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Research Paper

Effects of swine manure application and row spacing on growth of pearl millet (*Cenchrus americanus*) during the establishment period and quality of silage produced in Southwest Nigeria

Efectos de la aplicación de estiércol de porcinos y de la distancia de siembra en el establecimiento y la calidad del ensilaje de Cenchrus americanus *en el suroeste de Nigeria*

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Abstract

The effects of swine manure application and row spacing on dry matter yields of *Cenchrus americanus* (pearl millet) at 6 weeks after sowing and chemical composition, fermentative characteristics and in vitro gas production of silage produced from the forage were studied. The design was a 2 × 2 factorial with 2 row spacings (0.5 and 1.0 m) and 2 levels of manure application [no manure (Control) and swine manure at 5 t/ha (22% DM; 0.34% N on DM basis)] replicated 3 times. Swine manure application had no effect ($P>0.05$) on dry matter yield but a row spacing of 0.5 m produced higher ($P<0.05$) dry matter yields than 1.0 m spacing (mean 7.05 vs. 5.57 t DM/ha). Fresh forage from manured treatments had significantly higher crude protein concentration (114.9–124.2 g/kg DM) than from unfertilized plots (86.2–95.1 g/kg DM). After being ensiled for 42 days, CP% in the forage had declined by 16–18% but relative differences remained. Quality measurements indicated that silages from the various treatments were all of acceptable standard although CP% of silage from Control plots was barely high enough to provide a maintenance diet. This study suggests that, under the experimental conditions, planting of pearl millet at a spacing of 0.5 m rather than 1.0 m would increase DM yields obtained in the first 6 weeks of growth, while application of swine manure would not affect yields but would increase CP% of forage produced. The laboratory study indicates that the forage produced could be ensiled successfully although there was significant loss of crude protein during the process. Since there were no significant increases in DM yields of forage, other benefits, e.g. increase in N concentration, improved soil organic matter, etc., would need to be considered in justifying the additional cost of drying and applying the manure.

Keywords: Fertilization, forage conservation, nutritive value, tropical forages.

Resumen

En Abeokuta, Oguna State, Nigeria se estudiaron los efectos de la aplicación de estiércol porcino y el espaciado entre hileras sobre los rendimientos de materia seca de *Cenchrus americanus* a las seis semanas después de la siembra, la composición

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química, las características fermentativas y la producción de gas in vitro por el forraje ensilado de esta gramínea. Se empleó un diseño factorial 2 × 2 con dos distancias de siembra (0.5 y 1.0 m entre hileras) y dos niveles de aplicación de estiércol [sin y con 5 t/ha (22% MS; 0.34% N con base en MS)] y tres repeticiones. La aplicación de estiércol porcino no mostró ningún efecto (P>0.05) en el rendimiento de materia seca, pero la distancia entre hileras de 0.5 m produjo rendimientos de materia seca más altos (P<0.05) que la distancia de 1.0 m (media 7.05 vs. 5.57 t MS/ha). El forraje fresco en los tratamientos con estiércol presentó mayor (P<0.05) concentración de proteína cruda (114.9–124.2 g/kg de MS) que el de las parcelas no fertilizadas (86.2–95.1 g/kg de MS). Después de estar ensilado durante 42 días, el porcentaje de PC en el forraje se redujo en 16–18%, pero las diferencias relativas se mantuvieron. Las mediciones de calidad indicaron que los ensilajes en los tratamientos eran aceptables; no obstante en el testigo (tratamiento sin estiércol) el porcentaje de PC del ensilaje solo llenaba los requerimientos de mantenimiento para bovinos. Este estudio mostró que en las condiciones experimentales, la siembra de *C. americanus* a una distancia de 0.5 m aumenta los rendimientos de MS obtenidos en las primeras 6 semanas de crecimiento, mientras que la aplicación de estiércol porcino no afecta los rendimientos, pero aumenta la concentración de CP en el forraje.. El estudio de laboratorio indica que el forraje producido puede ser ensilado con éxito, pero con una pérdida significativa de PC durante el proceso. En vista de que la aplicación de estiércol no mostró aumentos significativos en el rendimiento de forraje, otros beneficios, p.ej. el aumento de la concentración de N y el incremento de la materia orgánica en el suelo, etc., deberían considerarse para justificar el costo adicional del secado y la aplicación del estiércol.

Palabras clave: Conservación de forraje, fertilización, forrajes tropicales, valor nutritivo.

Introduction

Forages are the primary diets for ruminants in many tropical regions and grasses constitute the bulk of the energy sources for grazing ruminants (Olanite et al. 2010). High-yielding forages of high quality are the most economical feed for ruminants and result in acceptable liveweight gains and animal performance. However, prolonged annual dry seasons negatively affect plant performance, resulting in limited quantity and poor quality of available forage at this time, leading to a reduction in voluntary feed intake and nutrient utilization, with reduced overall performance of ruminant animals.

Ojo et al. (2015a) suggested that the challenge of feed shortages could be solved through the cultivation of forage crops with better nutritional values than the existing native feed resources. Similarly, Bamikole et al. (2004) reported that high concentrations of protein, vitamins and minerals in sown forages could markedly improve animal performance. Conservation and preservation of these cultivated species, combined with improved management practices, is a possible solution to the limitations posed by poor quality and quantity of native forages in the dry season (Ojo et al. 2015b). Babayemi (2009) recommended the ensiling of forages, at a growth stage when there is a balance between yield and quality of the available crop, for feeding to animals during times of nutritional stress.

Amodu et al. (2005) indicated that pearl millet [*Cenchrus americanus* (L.) Morrone syn. *Pennisetum americanum* (L.) Leeke] is a promising forage crop with high potential for integration into Nigerian livestock production systems. The crop is well adapted to a wide range of agronomic conditions varying from the semi-arid to the subhumid zone, where annual rainfall varies between 600 and 1,100 mm, with forage yields of 2.7–7.7 t DM/ha (Agishi 1985). Preliminary studies with pearl millet confirmed that it could be harvested and conserved for feeding to ruminant animals during prolonged dry seasons (Nuru 1989).

To ensure both adequate yields and acceptable quality of forage, application of fertilizer and optimal row spacing are essential (Miah et al. 1990; Olanite et al. 2010). In the past, application of inorganic fertilizer has been the normal practice, but increased costs of these products, combined with the attendant nutrient depletion and negative residual effects of inorganic fertilizers on the environment (Malhi et al. 2002), have resulted in increased interest in using organic manures on soils. Applying organic manures to soils/crops would have multiple benefits by overcoming the problem of manure management and disposal, improving the nutrient status of the soils and possibly improving both yields and nutrient value of the forage produced (Ojo et al. 2013).

The present study investigated the effects on DM yields and nutritive value of the resulting forage of applying swine manure to a crop of pearl millet sown at 2 different row spacings, and quality of silage produced from the forage.

Materials and Methods

Location

The experiment was conducted at the Pasture Unit of Federal University of Agriculture, Abeokuta (FUNAAB)

Farm, Ogun State, Nigeria (7°58' N, 3°20' E; 75 masl). The site is situated in the derived savannah agro-ecological zone of Southwest Nigeria with average annual rainfall of 1,037 mm. Mean monthly temperature ranges from 25.7 ºC in July to 30.2 ºC in February (earth.google.com/). Data on rainfall, temperature and humidity covering the period when the study was conducted are shown in Table 1.

Table 1. Meteorological data for the experimental area during June–December 2015.

Month	Rainfall (mm)	Mean temp. (°C)	Mean rel. humidity (%)
Jun	165	26.9	79.4
Jul	66	26.6	80.9
Aug	29	26.3	79.3
Sep	165	26.5	81.3
Oct	159	27.4	81.9
Nov	17	28.6	72.5
Dec	0	26.1	39.7

Source: Agrometeorology Department, FUNAAB, Nigeria.

Land preparation

A total land area of 598 m^2 was cleared, plowed and allowed to rest for a period of 2 weeks before harrowing, following conventional tillage operations to provide a fine seed bed. Prior to sowing, soil samples were collected at random from the area to a depth of 15 cm using a soil auger to determine the pre-planting nutrient status of the soil. Analysis of these soil samples indicated that it was a sandy silt with the following parameters: pH 6.75, organic carbon 1.27%, available phosphorus (P) 30.4 mg/kg, potassium (K) 0.79 cmol/kg, calcium (Ca) 3.36 cmol/kg, magnesium (Mg) 2.42 cmol/kg, sodium (Na) 1.51 cmol/kg and total nitrogen (N) 0.11%.

Swine manure was collected from the Piggery Section of the Directorate of University Farms, FUNAAB, 14 days before application in bi-axially oriented polypropylene bags. Following collection, the manure was spread to dry and stored under a barn to allow for normal decomposition. The pigs had been fed a standard “Pigs finisher diet”. Chemical analysis of the manure revealed that it contained: 4.76% Ca, 2.40% Mg, 1.92% K, 2.07% Na, 0.34% N and 1.2% P on a DM basis.

Experimental design

The experiment was laid out as a 2 × 2 factorial design comprised of 2 row spacings (drilled at 0.5 and 1.0 m inter-row intervals) and 2 levels of swine manure application (0 and 5 t/ha at 22% DM). A randomized complete block design was used with a total land area measuring 19 × 17 m divided into 3 equal blocks. Each block measured 5 × 17 m with a buffer zone of 1 m between blocks, while each plot measured 4 × 5 m, with a buffer zone of 1 m between plots. Variability in soil was blocked across the slope and each treatment was replicated 3 times.

The manure was broadcast onto individual plots according to treatment in a single application and subsequently raked into the soil manually and the plots were left for 2 weeks before sowing the grass. Seeds of *C. americanus* were drilled in rows at the predetermined row spacings at a seeding rate of 20 kg/ha in August 2015. No herbicides were applied.

Forage harvest and ensiling process

Millet forage was harvested at 6 weeks after sowing by cutting the entire forage in each plot at 15 cm above ground level. Fresh weight of the forage was determined immediately after harvesting, following which 500 g subsamples of the fresh forage from each treatment were collected to determine DM% and chemical composition. Thereafter, the harvested forage was bulked within treatments and allowed to wilt for 4 hours. Wilting helped reduce the moisture content of the forage to give a DM concentration of 33%, following which the material was manually chopped to lengths of about 2 cm. The chopped forage was rapidly compressed and sealed into laboratory glass silos of 960 mL capacity with 3 silos per treatment. Small glass silos were used as this was an exploratory study and no animal feeding trials were planned. A total of 500 g of forage was manually compressed into the silo bottles to a density of 0.52 g/mL. The silos were tightly sealed with 6 layers of duct tape to prevent re-entry of air into the silos, and the ensiled materials were allowed to stand for a period of 6 weeks, at an ambient room temperature of 26 ºC.

Quality analyses

Fresh forage. Analysis of the fresh forage commenced immediately after sample collection. Subsamples (500 g) were oven-dried to a constant weight at 65 ºC. The dried samples were then milled through a 1 mm sieve and crude protein (CP) and ash concentrations were determined according to the standard methods of AOAC (2000). Fiber fraction concentrations [neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL)] were determined according to Van Soest et al. (1991). Cellulose concentration was estimated as the difference between ADF and ADL concentrations, while hemicellulose concentration was estimated as the difference between NDF and ADF concentrations.

Silage. At the expiration of the ensiling period, the silos were opened and assessed for physical and sensory properties, including color, odor, moisture and presence of mold (Appendix 1). Six trained silage experts assessed all treatments using a scoring sheet (Bates 1998). After opening the silos, about 200 g of silage was weighed into 500 ml beakers. Color and moldiness scores were awarded based on the visual appearance of the silage. Odor score was based on how assessors felt when smelling a sample of silage. For moistness, the assessors – wearing latex gloves – squeezed moisture from about 30 g of the silage and allocated a score for the level of free water in the silage. For the scoring schemes, see Appendix 1. Ammonia and volatile fatty acid concentrations (acetic, propionic, butyric and lactic acid concentrations) in the silages were determined according to the procedures of AOAC (1990) and Mathew et al. (1997), respectively. Immediately after opening of the silos, 10 g samples of silage were taken from each silo and soaked in 100 mL of distilled water for 12 hours. The mixtures were then filtered and the supernatant divided into 4 aliquots each for pH determination using a pH meter (Hanna instruments, pH 211, microprocessor pH meter, K012818, Portugal) (Wilson and Wilkins 1972).

Subsamples of 300 g silage were oven-dried to a constant weight at 65 ºC. Concentrations of CP, ash and fiber fractions were determined following the same procedures outlined for the fresh samples. In addition, mineral concentrations (Ca, P, K, Mg, iron and copper) of the silage samples were determined according to the standard methods of AOAC (2000).

To evaluate the degradability of the ensiled forage materials, in vitro gas production was determined according to the procedure of Menke and Steingass (1988).

Statistical analysis

Data collected were subjected to a 2-way analysis of variance and treatment means were separated using Duncan's Multiple Range Test (SAS 2003) and analyzed using the PROC GLM procedure.

Results

Fresh forage

The narrower row spacing produced significantly ($P<0.05$) higher forage yields (6.85 and 7.25 t DM/ha for no manure and manured, respectively) than the wider row spacing (5.48 and 5.65 t DM/ha for no manure and manured, respectively) (Figure 1). There was no significant ($P>0.05$) response to manure application at either row spacing.

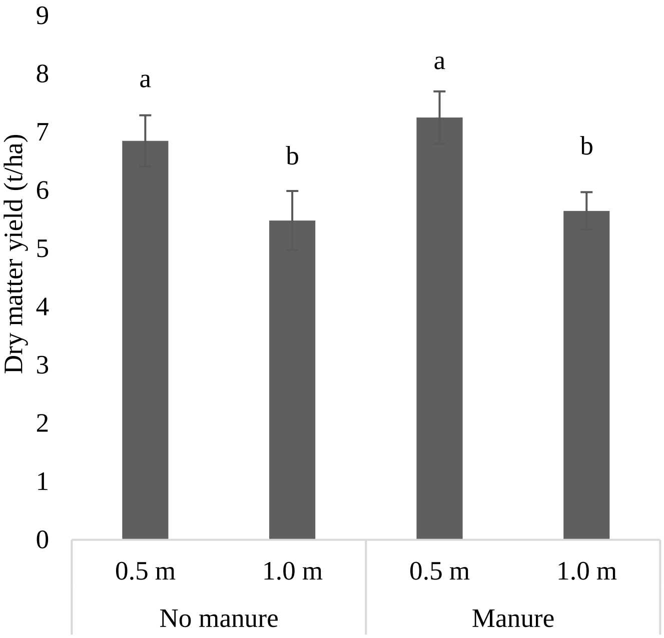

Figure 1. Yields of *Cenchrus americanus* as affected by row spacing and swine manure application. Error bars indicate standard error of the mean. Values for columns with different letters are significantly ($P<0.05$) different.

At both row spacings, fertilized pearl millet had higher ($P<0.05$) CP percentage than the unfertilized grass (Table 2). There were no consistent patterns between treatments in NDF, ADF, ADL, hemicellulose and cellulose levels but unfertilized forage at the wider row spacing tended to have the lower levels of NDF, ADF and cellulose.

Table 2. Chemical composition (g/kg DM) of fresh *Cenchrus americanus* forage as affected by row spacing and swine manure application.

Row spacing (m)	Manure application	CP	Ash	NDF	ADF	ADL	Hemi-cellulose	Cellulose
0.5	Manure	114.9a[1]	163	645a	386a	87.7	199b	297b
	No manure	95.1b	179	668a	390a	82.0	287a	305b
1.0	Manure	124.2a	151	626ab	409a	89.9	203b	321a
	No manure	86.2b	200	586b	365b	80.3	227b	277c
s.e.m.		5.76	8.3	22.7	6.2	4.39	30.8	6.3

[1] Means in the same column followed by different letters are significantly ($P<0.05$) different.

Silage

Irrespective of row spacing, silage made from unfertilized pearl millet recorded higher ($P<0.05$) silage color scores than silage from fertilized forage, with the silage having desirable green to yellowish-green color (Table 3; Appendix 1). All silages except that from the fertilized plots at wide row spacing had quite acceptable odors.

Fermentative characteristics of the silage were significantly ($P<0.05$) affected by both row spacing and manure application (Table 4). Fertilized forage from the narrow row spacing had lower VFA (volatile fatty acid) concentrations but higher ammonia N concentrations and pH values than other silages. Meanwhile, silage from unfertilized treatments had the lowest pH regardless of row spacing.

Silage from the narrow row spacing had significantly ($P<0.05$) higher DM percentage than that from the wider row spacing irrespective of manure application (Table 5), while manure application had no effect on DM% ($P>0.05$). Manure application at both row spacings increased ($P<0.05$) CP% of silage. There were no consistent patterns in the effects of both manure application and row spacing on ADF, ADL, hemicellulose and cellulose concentrations.

All mineral concentrations in silage followed the same pattern except for P, in the order Narrow + manure > Wider + manure > Wider + no manure > Narrow + no manure ($P<0.05$) (Table 6). Concentration of P in silage showed an increase from manure application at narrow row spacing but a reduction from manure application at the wider spacing.

In general, patterns of gas production from silage over time were inconsistent and not significantly affected by either manure application or plant spacing ($P>0.05$) (Table 7). Fermentation of substrates was ongoing beyond 24 hours of incubation.

Table 3. Physical characteristics of *Cenchrus americanus* silage as affected by row spacing and swine manure application.

Row spacing (m)	Manure application	Color	Odor	Moistness	Moldiness
0.5	Manure	7.8b[1]	23.6b	9.0a	8.0b
	No manure	9.8a	26.0a	9.0a	9.0a
1.0	Manure	6.7c	14.9d	6.0c	5.0d
	No manure	9.6a	22.0c	8.0b	6.0c
s.e.m.		0.16	0.13	0.06	0.07

For the scoring schemes, see Appendix 1.

[1] Means in the same column followed by different letters are significantly ($P<0.05$) different.

Table 4. Fermentative characteristics of *Cenchrus americanus* silage as affected by row spacing and swine manure application.

Row spacing (m)	Manure application	VFA[1]	Ammonia N	Acetic acid	Propionic acid	Butyric acid	Lactic acid	pH
					(%)			
0.5	Manure	10.8c[2]	3.0a	1.30bc	0.87c	0.13b	1.95c	5.17a
	No manure	12.0a	1.7c	1.44a	0.96a	0.14a	2.16a	4.15c
1.0	Manure	11.7ab	2.2b	1.25c	0.94ab	0.14a	2.11ab	4.70b
	No manure	11.3b	1.4d	1.36ab	0.90c	0.14a	2.03b	4.27c
s.e.m.		0.09	0.02	0.05	0.01	0.00	0.02	0.02
P-value		0.0001	<0.0001	0.0001	0.0001	0.0001	0.0001	<0.0001

[1] Volatile fatty acids. [2] Means in the same column followed by different letters are significantly ($P<0.05$) different.

Table 5. Chemical composition of *Cenchrus americanus* silage as affected by row spacing and swine manure application.

Row spacing (m)	Manure application	DM (%)	CP	Ash	NDF	ADF	ADL	Hemicellulose	Cellulose
			(g/kg DM)						
0.5	Manure	68.0a[1]	94.6a	137ab	537ab	320	73.3	167	247
	No manure	64.1a	79.9b	147ab	557a	320	66.7	237	253
1.0	Manure	59.1b	101.3a	127b	510ab	340	73.3	170	267
	No manure	55.1b	71.2b	167a	490b	300	66.7	190	233
s.e.m.		4.22	2.64	6.37	13.5	11.55	6.67	14.7	11.7

[1] Means in the same column followed by different letters are significantly ($P<0.05$) different.

Table 6. Mineral concentrations in *Cenchrus americanus* silage as affected by row spacing and swine manure application.

Row spacing (m)	Manure application	Calcium	Phosphorus	Potassium	Magnesium	Iron	Copper
		(g/kg DM)				(mg/kg DM)	
0.5	Manure	9.83a[1]	5.22a	20.3a	6.25a	74.3a	7.44a
	No manure	3.83d	3.65c	18.1d	4.58d	36.7d	2.34d
1.0	Manure	8.09b	3.77c	20.2b	5.45b	62.4b	6.69b
	No manure	7.37c	4.33b	19.7c	5.31c	41.9c	4.13c
s.e.m.		0.00	0.08	0.00	0.00	0.01	0.02

[1] Means in the same column followed by different letters are significantly ($P<0.05$) different.

Table 7. In vitro gas production (mL/h) of *Cenchrus americanus* silage as affected by row spacing and swine manure application.

Row spacing (m)	Manure application	Time (h)						
		3	6	9	12	24	36	48
0.5	Manure	1.3	3.3	6.7	8.7	20.7	30.0	31.3
	No manure	2.0	4.0	8.0	10.7	20.0	24.0	24.0
1.0	Manure	1.3	4.7	8.0	10.7	19.3	24.0	25.3
	No manure	1.0	4.7	8.7	9.3	22.0	28.7	30.7
s.e.m.		0.77	1.35	2.09	2.48	3.85	4.09	4.10

Discussion

This study revealed that planting *Cenchrus americanus* with narrow row spacing under the conditions existing in this study resulted in about 25–28% increase in DM yield compared with the wider row spacing. This higher DM yield recorded for plants on the narrow-spaced plots may be due to higher nutrient use efficiency (Jiang et al. 2013) as a result of more effective distribution of plants over the available surface, as opposed to the wider-spaced plots with a higher plant density within rows.

Interestingly DM yields for plants on both manured and control plots were similar. A lack of response to manure application may be due to the slow nutrient release rate associated with swine manure (Chastain et al. 1999; Silva et al. 2016), implying that perhaps much of the nutrients in the applied manure may not have been converted to plant usable forms, and the quantities released to the plant may have been insufficient to induce higher dry matter yields. Since the quantity of manure applied supplied only about 3.7 kg N/ha it is scarcely surprising that no growth response occurred.

In contrast, the higher CP% in fertilized forage was surprising given the low N rates in the manure but corroborates an earlier study by Jimoh et al. (2019) who reported a 20.1% increase in CP% when swine manure was applied to *Panicum maximum* cvv. Local and Ntchisi relative to the control in southwestern Nigeria. It is possible that P in the manure may have influenced the increased N uptake by the plants since N uptake has been reported to be influenced by higher P availability (Cleveland et al. 2011; Alkhader and Abu Rayyan 2015). The quality of grasses remains comparatively stable from vegetative to early stages of stem elongation (Jones and Wilson 1987) and declines as the plant matures (Ojo et al. 2016a, 2018; Ali et al. 2019). In this study, forages were harvested at 6 weeks of growth, when forage should have ample CP% to meet ruminant demand, allowing multiple harvests within the growing season. CP concentrations in the fresh forage were quite satisfactory for ruminant feeding at 8.6–12.4%. However, there was a marked reduction in CP% in the corresponding silages with a range of 7.1–10.1%, which agrees with the findings of Naeini et al. (2014), who reported a reduction in CP%

from 6.2% in fresh sweet sorghum to 5.4% in the silage. The critical limit required by rumen microbes to build their body protein for effective digestion of forages in ruminants is 7.0% (Van Soest 1994). The lower values for silage in our study are barely high enough to provide maintenance levels of protein for ruminants and values below this could result in reduction in DM intakes.

The color of the silages in this study fell within the range of 5–8 (green to yellowish-green) and 9–12 (yellow to brownish) which are regarded as good to acceptable ranges for silage (Bates 1998; Babayemi 2009). Further, the odor of the silage also fell within the range of 11–23 (acceptable) and 24–28 (desirable) reported by Bates (1998), although better scores were obtained from silage made from the narrowly spaced plots which could be due to the higher dry matter percentage that has been reported to influence the stability of ensiled forages (Wilkinson and Davies 2013).

The pH values recorded for the silages were within the range of 4.5–5.5 classified as indicative of good silage (Meneses et al. 2007). However, concentrations of desirable lactic acid in silage (1.95–2.16%) were below the range of 2.37–5.89% reported by Kung and Shaver (2001). High concentrations of lactic acid in silage are a clear indication of good preservation, which invariably results in lower loss of DM and energy during storage. Ammonia nitrogen is an important indicator of proteolytic activity during the fermentation process. Ammonia concentrations in the silage were very low and well below 12%, which is considered the indicator of an excellent and well preserved forage (Silveira 1975; Kung and Shaver 2001). Acetic acid concentrations were within the range (0.5–3.0% DM) classified as normal for grass silage (Kung and Shaver 2001) and also fell in line with the range of 0.74–1.53% DM for *Pennisetum* hybrid silage reported in another experiment (Ojo et al. 2016b).

The NDF values of *C. americanus* silage recorded in this study were well below the 65% threshold suggested as the level at which intake and degradability of tropical feeds by ruminants would be limited (Eastridge 2006). This was not surprising given the growth stage at which the forage was harvested. Higher NDF concentration in silage made from the forage planted at 0.5 m intervals could be a function of competition for light owing to the close spacing, resulting in continuous elongation in the height of the plants, thereby leading to increased fiber concentration.

There were general improvements in the Ca, K, Mg, Fe and Cu concentrations of silage made from the manured plants. This was expected as the manure may have made more nutrients available to the plants and corroborates the report by Christophe et al. (2019) that organic amendments tend to improve plant mineral composition. In addition, mean concentration values for major limiting nutrients (Ca, P, Mg and Cu) were higher than the minimal concentration levels of 2.3–2.9, 2.0–3.5, 0.4–0.5 g/kg and 4 mg/kg, respectively, suggested for dairy cows (NRC 1984). This implies that there would be no need for supplements if the silage were fed to animals. Usually, deficiencies and imbalances in nutrients are neutralized by mineral supplements which may be costly for poor resource farmers (Tiemann et al. 2009); however, the mineral concentration values recorded for the silages in this study, especially those from the manured treatments, were at favorable levels.

The observed similarities in the in vitro gas volumes implies that despite the differences in the NDF concentrations of the ensiled forages, this may not be sufficient to hinder the degradability of the forages if fed to ruminants. Anassori et al. (2012) had asserted that gas volume readings could be used to estimate the degradability of forages in vitro. This finding further supports the initial proposition that the higher NDF values recorded for the narrow spaced plants falls within the threshold of what can be efficiently degraded by rumen microbes.

Conclusion

While application of swine manure to pearl millet at 5 t/ha increased CP% of forage and N recovery rate when harvested at 42 days, it failed to increase forage yields. However, decreasing row spacing from 1.0 to 0.5 m increased DM yield by 25–28%, indicating significant gains to be made by planting pearl millet at a closer row spacing at the sowing rates used in that environment. Plant populations, soil fertility and rainfall levels could have significant impacts on these findings. While silage made from the forage was of a good standard, CP% in the forage had declined by 16–18%. It seems that applying swine manure at 1.1 t DM/ha to pearl millet planted at 0.5 m spacing and cutting at 6 weeks after planting could produce high yields of forage. Ensiling this material would give a product of sufficient quality to be fed as supplements or a complete diet to ruminants especially during the dry season. Better responses in yield might be expected from other manure sources with higher N content. Cutting at more mature stages of growth would be expected to increase DM yields but quality of forage should decline, especially N concentration, and ability to compress the forage during ensiling would be expected to decline as well. Longer-term studies to determine if yield advantages from the narrower row spacing could be maintained as the stand matured as well as the quality outcomes of repeated cutting at close intervals with those from less frequent cutting seem warranted.

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(Note of the editors: All hyperlinks were verified 4 May 2020.)

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Appendix 1. Silage physical and sensory evaluation sheet.

Factor	Description	Score range
Color	Desirable: Green to yellowish-green	9–12
	Acceptable: Yellow to brownish	5–8
	Undesirable: Deep brown or black indicating excessive heating or putrefaction	0–4
Odor	Desirable: Light, pleasant odor with no indication of putrefaction	24–28
	Acceptable: Fruity, yeasty, musty which indicate a slightly improper fermentation; slight burnt odor, sharp vinegar odor	11–23
	Undesirable: strong burnt odor indicating excessive heating; putrid, indicating improper fermentation	0–10
Moistness	No free water when squeezed in hand; well preserved	9–10
	Some moisture can be squeezed from silage or silage dry or musty	5–8
	Silage wet, slimy or soggy, water easily squeezed from sample; silage too dry with a strong burnt odor	0–4
Moldiness	No mold	9–10
	Slightly moldy	5–8
	Highly moldy	0–4

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