et al. 2004).

In this age of Global Warming one of the major concerns for cattle industries is how the changing climate will affect forage quality and availability. The Intergovernmental Panel on Climate Change (IPCC 2013) concluded that elevated greenhouse gas concentrations are likely to lead to general drying of the subtropics by the end of this century, creating widespread stress on agricultural crops and pastures. The Panel suggested that every degree Celsius increase in seasonal temperature would lead to 2.5–16.0% direct yield loss of the major grain crops (IPCC 2013). Battisti and Naylor (2009) calculated that, by the end of this century, there is a 90% possibility that average summer temperatures will exceed the current hottest recorded temperature throughout the world. Higher temperatures will also lower soil organic matter content by oxidation and further result in reduction of crop yields and land quality. These climatic changes can have serious effects for meeting food, forage, water and energy needs of human and livestock populations. Hence, it is necessary to develop/identify crop varieties that are tolerant of heat and heat-induced water stress.

Several researchers (Gupta and Bhardwaj 1975; Ogwang and Mugerwa 1976; Gupta and Mhere 1997) have indicated the vast potential for improvement in the yield and quality of pearl millet × napier grass (PMN) hybrids over napier grass. The interspecific hybrids produce more tillers and leaves and grow faster than their parents (Gupta and Mhere 1997). Pearl millet is drought-tolerant and is also resistant to most pests and diseases. Hence, PMN hybrids have been developed, which have high seed set and viable seeds. Additionally, with over 21,000 pearl millet accessions worldwide, there is high potential to transfer desirable traits into napier grass. The PMN hybrids can play a major role in producing high quality forages with lower water demands for the cattle industry in tropical regions of the world.

Biomass yield and chemical composition of napier grass vary significantly depending on variety, age, season, location and management practices (Ogoshi et al. 2010; Rengsirikul et al. 2011; Xie et al. 2011). Field trials in Hawaii have shown the ratoon crop yield was 13% higher than the plant crop for Bana grass, a napier grass variety (Osgood et al. 1996). In addition, the nutritive value of forage affects the utilization by animals, which in turn affects the production of animals as well as emissions of methane, a major greenhouse gas (Mirzaei-Aghsaghali and Maheri-Sis 2011). There are limited data on the nutritional content and digestibility of PMNs, a situation that must be corrected before recommendations for animal feeding are made. It was hypothesized that PMN hybrids would be more drought-tolerant and nutritious than napier grass varieties. The objective of this study was to evaluate the growth and nutritional value of some PMN hybrids and napier grass varieties under both rain-grown and irrigated conditions to identify the most productive of these forages for use in the cattle industry.

Materials and Methods

Germplasm

In the study, 4 PMN hybrids were used: PMN2, PMN3, 5344 and 4604; and 4 napier grass varieties (cultivars): Bana grass, Mott, MB4 and N51. PMN2 and PMN3 are pearl millet × napier grass interspecific hybrids resulting from a field-pollinated polycross utilizing 6 napier grass varieties (OB06, 514B, N51, OB07, Green and Bana grass) and cytoplasmic male-sterile (CMS) pearl millet varieties (ICMA 07333 and ICMA 00999). They were selected from a screening of over 800 progeny from these crosses on the basis of rapid growth, plant morphology (e.g. smooth and soft leaves, high leaf:stem ratio, leaf area, stem thickness) and disease resistance. Hybrid 5344 is a PMN hybrid from crossing of napier grass cv. Bana with the CMS pearl millet, Tift 23A1E1. Hybrid 4604 was derived from a polycross of napier grass cultivars N74, N23 and N14 with CMS pearl millet, Tift 23A1E1 (Osgood et al. 1997). MB4 is a wild napier grass accession collected on Maui Island (Hawaii, USA) in 2009. Bana grass is commonly used as a windbreak throughout Hawaii. Variety N51 (Hanna and Monson 1980) is another tall napier grass variety, and cv. Mott is a dwarf napier grass, N75 (Hanna and Monson 1988.

Field trials

The 4 napier grass varieties and 4 PMN hybrids were field tested both with and without irrigation treatment in a strip plot design, with each treatment consisting of 3 replicated plots at the College of Tropical Agriculture and Human Resources, Waimanalo Research Station, University of Hawaii, USA (21°20’18” N, 157°42’53” W; 18 masl), where annual rainfall averages 1,400 mm. Stem cuttings (~46 cm long) were planted in shallow furrows and urea and potassium chloride were applied at 33.6 kg/ha each. A similar second application of urea and potassium chloride was applied at 55 days after planting. All plots were drip irrigated at 100% pan evaporation for the first 30 days. Plots were 2 m × 6 m in size. Grasses were planted in 3 rows with 2 m between rows and overlapping stem cuttings placed in 2 m furrows. An area of 2 m^2 of the center row of the forages was harvested at about 20 cm above the soil on day 110 after planting, when samples were collected, chopped and dried in a forced-draft oven at 100 °C until constant weight. Dry matter yields were calculated. During the 110-day trial period, plots received 268 mm of rainfall and 18,915 liters of irrigation were applied (0.002 hectare-meter) (Figure 1). Plots used for the experiments contained silty clay soils in the Waialua series (isohyperthermic Pachic Haplustolls).

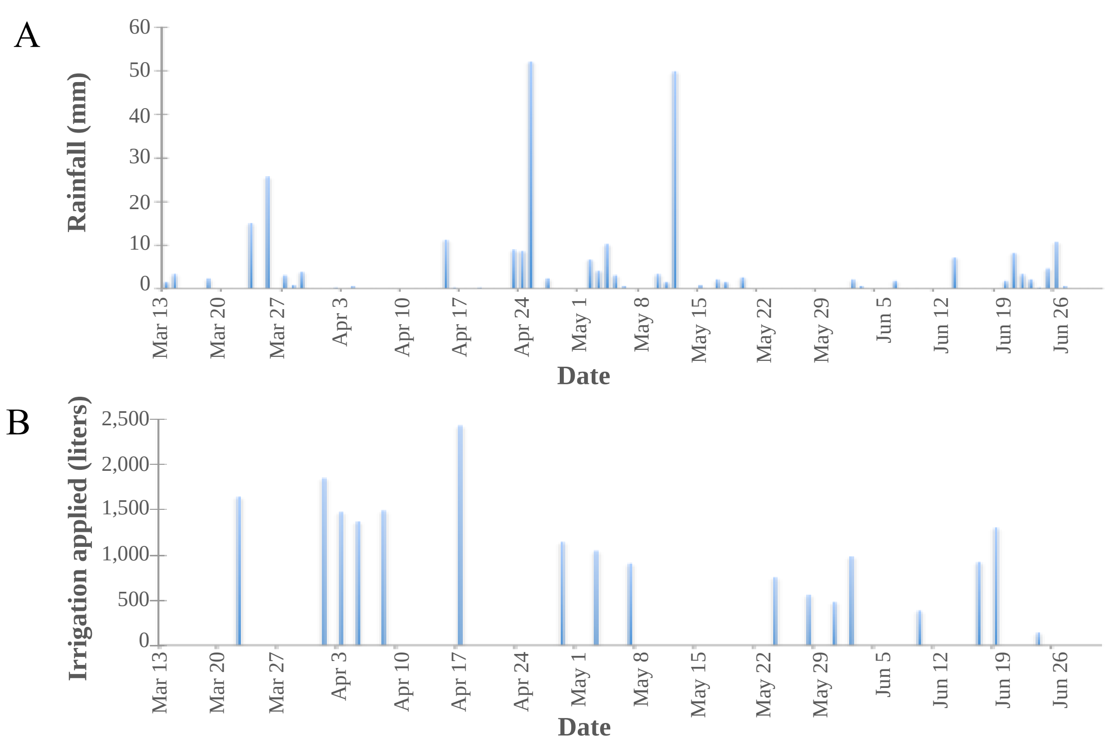

Figure 1. Rainfall and irrigation during trial period (13 March 2013 to 1st July 2013). A. Rainfall in mm per day. B. Irrigation applied in liters per application.

Sample analysis

The representative dried sample from each plot was ground to pass through a 1 mm screen using a Thomas Wiley laboratory mill. Subsamples were subjected to determination of basic proximate constituents, fiber and energy content, and in vitro digestibility parameters using near infrared spectroscopy, an approved method of AOAC (Association of Official Analytical Chemists, Gaithersburg, MD, USA) at a certified commercial lab (Dairy One Cooperative Inc., Forage Lab, Ithaca, NY, USA). The NIR analysis was conducted using Foss NIR systems model 6500 equipped with software win ISI ii v1.5. The laboratory uses broad-based calibrations for NIR by incorporating samples collected over several decades based on reference chemistry using traditional procedures. The analysis included dry matter, ash, crude protein, digestibility of protein, neutral detergent insoluble crude protein, starch, non-fiber carbohydrate, soluble carbohydrate, acid detergent fiber, neutral detergent fiber, lignin, total digestible nutrients, metabolizable energy, net energy for growth, net energy for lactation, net energy for metabolism, in vitro total digestibility, neutral detergent fiber digestibility and rate of digestion. It also included most of the minerals with importance to animal nutrition. For predicting TDN and net energy, the laboratory uses the summative energy equation of NRC (1988).

Statistical analysis

The dry matter yields, nutritional profiles and in vitro digestibility characteristics were compared using the MIXED procedure of SAS v. 9.2 (SAS Institute Inc., Cary, NC, USA) with a strip-plot arrangement of variety and treatments (with or without irrigation). Means were separated using the Tukey method, using pdmix macro of SAS. Differences were considered significant if $P<0.05$.

Results

Dry matter (DM) yields of the PMN hybrids and napier grass varieties showed a significant overall effect of variety ($P<0.0001$) and irrigation ($P=0.0002$), but variety × irrigation interactions were not significant ($P=0.2636$). Dry matter yields in the non-irrigated plots ranged from 10.3 t/ha (Mott) to 32.1 t/ha (PMN3), while corresponding yields in the irrigated plots ranged from 19.6 t/ha (Mott) to 55.8 t/ha (PMN3) (Figure 2). PMN3 had significantly higher DM yields under irrigation than the other varieties and hybrids, while Mott had significantly lower DM yields without irrigation than the other varieties and hybrids. While all varieties and hybrids produced higher yields when irrigated, the differences were significant only for MB4, PMN2 and PMN3 (Figure 2).

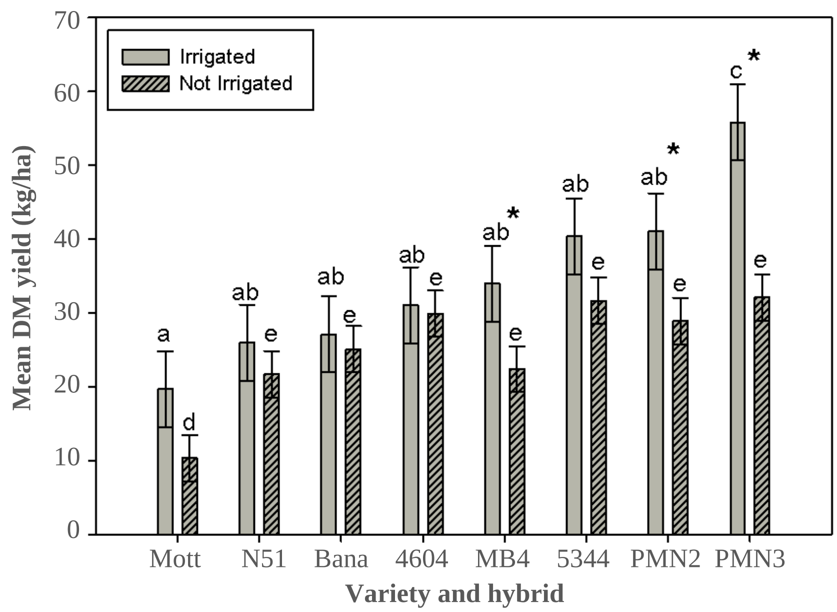

Figure 2. Mean dry matter (DM) yields for 110-day harvest of napier grass varieties (Mott, N51, Bana grass and MB4) and pearl millet × napier grass hybrids (PMN2, PMN3, 4604 and 5344) under irrigated ( ) and non-irrigated ( ) conditions. Letters indicate Tukey comparisons of mean DM yields within irrigated and non-irrigated treatments. Varieties and hybrids with the same letter are not significantly different. * denotes mixed model ANOVA significant difference between irrigated and non-irrigated DM yields for a variety/hybrid. Error bars are ±standard error of the mean.

In general, DM concentration of PMN hybrids was higher than that of napier grass varieties, with DM% of PMN2 (24.3%) and PMN3 (22.9%) being significantly higher ($P<0.05$) than those of 5344 (18.5%), Bana grass (18.1%) and N51 (17.9%) (Table 1).

Ash was lowest ($P<0.05$) in PMN2 (8.9%) and highest in 5344 (14.6%) (Table 1). No significant differences ($P>0.05$) in concentrations of acid detergent fiber (ADF), neutral detergent fiber (NDF), crude protein (CP), lignin and metabolizable energy (ME) were found among napier grass varieties and PMN hybrids (Table 1) or between irrigated and non-irrigated treatments (Table 2).

The in vitro dry matter digestibility (IVDMD) varied between varieties and hybrids, being significantly higher ($P<0.05$) in 5344 and Bana grass (70.0 and 68.0%, respectively) than in PMN2 (54.5%) (Table 3). Rate of digestion varied from 4.9%/h in 5344 to 2.7%/h in PMN2 ($P<0.05$).

Irrigation had no effect on mineral concentrations in forages but varieties and hybrids differed in concentration of minerals (Table 5), with the following ranges: calcium – 0.36% (5344) to 0.17% (PMN2) ($P<0.05$); potassium – 3.91% (N51) to 2.15% (PMN2) ($P<0.05$); phosphorus – 0.26% (Mott) to 0.19% (PMN2), 0.18% (N51) and 0.17% (MB4) ($P<0.05$); magnesium – 0.27% (4604) to 0.14% (Mott) ($P<0.05$); zinc – 24.8 ppm (PMN3) to 18.7 ppm (Bana) ($P<0.05$); copper – 10.7 ppm (MB4) to 7.3 ppm (PMN3, 5344) ($P<0.05$); selenium – 0.15 ppm (5344) to 0. 06 ppm (PMN2, N51) ($P<0.05$); and chloride – 1.27% (5344) to 0.82% (PMN2) ($P<0.05$).

The neutral detergent fiber (NDF) concentration of the grasses ranged between 68.4 and 73.3%, with no significant differences ($P>0.05$) (Table 1). Neutral detergent fiber digestibility (NDFD) of 5344 and Bana grass (56.7 and 53.2%, respectively) was significantly higher ($P<0.05$) than that of PMN2 (38.0%).

Table 1. Nutrient profile of forage from napier × pearl millet hybrids and napier grass varieties[1].

Variable	Hybrid				Variety				s.e.m.	P-value		
	PMN2	PMN3	5344	4604	Bana	Mott	MB4	N51		Var	Trt	Var × Trt
Dry matter (%)	24.2	22.9	18.5	21.6	18.0	20.6	20.4	17.9	0.88	<0.001	0.441	0.929
Ash (%)	8.9	11.4	14.6	11.2	14.1	12.7	13.2	11.3	0.90	0.002	0.706	0.718
Crude protein (%)	6.4	7.0	7.9	7.9	8.3	6.5	7.4	7.5	0.71	0.444	0.974	0.789
Digestibility of protein (%)	55.5	60.2	59.8	59.3	57.0	56.7	62.5	55.7	2.97	0.666	0.906	0.491
NDICP (%)	2.3	2.5	3.0	2.8	2.8	2.2	2.8	2.9	0.26	0.381	0.205	0.462
Starch (%)	1.6	1.4	1.7	0.7	1.7	1.3	1.8	1.2	0.24	0.079	0.157	0.011
NFC (%)	12.8a	10.6ab	10.2ab	10.8ab	10.9ab	9.6ab	8.8b	9.6ab	0.73	0.025	0.477	0.015
Soluble carbohydrate (%)	4.2	3.4	4.4	4.1	5.8	3.0	3.6	4.6	0.50	0.017	<0.001	0.072
ADF (%)	51.2	52.3	47.4	52.3	47.8	52.9	51.6	49.7	1.53	0.133	0.321	0.630
NDF (%)	73.3	72.5	68.9	71.7	68.4	72.2	72.2	73.0	1.41	0.143	0.631	0.344
Lignin (%)	6.6	6.5	5.2	8.2	5.5	6.2	6.3	6.6	0.64	0.084	0.288	0.817
TDN (%)	46.5	46.7	51.2	46.2	50.3	44.7	49.2	51.2	1.75	0.073	0.484	0.780
ME (Mcal/kg)	1.7	1.7	1.7	1.6	1.7	1.7	1.6	1.7	0.05	0.438	0.091	0.751
NEL (Mcal/kg)	0.71	0.73	0.90	0.73	0.86	0.70	0.78	0.80	0.056	0.146	0.405	0.490
NEM (Mcal/kg)	0.70	0.73	0.88	0.68	0.83	0.66	0.8	0.86	0.063	0.107	0.576	0.702
NEG (Mcal/kg)	0.16	0.16	0.35	0.18	0.33	0.10	0.25	0.31	0.060	0.043	0.332	0.704

[1]All data, except dry matter, are expressed on a dry matter basis.

ADF - acid detergent fiber; ME - metabolizable energy; NEG - net energy for growth; NEL - net energy for lactation; NEM - net energy for metabolism; NDF - neutral detergent fiber; NDICP - neutral detergent insoluble crude protein; NFC - non-fiber carbohydrate; TDN - total digestible nutrients; Trt - treatment; Var - variety.

Table 2. Nutrient profile of forage from napier × pearl millet hybrids and napier grass varieties grown under irrigated and non-irrigated conditions[1].

Variable	Hybrid								Variety								s.e.m.
	PMN2		PMN3		5344		4604		Bana		Mott		MB4		N51		
	Irr.	Non-Irr.	Irr.	Non-Irr.	Irr.	Non-Irr.	Irr.	Non-Irr.	Irr.	Non-Irr.	Irr.	Non-Irr.	Irr.	Non-Irr.	Irr.	Non-Irr.	
Dry matter (%)	23.6	24.9	22.7	23.0	18.5	18.5	22.1	21.0	16.9	19.1	20.1	21.2	20.5	20.4	17.9	17.9	0.9
Ash (%)	8.5	9.3	12.5	10.2	14.7	14.5	11.5	11.0	14.3	13.9	11.5	13.9	13.9	12.4	11.4	11.2	1.3
ADICP	0.9	0.9	0.7	1.0	0.8	0.7	1.0	0.8	0.8	0.8	0.8	0.9	1.1	1.0	0.9	0.9	0.1
AvCP	4.6	6.4	6.3	6.0	7.5	7.4	6.8	7.1	8.1	6.8	5.2	6.2	7.0	5.7	6.7	6.5	0.9
Digestibility of protein (%)	57.3	53.7	58.0	62.3	65.0	54.7	62.0	56.7	56.0	58.0	53.7	59.7	60.0	65.0	55.7	55.7	4.2
NDICP (%)	2.0	2.7	2.7	2.3	3.0	3.0	2.9	2.6	3.1	2.4	2.2	2.3	3.2	2.3	3.0	2.8	0.4
Crude fat (%)	0.8	1.2	1.1	1.0	0.9	1.4	1.2	1.1	1.1	1.2	1.1	1.4	1.2	1.2	1.4	1.5	0.2
Starch (%)	1.7	1.5	1.4	1.3	1.1	2.3	0.76	0.70	2.2	1.1	1.3	1.2	2.66	0.9	1.1	1.3	0.3
NFC (%)	12.8	12.8	10.2	11.1	8.3	12.0	9.6	12.1	10.8	11.0	10.7	8.6	10.8	6.7b	8.6	10.6	1.0
Soluble carbohydrate (%)	4.3	4.3	3.1	3.9	2.3c	6.6	3.3	5.0	4.5	7.2a	3.0	3.0	3.3	4.0	4.0	5.3	0.7
ADF (%)	53.2	49.2	51.1	51.2	48.6	46.1	51.7	52.9	47.7	47.9	55.2	50.5	50.1	53.1	50.7	48.6	2.2
NDF (%)	74.4	72.1	71.9	73.1	70.7	67.1	72.9	70.6	68.1	68.7	72.9	71.4	69.2	75.2	74.0	72.1	2.0
Lignin (%)	7.3	5.8	5.8	7.2	5.3	5.0	8.5	8.0	5.6	5.3	6.9	5.5	6.4	6.3	7.2	6.1	0.9
TDN (%)	44.0	49.0	47.7	45.7	49.7	52.7	46.0	46.3	50.3	50.3	44.0	45.3	50.7	47.7	50.0	52.3	2.5
ME (Mcal/kg)	1.7	1.8	1.7	1.7	1.6	1.8	1.6	1.6	1.7	1.7	1.6	1.7	1.6	1.6	1.6	1.7	0.1

[1]All data, except dry matter, are expressed on a dry matter basis.

ADF - acid detergent fiber; ADICP - acid detergent insoluble crude protein; AvCP - available crude protein; ME - metabolizable energy; NDF - neutral detergent fiber; NDICP - neutral detergent insoluble crude protein; NFC - non-fiber carbohydrate; TDN - total digestible nutrients.

Table 3. In vitro digestibility parameters of forage from napier × pearl millet hybrids and napier grass varieties.

Variable	Hybrid				Variety				s.e.m.	P-value		
	PMN2	PMN3	5344	4604	Bana	Mott	MB4	N51		Var	Trt	Var × Trt
IVTD (30 h, % of DM)	54.5	59.2	70.0	59.7	68.0	59.7	63.7	63.5	2.71	0.007	0.983	0.650
NDFD (30 h, % of NDF)	38.0	44.2	56.7	43.7	53.2	44.2	50.0	49.8	2.97	0.002	0.813	0.643
Rate of digestion (%/h)	2.7	3.3	4.9	3.7	4.4	3.3	4.0	4.1	0.35	0.002	0.305	0.797

IVTD - in vitro total digestibility; NDFD - neutral detergent fiber digestibility; Var - variety; Trt - treatment.

Table 4. In vitro digestibility parameters of forage from napier × pearl millet hybrids and napier grass varieties grown under irrigated and non-irrigated conditions[1].

Variable	Hybrid								Variety								s.e.m.
	PMN2		PMN3		5344		4604		Bana		Mott		MB4		N51		
	Irr.	Non-Irr.	Irr.	Non-Irr.	Irr.	Non-Irr.	Irr.	Non-Irr.	Irr.	Non-Irr.	Irr.	Non-Irr.	Irr.	Non-Irr.	Irr.	Non-Irr.	
IVTD (30 h, % DM)	50.3	58.7	62.3	56.0	69.7	70.3	59.7	59.7	69.7	66.3	58.3	61.0	65.7	61.7	62.3	64.7	3.8
NDFD (30 h, % NDF)	33.3	42.7	48.0	40.3	58.0	55.3	44.3	43.0	55.3	51.0	43.0	45.3	50.7	49.3	49.0	50.7	4.2
Rate of digestion (%/h)	2.3	3.0	3.6	3.0	5.1	4.6	3.8	3.6	4.9	3.9	3.2	3.3	4.2	3.8	4.1	4.1	0.5

IVTMD - in vitro total digestibility; NDFD - neutral detergent fiber digestibility.

Table 5. Mineral concentration in forage from napier × pearl millet hybrids and napier grass varieties[1].

Variable	Hybrid				Variety				s.e.m.	P-value		
	PMN2	PMN3	5344	4604	Bana	Mott	MB4	N51		Var	Trt	Var×Trt
Calcium (%)	0.17b	0.24ab	0.36a	0.27ab	0.31ab	0.29ab	0.20ab	0.21ab	0.035	0.0129	0.193	0.786
Potassium (%)	2.15e	2.50de	3.38abc	2.73cde	3.50ab	3.01bcd	3.23abcd	3.91a	0.016	0.0001	0.620	0.575
Phosphorus (%)	0.22ab	0.19b	0.20ab	0.21ab	0.19b	0.26a	0.17b	0.18b	0.262	0.0045	0.001	0.491
Magnesium (%)	0.18bc	0.21abc	0.23ab	0.27a	0.24ab	0.14c	0.22ab	0.20abc	0.018	0.0005	0.110	0.957
Sodium (%)	0.023	0.03	0.031	0.033	0.032	0.032	0.04	0.03	0.006	0.7372	0.573	0.774
Iron (ppm)	370	968	702	484	499	491	742	659	202.1	0.5213	0.554	0.793
Zinc (ppm)	23.7	24.8	22.8	19.5	18.7	22.7	22.2	21.0	1.742	0.229	0.386	0.795
Copper (ppm)	6.50c	7.33bc	7.33bc	8.5abc	9.83ab	10ab	10.67a	9.5ab	0.618	0.0002	0.850	0.914
Manganese (ppm)	35.7	61.5	49.3	40.0	41.5	35.0	45.0	44.3	8.338	0.4204	0.130	0.981
Molybdenum (ppm)	0.14	0.00	0.15	0.26	0.30	0.18	0.20	0.35	0.474	0.0568	0.476	0.693
Selenium (%)	0.06	0.08	0.15	0.11	0.11	0.07	0.14	0.06	0.020	0.174	0.320	0.664
Chloride ion (%)	0.82c	0.95abc	1.27a	1.16ab	1.05abc	0.93bc	1.14ab	1.18ab	0.069	0.0009	0.003	0.883

[1]All data are expressed on a dry matter basis.
Trt - treatment; Var - variety.

Table 6. Mineral concentration in forage from napier × pearl millet hybrids and napier grass varieties grown under irrigated and non-irrigated conditions[1].

Variable	Hybrid								Variety								s.e.m.
	PMN2		PMN3		5344		4604		Bana		Mott		MB4		N51		
	Irr.	Non-Irr.	Irr.	Non-Irr.	Irr.	Non-Irr.	Irr.	Non-Irr.	Irr.	Non-Irr.	Irr.	Non-Irr.	Irr.	Non-Irr.	Irr.	Non-Irr.	
Calcium (%)	0.13	0.22	0.25	0.23	0.31	0.41	0.26	0.28	0.30	0.33	0.25	0.33	0.21	0.19	0.22	0.21	0.05
Potassium (%)	2.07	2.24	2.87	2.14	3.39	3.38	2.72	2.74	3.40	3.61	3.06	2.97	3.17	3.29	3.99	3.84	0.23
Phosphorus (%)	0.23	0.21	0.21	0.18	0.20	0.20	0.22	0.20	0.23	0.16	0.30	0.22	0.19	0.16	0.20	0.17	0.02
Magnesium (%)	0.16	0.20	0.21	0.21	0.22	0.24	0.26	0.30	0.22	0.27	0.13	0.15	0.22	0.23	0.20	0.20	0.03
Sodium (%)	0.02	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.04	0.02	0.03	0.04	0.03	0.03	0.03	0.01
Iron (ppm)	3967	344	1037	898	905	498	343	624	522	477	265	717	529	955	574	744	285.9
Zinc (ppm)	21.3	26.0	24.3	25.3	21.7	24.0	19.0	20.0	20.7	16.7	23.0	22.3	21.3	23.0	19.7	22.3	2.46
Copper (ppm)	6.00	7.00	7.67	7.00	7.67	7.00	8.33	8.67	10.33	9.33	9.67	10.33	11.00	10.33	9.33	9.67	0.87
Manganese (ppm)	30.3	41.0	57.7	65.3	50.0	48.7	33.7	46.3	42.0	41.0	24.0	46.0	38.7	51.3	39.3	49.3	11.79
Molybdenum (ppm)	0.15	0.13	0.10	0.00	0.10	0.20	0.27	0.25	0.33	0.27	0.17	0.20	0.20	0.20	0.27	0.43	0.07
Selenium (%)	0.05	0.07	0.10	0.06	0.18	0.12	0.14	0.09	0.09	0.13	0.07	0.07	0.14	0.13	0.07	0.06	0.03
Chloride ion (%)	0.76	0.89	0.96	1.01	1.17	1.38	1.11	1.22	0.88	1.23	0.85	1.02	1.08	1.21	1.12	1.25	0.10

[1]All data are expressed on a dry matter basis.

Discussion

The higher dry matter yields obtained from the irrigated plots indicated that moisture availability was a limiting factor for growth on the non-irrigated plots. The significantly higher DM yields for the newly developed hybrid, PMN3, under irrigated conditions in the study shows its potential for high levels of production when moisture levels are adequate. Although PMN3 had the highest DM yields under irrigated conditions, it was expected that the PMN hybrids would outperform napier grass under non-irrigated conditions due to the high drought tolerance of pearl millet varieties. It is possible that the 268 mm of rainfall during the 110-day trial prevented plant water stress from developing to a stage when significant yield differences would occur. The advantage of the new hybrids over napier varieties when water is limiting might not be as great as anticipated. Future trials will monitor plant water stress to address this issue.

Nyambati et al. (2010) found that mean annual DM yields of Bana grass over 3 harvests were 10.3 t/ha and 22.1 t/ha in the following year over 6 harvests. In comparison, Bana grass yielded 27.1 t/ha under irrigation in this study over only 110 days. The difference is likely due to genotype by environment interaction. The DM yields of both PMN2 and PMN3 were well above the range (15–22 t/ha/yr) reported for napier grass in eastern Africa (Mugerwa and Ogwang 1976; Muia et al. 2001).

Nutritional quality of forage is at least as important as yield in the selection of the best grass variety for cattle. A dairy cow weighing 600 kg would require around 52.6 Mcal/kg of energy from its feed to produce 30 kg of milk with 4.04% of milk fat (Alderman and Cottrill 1993). To meet this requirement, she would need to eat about 17.5 kg DM/d of feed containing 3 Mcal ME/kg DM. Even when good quality forages are fed to cattle, the major limitation for milk production in any pasture-based diet is energy intake. All grasses in this study can provide only 1.7 Mcal ME/kg DM, and a cow would have to eat around 30.9 kg DM/d, equivalent to 128 kg fresh PMN2, 135 kg PMN3, 143 kg 4604 and 168 kg 5344, whereas 172 kg Bana grass and N51 would be required, because of differing DM concentrations. Hence, the ME density of these grasses would be the primary limitation to milk production, if they were the sole component of the diet. Harris et al. (1997) reported that even good quality ryegrass-white clover pasture did not contain sufficient energy for high-yielding dairy cows producing 30 kg milk/cow/d.

Maximum herbage dry matter intake that a grazing cow can consume from pasture is reported to be 2.5−4.2% of live weight (NRC 1988). This means, when the best quality pasture is fed, a cow weighing 600 kg could potentially consume 25 kg DM/d and would meet the ME requirement for more than 30 kg milk/d. With the limited ME concentration in the grasses in this study, a cow could not possibly consume sufficient pasture to give satisfactory milk yields.

Hemicellulose concentration in the grasses in this study was high and ranged from 19% (Mott) to 23% (N51), which is another factor which would limit intake and digestibility of the forage. In spite of higher NDF content, ME value of all the grasses was reasonably high (1.7 Mcal/kg DM); this higher ME is possibly associated with the presence of comparatively higher amounts of hemicellulose (30% of NDF) than in other grasses.

Though there are still unresolved mechanisms, lignin inhibits digestion of plant cell wall components (Morrison 1983). The higher the lignin concentration the lower the digestibility of forage, as lignification is negatively associated with NDF digestibility. Hybrid 4604 had the highest lignin concentration (8.2%), while 5344 had the lowest lignin concentration (5.2%). This might explain why 5344 had the highest in vitro dry matter digestibility of all grasses tested. However, Dehority and Johnson (1961) and Van Soest (1994) indicated that lignin concentration itself may not be the only factor influencing digestibility, as legumes tend to have twice the lignin concentration of grasses at the same digestibility.

Mineral deficiency is an important cause of reproductive failure and low production rates in ruminants. Forages neither contain all the minerals that animals require nor are they present in adequate quantity (Vargas and McDowell 1997). Mean calcium (Ca) concentration of the forage studied ranged from 0.17 to 0.36%, while the recommended Ca requirement for maintenance, growth and lactation in sheep ranges from 0.12 to 0.26% (Reuter and Robinson 1997). Hence, a complete diet of these forages should provide sufficient dietary Ca for sheep. Although ruminants can tolerate calcium:phosphorus ratios of more than 10:1 (Ternouth 1990), the recommended Ca:P ratio should be around 1:1–2:1 (Underwood 1981). All forages in this study had Ca:P ratios falling in this range. Recommended potassium

(K) concentration for maintenance of ruminants is 0.8% (ARC 1980), while the K concentration in the forages studied ranged from 2.15 to 3.91%. Therefore, ruminants grazing on the grasses studied would receive adequate levels of K. However, magnesium (Mg) absorption from the rumen is inhibited by high levels of dietary K (Judson and McFarlane 1998; McDowell 2003). Requirement of Mg decreases with the increase in level of Ca and soluble carbohydrates (Judson and McFarlane 1998). Metabolic requirements of Mg for adult sheep and goats are 1.5 and 1.6%, respectively (NRC 2007). None of the forages studied can meet the Mg requirement. While most grasses are deficient in sodium (Na), both the hybrids and napier grass varieties contain adequate amounts of Na for adult small ruminants. Non-fiber carbohydrate (NFC) concentration was significantly higher in PMN2 both under irrigated and non-irrigated conditions, which were 12.8 and 12.7%, respectively (Table 2). These carbohydrates are digested more rapidly than fiber, yielding weaker acids as by-products. Volatile fatty acids, primarily propionate, are produced from the fermentation of NFCs, which are absorbed from the rumen and are also used as a source of energy by ruminant animals. NFCs are also used by rumen microbes to make microbial protein, which in turn is utilized by animals as a protein source.

As the rate of digestion of PMN2 was slow, only 2.3% being digested per hour, feed intake would be limited due to rumen fill, whereas a faster rate of digestion in 5344 and Bana would result in higher intake and greater levels of production, if adequate feed is available to satisfy appetite.

The neutral detergent fiber digestibility (NDFD) was highest in 5344 and Bana grass, which again favors these grasses as fodder sources for livestock. The more digestible the NDF in pasture the more energy is available to the animal. The lower digestibility of NDF in PMN2 would be a contributing factor to the low rates of digestion in this hybrid.

Overall, the low crude protein, high fiber and low energy density of these grasses at this age would not sustain growing beef animals and would not meet the needs of cows in late stages of pregnancy and early lactation, or growing and lactating dairy animals, especially if fed in stalls, as the sole diet. However, under grazing conditions, animals are able to select a higher quality diet than the total on offer and would produce at a higher level.

Conclusion

This study suggests that the hybrids tested have some advantages over the napier grass varieties tested. While yield differences were small under rainfed conditions, only 2 hybrids (PMN2 and PMN3) and napier variety MB4 showed significant responses when irrigation was provided. This suggests that the main advantages of these hybrids might be seen in higher rainfall years or when irrigation is available. In terms of DM yield, PMN3 showed outstanding potential. While hybrid 5344 produced lower DM yields than PMN3, it had a much higher digestibility and displayed more rapid digestion than the other hybrids and varieties except Bana. Low IVDMD, low NDFD and slow rate of digestion are limiting factors in the use of PMN2.

PMN3 exhibited a positive combination of high biomass yield, favorable lignocellulosic content, good digestibility and high nutritional value. This hybrid appears to have definite potential for both cattle feeding (as forage) and as a source of bioenergy. For the growing conditions experienced in this study, hybrids PMN3 and 5344 seem preferable to napier grass varieties for forage production for ruminant feeding systems, even under rainfed farming conditions. Additional research is required to obtain detailed information on the long-term performance of PMN grasses, as well as their chemical composition and biomass yield at different cutting intervals and at different locations. Feeding studies would provide data on the palatability of these grasses and performance of stock consuming the forage.

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