ROW SPACING OF ANNUAL PEANUT (*ARACHIS HYPOGAEA L.*) AND THE CONSERVATION OF PEANUT HAULM AS HAY OR SILAGE: EFFECTS ON NUTRITIVE VALUE AND GROWTH PERFORMANCE OF SHEEP

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ABSTRACT
This study investigated the effects of planting annual peanut at inter-row spacings of 30, 45, 60 or 75 cm on haulm yield and nutritional quality (Experiment I), in vitro digestibility (Experiment II) and growth performance of sheep fed peanut hay or silage diets (Experiment III). At harvest, peanut haulms were either sun-dried as hay or ensiled and used to formulate two diets that were fed to sheep. Twenty West African Dwarf ram-lambs (29.7±0.99 kg) were randomly assigned to these two dietary treatments in a completely randomized design. Grain (P=0.033) and haulm (P=0.045) yields were highest at 30 cm as compared to the other spacings; whereas yeasts populations, and butyric acid and ammonia N concentrations were higher in the silage than hay (Experiment I). In vitro NDF digestibility linearly decreased (P=0.001) with increasing row space (Experiment II). In experiment III, the DM intake of the silage-based diet was depressed (P=0.069) by 235.8 g/d compared to the hay-based diet; whereas feed efficiency (P=0.053) and average daily gain (P=0.012) were lower for the silage- than hay-based diet. In conclusion, in vitro NDF digestibility of peanut haulm was higher at narrow row spacing whereas growth performance was superior for sheep fed the hay-based rather than the silage-based diet.

Keywords: *Crop residues, growth performance, peanut haulm, plant spacing, sheep, in vitro digestibility*

INTRODUCTION
In the tropics, only farming systems that involve the production of by-products and crop residues from the cultivation of food crops are consistently relied upon to produce livestock feed. Per unit area, these systems have been proposed to produce more high-quality forage than natural grasslands (Suttie, 2000) and some planted pastures (Blümmel *et al*., 2005). Crop residues are very important feed resources in smallholder crop-livestock farming systems in sub-Saharan Africa. Their feed value is better defined in terms of animal output such as daily weight gain and milk yield, which is a function of the quantity (yield) and quality (CP, intake and digestibility) of the crop residue available. Yield is affected by several factors especially agronomic practices such as row spacing and fertilization; whereas nutritive value depends on botanical composition and post-harvest conservation practices such as drying or ensiling.

Annual peanut (*Arachis hypogaea L.*) haulm is the most common and important leguminous crop residue for feeding ruminants and has thus become the mainstay of smallholder livestock production in sub-Saharan Africa (Larbi *et al*., 1999), and is used in the southern USA (Johnson *et al*., 1979; Foster *et al*., 2011) and in arid parts of Asia (Suttie, 2000). Haulm consists of leaves, stems and roots and is obtained after the harvest of the nuts, followed by sun-curing in the field. The CP content (13.4% DM) and yield (4547 kg DM/ha) of peanut haulms are high (Larbi *et al*., 1999), with the CP content being comparable to full-bloom alfalfa hay (Yang, 2005). In northern Ghana, peanut haulms are fed to ruminants with the surplus sold to supplement household incomes (Konlan *et al*., 2018).

The recommended inter-row spacing for planting both erect and runner cultivars of peanut in Ghana ranges from 30 cm (Konlan *et al*., 2012; 2013) to 70 cm (Daapah *et al*., 2014). Closer inter-row spacing of 46 cm has been reported to improve canopy closure, light interception and DM yield as compared to a wider spacing of 91cm (Jaaffar and Gardner, 1988). Narrower planting distances also have additional agronomic benefits in terms of weed control. Plant spacing has effects on the fractional components (leaf and stem) and total fodder yield, and nutrient composition of peanut crops (Bell *et al*., 1987; Giayetto *et al*., 1998). Planting systems that concomitantly increase grain and haulm yields, without adversely affecting the nutritional quality of the haulms can help meet the nutrient requirements of ruminants, particularly in the dry season.

Sun-drying is the main method of conserving peanut haulms in the tropics, but peanut is typically harvested during the mid- to late- rainy season, making it difficult to conserve as sun-dried hay. Given that peanut haulm has a high leaf: stem ratio (34:1), and that the leaves are more digestible and contain more CP than stems (Larbi *et al*., 1999), leaf losses and spoilage in the field may also reduce the nutritional value of this forage. Attempting to field-cure forage in the rainy season (>100 mm) can reduce OM digestibility by as much as 14% in temperate climates (Minson, 1990). Ensiling is one strategy to conserve fresh agricultural residues produced by smallholder farming systems in the rainy season. Compared to sun-drying, ensiling may help reduce nutritional losses and improve DM digestibility (4–8%) of peanut haulms (An, 1998). However, peanut haulms have a lower concentration of water-soluble carbohydrates (WSC) and a high buffering capacity and the tubular-hollow stems trap air in the forage (Yang, 2005). These characteristics, combined with high ambient temperatures in the tropics predisposes silage to a greater risk of poor fermentation and spoilage during ensiling, and more rapid deterioration upon exposure to air during feed-out (Bernardes *et al*., 2018; Yang, 2005). Aerobic deterioration of silage is particularly a problem in the tropics where individual smallholder farmers have only small quantities of crop residues to ensile at a time.

This paper reports the results of three experiments on: (1) the effects of inter-row spacing of peanut plants on haulm yield and nutrient composition (Experiment I); (2) the *in vitro* digestibility of haulms obtained from peanut planted at different inter-row plant spacing and of haulms conserved as hay or silage (Experiment II); and (3) the voluntary intake and growth performance of West African Dwarf sheep fed peanut haulm hay or silage (Experiment III).

MATERIALS AND METHODS

Three experiments were conducted. Experiment I compared the effects of inter-row spacing on grain and haulm yield of peanuts. In Experiment II, the *in vitro* digestibility of haulms from peanut planted at inter row spacing of 30, 45, 60 or 75 cm and of haulms conserved as hay or silage were determined. Experiment III compared the effects of using hay or silage in total mixed diet (Table 1) on growth performance of West African Dwarf sheep.

Experiment I

In Experiment I, a uniform field was prepared and fertilized at 8.5 tonnes DM/ha with sheep manure. The field was divided into triplicate plots (10 m x 10 m) and randomly assigned to 4 different inter-row plant spacing (30, 45, 60 and 75 cm) with plants spaced 15 cm apart within rows. Annual peanut (Chinese cultivar) seeds were planted on July 17, 2018 by hand using a rope and dibbler. At the full-pod stage (31% DM), a one-metre quadrant was randomly thrown 3 times in each plot and each quadrant was harvested. The weight of forage harvested within each quadrant was recorded. The pods were then plucked by hand and the weights of the pods and haulms were recorded for subsequent estimation of grain and haulm yields. The haulm was then separated into leaves and stems and then subsampled. The subsample of leaves, and stems were air-dried to 94% DM under a shed and subsampled for subsequent chemical analysis and estimation of *in vitro* NDF digestibility. The entire field was then harvested, pods removed manually by hand and the haulms (i.e., stems, leaves and roots) were shaken by hand to remove soil (Johnson *et al*., 1979) and subsampled for laboratory analyses for determination of nutrient composition prior to being sun-dried or ensiled on the same day.

The harvested haulms were divided into 2 lots of ≈1000 kg each. One lot was allowed to sun-cure on the field to 45% DM over a period of 6 d, chopped (3–4 cm) and used for ensiling. The second lot of forage was collected, chopped (3–4 cm) and further sun-dried for an additional 165 d. Chopped forage (theoretical length of 3–4 cm) was ensiled at 45% DM in 2 polyethylene bulk silo bags (120 × 90 × 90 cm; Shandong Anthente New Materials Technology Co., Ltd; Shandong, China) with a capacity of 550 kg each. Chopped haulms were manually compressed into each polyethylene-lined bag silo immediately after collection, via trampling the forage (≈500 kg) into the silo. Three concrete slabs (≈200 kg) were placed on top of each bag until they were opened after 171 d of ensiling. On the day of silo opening, both silage and sun-dried hay were subsampled for chemical analysis before being used in the feeding trial.

Experiment II

In Experiment II, rumen contents were collected randomly from 3 slaughtered rams at a local abattoir in the morning. A detailed outline of the procedure for the collection of rumen samples from slaughtered animals has previously been described (Lutakome *et al*., 2017; Wang *et al*., 2018). Briefly, fresh rumen content was collected from four different compartments of the reticulo-rumen within 10-15 min of slaughter and evisceration. Contents were immediately strained through 3 three layers of cheese cloth under a stream of carbon dioxide gas, into a 250 mL pre-warmed bottle. The samples of rumen fluid from each ram were placed in an airtight thermo-flask containing warm water and transported to the laboratory within 1 h of collection. Contents were used in an *in vitro* digestibility experiment according to the procedures of Tilley and Terry (1963). At the laboratory, the 3 bottles of rumen fluid were pooled, thoroughly mixed and added to simplex buffer (Piwonka and Firkins, 1996) in a ratio of 1: 2 (vol/vol). Forage samples (leaves, stems, hay and silage) were ground through a 2 mm screen. Hay and silage samples used for the *in vitro* experiment were subsampled weekly and pooled from the feed-out of the hay and silages during the growth performance trial (Experiment III). The samples (0.5 g) were incubated in a 20 mL buffer plus 5 mL of rumen fluid in a 50 mL test tube for 24 and 48 h. There were two runs each for row spacing, silage vs. hay and leaf vs. stem, and 3 tubes (replicates) for each treatment maintained in a water bath at 39° C. For the effect of peanut planting space on digestibility, there were 30 tubes; these included four types of peanut haulm forage (30, 45, 60 and 75 cm) × 2 times × 3 replicates, plus 3 blanks (rumen fluid only). For the effect of conservation (hay or silage) and botanical component (leaf or stem), there were 15 tubes each including two types of peanut haulm forage × 2 times × 3 replicates, plus 3 blanks (rumen fluid only).

After incubation, undigested sample in the tube was centrifuged (1000 × g; 10 min) and aerated in an oven (60°C) for 48 h. Degradability of NDF (NDFD) was determined from the precipitate of the triplicate tubes aerated at 60°C using the Ankom bag technique (Ankom, NY; USA). Neutral detergent fibre digestibility was estimated as the difference between the NDF content of the samples before incubation and the residual NDF content.

Experiment III

In Experiment III, the conserved haulms (silage or hay) were used to formulate 2 total mixed rations (TMR) as shown in Table 1. Whole cottonseed was obtained from the Ghana Cotton Company Ltd. (Tamale, Ghana). Mill wastes were gathered from small-scale food processing mills and corn chaff (bran plus spent corn dough) was collected from local corn dough processors and dried prior to inclusion in the diets.

Table 1: Ingredient and chemical compositions of total mixed rations containing peanut haulm conserved as either hay or silage

Item (% DM)	Diets	
	Hay[1]	Silage[1]
Ingredients		
Corn chaff	45	45
Rice bran	15	15
Whole cotton seed[2]	20	20
Ensiled peanut haulm (silage)	-	20
Sun-dried peanut haulm (hay)	20	-
Total	100	100
Chemical composition (mean ± SD)		
Dry matter	84.8 ± 3.7	80.3 ± 4.0
Crude protein	8.9 ± 3.5	10.8 ± 1.8
Neutral detergent fibre	44.5 ± 8.7	47 ± 1.2
Acid detergent fibre	35.2 ± 11.3	22.5 ± 8.7

[1]Peanut haulm was ensiled for 171 d in bag (120 × 90 × 90 cm) silos whereas hay was initially field-cured for 3 d and then stored unprotected for additional 168 d.
[2]Whole cotton seed was treated with 1% (fresh basis) saline solution

Feed ingredients, TMR and orts were sampled weekly and composited bi-weekly for DM determination. The composited samples were stored at −40^{o}C until analyzed. The DM of all ingredients was measured weekly and the ingredient composition was adjusted accordingly if DM estimates differed by more than 3% from the mean. Diets were formulated to meet the nutrient requirements of growing sheep (National Research Council, 1996).

Twenty West African Dwarf (Djallonké) ram-lambs with an initial average body weight of 29.7 ± 0.99 kg (mean ± SD) were randomly allocated to twenty individual pens (1.25 m × 1.50 m) and the pens were then randomly allocated to the two diets (Table 1). Ram-lambs were housed in a sheep barn at University for Development Studies, Tamale, Ghana. They were weighed on 2 consecutive days at the beginning and end of the 60-d day experiment during the dry season (April-May), with the average of two daily consecutive body weights used as the initial and final body weights, respectively.

Rams were fed twice daily in two equal portions at 0800 and 1700. The total daily amount of feed offered and orts were recorded daily. Orts from the previous day were collected and weighed the next morning before the morning feed was delivered. Both feed and water were offered *ad libitum.* The TMR and orts were sampled weekly and rams were weighed every two weeks for 60 d. The DM of the TMR and orts were used to estimate daily DM intake for each ram. The ADG and feed efficiency (expressed as gain per feed) for each ram was estimated for the entire 60-d feeding period.

The protocol for experiments II and III were reviewed and approved by the Research Ethics Committee of the University for Development Studies, Tamale and animals were cared for and managed in a manner consistent with the guidelines of the Canadian Council on Animal Care (1993).

Chemical and Microbial Analysis

For chemical analyses of fresh (day 0) or conserved haulms (hay or silage; day 171), 15 g of fresh forage, silage or hay was mixed with 135 mL of distilled water. This mixture was blended *in a Black and Decker kitchen blender (*Black and Decker Corporation; Maryland, USA*)* for 45 s at the highest speed. The pH of the blended material was immediately measured with a Basic 20 Crison pH meter (Crison Instruments, SA, Barcelona, Spain). The blended material was then thoroughly mixed and divided into two equal portions. The first portion was immediately boiled for 10 min and stored at –20°C for subsequent analysis of WSC (glucose equivalent) according to the Nelson-Somogyi method (Nelson**,** 1944) using a Spectrotroquant Pharo 300 spectrophotometer (JP Selecta SA, Barcelona, Spain).

The second portion of the blended material was filtered through 2 layers of cheesecloth and the filtrate was centrifuged for 15 min at 10,000 × *g* (4°C). The supernatant was collected for analysis of NH_3-N. The procedure involved combining the supernatant (1.6 mL) with 0.15 mL of 65% (wt/vol) trichloroacetic acid before the solution was analyzed by the phenol-hypochlorite method (Broderick and Kang, 1980). Colorimetric calibration and quantification of NH_3-N was then done on a Spectrotroquant Pharo 300 (JP Selecta, SA, Barcelona, Spain) photo-spectrometer at a wavelength of 630 nm. Volatile fatty acids in the supernatant were also determined by deproteinizing 1.5 mL of the fluid with 0.3 mL of 25% (wt/vol) meta-phosphoric acid. The solution was combined with 0.2 mL of 0.1 M crotonic acid as an internal standard and analyzed using a Trace 1310 gas-liquid chromatograph (ThermoFisher, USA). For lactic acid, 400 µL of each sample was deproteinized using 0.3 mL of 25% (wt/vol) meta-phosphoric acid and combined with 50 µL of 3 mM malonic acid (5 mg/mL) as an internal standard. Lactic acid was then quantified using the method of Kudo *et al*. (1987) with the same chromatography system used for volatile fatty acids.

Dry matter of fresh haulms, leaves, stems, hay and silages, and diets was determined by drying at 60°C for 48 h in a forced air oven. Organic matter was determined by ashing samples (1 g) in a muffle furnace at 550°C for 5 h. Subsamples of the diets, pooled every 2 weeks, were stored at –20°C and subsequently ground through a 1-mm screen prior to analysis of NDF and ADF using the Van Soest method (Van Soest *et al*., 1991). The solution for analysis of neutral detergent fiber (NDF) included sodium sulfite and α-amylase. Both NDF and ADF values were expressed inclusive of residual ash. Crude protein was determined by the Kjeldhal procedure for total N and CP estimated as total N × 6.25 (AOAC, 2005).

For enumeration of yeasts and moulds, fresh forage, hay or silage samples (10 g) were added to 90 mL of distilled water. The mixture was manually agitated for 1 min and the suspension was serially diluted (10^{-2} to 10^{-5}) and 100-µL aliquots of each dilution were spread onto duplicate semi-selective lactobacilli media (de Man-Rogosa-Sharpe, MRS; Oxoid, Basingstoke, Hampshire, UK) plates for the enumeration of LAB and onto a Sabouraud's dextrose agar (SDA; Difco, Detroit, MI, USA) for the enumeration of yeasts and moulds. Inoculated plates were incubated at ambient temperature for 72 h and colonies were enumerated from those plates that contained from 30 to 300 colonies.

Statistical analysis of data

Statistical analysis of data was done by ANOVA using the PROC MIXED procedure of SAS (Statistical Analysis System, 1998). In experiment I, data on the effect of plant spacing and plant components (leaf or stem) on the nutritional value of peanut haulms were analyzed using the following statistical model:

$$Y_{ijk} = \mu + S_i + P_j + SP_{ij} + \varepsilon_{ijk}$$

Where Y_{ijk} is the observation (haulm or grain yield, crude protein, NDF, NDFD etc); µ is the overall mean effect; S_i is the effect of inter-row plant spacing (30, 45, 60 and 75 cm); P_j is the effect of each botanical forage component (leaf or stem); SP_{ij} is the interaction effect of inter-row plant spacing and forage component; ε_{ijk} is the residual error effect. Haulm and grain yields were analyzed for only the main effects of row spacing. Microbial counts were $\log_{10}$ transformed prior to statistical analysis. The linear effect of plant spacing on *in vitro* degradability of leaves and stems of haulms of peanuts was analyzed using linear contrast statement of SAS (SAS Institute, 1998).

In experiments II and III, data on *in vitro* NDF degradability, and voluntary DM intake and growth performance (weight gain, ADG and gain-to-feed ratio) of rams were analyzed as a completely randomized design with each triplicate test tube and ram as the experimental units, respectively, using the statistical model below:

$$Y_{ijk} = \mu + T_i + \varepsilon_{ijk}$$

Where Y_{ijk} is the observation (*in vitro* NDFD, growth performance); μ is the overall mean effect; T_i is the effect of conserving peanut haulms as hay or silage; ε_{ijk} is the residual error effect.

Differences in least-square means were declared significant at $P \leq 0.05$.

RESULTS

Grain and haulm yields of peanut planted at inter-row spacing of 30, 45, 60 or 75 cm in Experiment I are indicated in Figure 1. Grain yield was greatest for inter-row spacing of 30 cm and lowest for 75 cm compared to intermediate spacings of 45 and 60 cm (P = 0.033) but the grain yield between 45 cm and 60 cm plant spacing was not significant (P = 0.545). Haulm yield showed a similar response to spacing as grain yield, however the difference in haulm yield among 45, 60 and 75 cm was not significant (P = 0.892).

The nutrient composition and *in vitro* NDFD of peanut haulms are shown in Table 2. The concentration of CP was greater (P = 0.001) in the leaves than in the stems (8.8 vs 5.8% DM). In contrast, concentrations of NDF (P = 0.002) and ADF (P = 0.001) were both higher in the stem than leaf fractions. Nutrient composition and *in vitro* NDFD of leaves and stems did not differ (P ≥ 0.165) with row spacing (Experiment II).

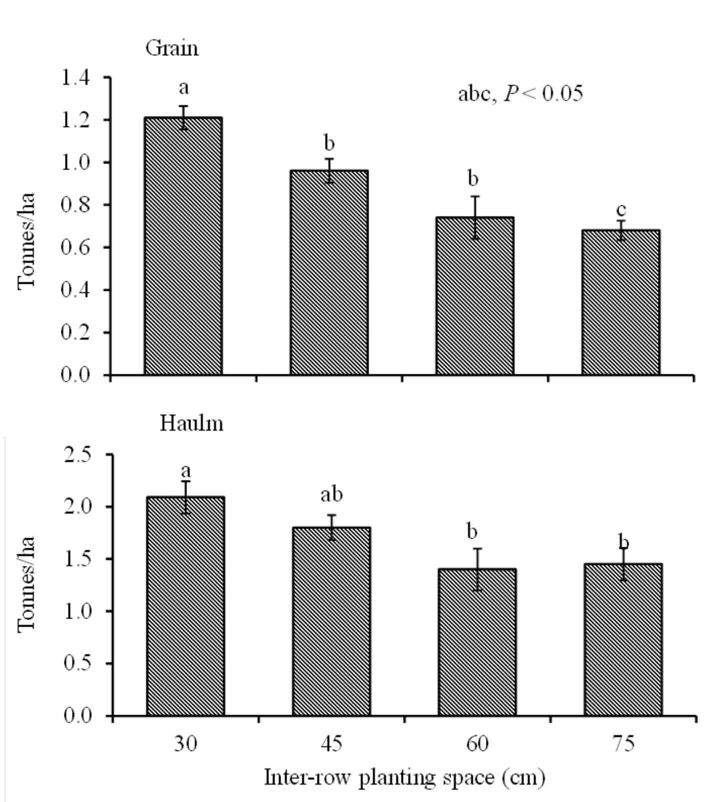

Figure 1: Effect of inter-row spacing on grain (nuts) and haulm yields of peanuts. Least square means with different letters (abc) differ significantly (*P* <0.05). Vertical bars indicate standard errors of least square means (n = 3).

There was no interaction between row spacing and the amount of leaf vs. stem in peanut forage (Table 2). There was however a linear effect (P = 0.001) of row spacing on the digestibility of NDF at 24 and 48 h as NDFD linearly decreased with increasing row spacing (Table 2)

Table 3 shows the chemical and microbial compositions of peanut haulm conserved as hay or silage. Water-soluble carbohydrates decreased from 2.1% DM in the fresh haulm to 1.9 and 1.7% DM in hay and silage, respectively. The reductions in WSC concentration in the hay and silage compared to the fresh haulm were proportional to the increase in lactic acid in the hay and silage, respectively. As expected, pH was higher in hay than silage, whereas acetic acid, butyric acid and ammonia-N concentrations were higher in silage compared to fresh haulm and hay. Populations of lactic acid bacteria, yeasts and moulds were also increased by ensiling as compared to hay. Neutral detergent fibre concentration was higher in haulms conserved as silage (52.1% DM) than as hay (50.9% DM). However, the ADF concentration of hay was higher than in fresh and ensiled haulms (Table 3).

Even though CP concentration was higher in hay than silage (15.5 vs 14.5% DM; Table 3), the reverse was observed in the diets; the CP of silage TMR was 10.8% DM compared to 8.9% DM for the hay TMR.

The effects of conserving peanut haulm as hay or silage on dry matter intake and growth performance of rams are shown in Table 4 (Experiment III). Dry matter intake of rams fed the hay-based diet was 235.8 g/d higher (*P*=0.069) than those fed the silage-based diet. Weight gain and ADG were also higher (*P*=0.012) and efficiency of weight gain increased (*P*=0.053) in rams fed the hay-based diet as compared to the silage-based diet.

DISCUSSION

In general, compact inter-row spacing increases plant densities, resulting in greater competition for soil resources and early canopy closure (Jaaffar and Gardner, 1988). Canopy closure causes shading which reduces the growth rate of underlying vegetation, resulting in thinner stems and leaves and reduced biomass yield. This hypothesis is however true only when individual plants are considered. Giayetto *et al*. (1998) observed decreased DM yield per plant when the inter-row spacing was reduced from 70 cm to 30 cm due to greater intraspecific competition, but on a population per unit area basis, more DM was produced from 30 cm than 70 cm. Thus spacing arrangements that result in higher plant population densities are more efficient in the use of solar energy and other resources for biomass production (Konlan *et al*., 2012; 2013). Grain yields are also higher for peanut planted at narrower than wider distances . Compared to an inter-row spacing of 45 and 60 cm, Ahmad *et al*. (2007) observed the highest pod yield when peanut was planted at an inter-row distance of 30

Table 2: Chemical composition and *in vitro* degradability of leaves and stems of haulms of peanuts planted at different row spacing (cm)

Item (% DM)	30		45		60		75			*P* value			
	Leaf	Stem	Leaf	Stem	Leaf	Stem	Leaf	Stem	SEM	Spacing	Part	SxP	Linear effect of spacing
DM	95.5	96.4	95.6	96.3	95.9	96.8	95.4	96.1	0.12	0.095	0.001	0.891	0.814
CP	7.7	7.2	8.9	5.4	10.2	6.0	8.4	4.4	0.92	0.212	0.001	0.165	0.579
ADF	22.9	26.2	25.5	27.1	23.4	26.8	23.7	26.5	1.05	0.418	0.002	0.826	0.917
NDF	31.4	36.5	29.4	36.3	30.9	32.2	32.4	35.1	0.12	0.225	0.001	0.165	0.739
NDF degradability													
24 h	43.9	46.6	44.9	44.9	36.7	36.5	36.0	32.9	1.98	0.001	0.934	0.566	0.001
48 h	50.3	51.2	50.9	50.3	44.2	48.2	45.2	44.2	1.20	0.001	0.348	0.194	0.001

SEM, pooled standard error of the mean (n = 3)
S × P Spacing and plant component interactions

Table 3: Conservation characteristics (mean ± SD) of peanut haulm conserved as hay or silage

Item (mean ± SD)	Fresh haulm	Conserved haulm[1]	
		Hay	Ensiled
DM (%)	39.1 ± 2.4	93.7 ± 3.4	43.0 ± 0.1
pH	6.5 ± 0.60	6.7 ± 0.09	5.2 ± 0.08
Chemical composition (% DM)			
Water-soluble carbohydrates (mg/kg)	21.4 ± 03.60	19.1 ± 0.9	17.3 ± 1.12
Crude protein	16.1 ± 1.12	15.5 ± 0.1	14.5 ± 0.02
Neutral detergent fibre	54.0± 2.0	50.9 ± 2.3	52.1 ± 0.42
Acid detergent fibre	46.5 ± 0.98	52.1 ± 4.4	47.2 ± 2.01
Ammonia-N (% of total N)	1.6 ± 0.02	7.1 ± 0.03	17.0 ± 0.02
Lactic acid	ND	0.1 ± 0.01	1.7 ± 0.02
Acetic acid	0.2 ± 0. 01	0.1 ± 0.01	2.8 ± 0.01
Propionic acid	ND	0.1 ± 0.01	1.4 ± 0.01
Butyric acid	ND	0.1 ± 0.01	2.1 ± 0.08
Lactic: acetic	–	0.94 ± 1.15	0.95 ± 0.32
Microbial populations (Log_{10} CFU/g DM)			
Lactic acid bacteria	5.0 ± 0.6	6.0 ± 0.4	7.0 ± 0.2
Moulds	4.0 ± 1.9	6.0 ± 1.3	7.1 ± 1.0
Yeasts	5.0 ± 2.1	7.0 ± 0.8	7.2 ± 1.0

[1]Peanut haulm was ensiled for 171 d in bag (120 × 90 × 90 cm) silos whereas hay was initially field-cured for 6 d and then stored unprotected for additional 165 d.
ND, below limits of quantification

Table 4: Effect of conserving peanut haulm as hay or silage on DM intake and growth performance of rams

Item	Hay	Silage	SEM	*P* value
Dry matter intake (g/d)	1564.4	1328.6	85.64	0.069
Initial weight (kg)	30.4	29.0	1.92	0.618
Final weight (kg)	34.9	32.0	0.68	0.012
Weight gain (kg)	5.0	2.4	0.68	0.012
Average daily gain (g/d)	83.3	40.0	21.64	0.012
Feed efficiency (G:F)	0.053	0.030	0.038	0.053

SEM, pooled standard error of the mean (n = 10)
G:F, average daily weight gain divided by average daily feed intake

cm. Gulluoglu and Arioglu (2017) planted peanut at an inter-row distance of 70 and 75 cm and grain yield was higher at 70 cm than 75 cm. Planting distances for growing peanut in Ghana generally range from 30 cm (Konlan *et al.,* 2012; 2013) to 70 cm (Dapaah *et al.,* 2014). Biomass (Bell *et al*., 1987) and grain (Enyi, 1977) yields of peanut increases with increasing plant density. Increased grain yield for the narrowest spacing in this study is consistent with similar reports by Konlan *et al.* (2013) who found a greater pod yield for peanut planted at an inter-row spacing of 30 compared 40 and 50 cm. Closer plant spacing of peanut has been reported to increase ground cover, improve canopy light interception, growth rates and increase pod yields (Jaaffar and Gardner, 1988; Konlan *et al*., 2013).

Not only did the narrowest plant spacing increase fodder and grain yields but also NDF digestibility, as it linearly increased with decreasing spacing. Sparsely planted crops have lower canopy cover and hence lower shading. Shading of the lower portions of the plant reduces the interception of solar radiation and alters the nutritional composition, morphological development and yield of forages. Stem elongation in dicotyledonous species due to increased plant density is evidence of shading (Sanchez *et al.,* 1993) and can alter fibre digestion. For example, in legumes, shading reduces the interception of solar radiation, thereby reducing the biosynthesis and accumulation of lignin, which results in an increase in NDF digestibility (Wei-gua *et al*., 2014). Though plant growth responses to solar radiation may vary depending on plant species, solar (ultraviolet and blue) radiation has been observed to stimulate lignin deposition in plants (Buxton and Steven, 1994). The improvement in NDF digestibility with decreasing row spacing in this study could be attributed to shading in densely populated plants and a reduction in lignin synthesis. Closely related to the interaction between planting distance and shading is the impact of higher temperature. Shading reduces temperature in the crop. Higher temperature increases the concentration of indigestible cell wall fraction in forages whereas shading reduces cell wall thickness in forages with the impact of this reduction being particularly greater for cellulose and lignin, resulting in increased DM digestibility (Buxton and Steven, 1994). The effect of shading on forage quality in closely planted crops is however smaller than its effect on fodder yield (Buxton and Steven, 1994).

In smallholder crop-livestock farming systems, cropping systems that maximize crop and fodder yields without necessarily increasing the cultivated land area are the most desirable among African farmers. This is because most farmers are reluctant to change their traditional practices of forage production and utilization, especially when the innovations being introduced calls for extra expenditure, time and labour (Jayasuriya, 1993). With this consideration, the narrowest row spacing may be deemed the most suitable for peanut production.

Lactic acid bacteria that possess a heterolactic pathway of fermentation use WSC as their main substrate for production of lactic and acetic acids during fermentation. Lower concentrations of WSC in the silage relative to the fresh haulm could be attributed to the fermentation of more WSC into lactic acid in the silage (1.7% DM) compared to that in the hay (0.1% DM). Water soluble carbohydrates concentration of the fresh haulm was generally lower (21.4 mg/kg DM) than the 84 mg/kg DM reported by Yang *et al.* (2005).

To support a successful fermentation without the use of added sugar or silage additives, the WSC concentration in fresh forage should be at least 2.5% (Piltz and Kaiser, 2004) to 3.7% DM (Haigh, 1990). The WSC of the fresh peanut haulm in the present study was below these recommended thresholds. Lower concentrations of WSC for fermentation into lactic acid in this and other previous studies (Yang, 2005; Thom *et al*., 2012) appears to be the main limitation to the conservation of peanut haulm as silage. It is worth noting that peanut haulms are crop residues obtained after the crop has matured and the nuts have been harvested. They thus have lower concentrations of soluble sugars or storage carbohydrates for fermentation into organic acids. The proportion of stems in the haulm is also higher at the stage of maturity that is optimal for harvest of the nuts.

To address the challenges associated low WSC levels, some scientists have added corn meal (Yang 2005; Thom *et al*., 2012), and molasses (An, 1998) prior to ensiling in an effort to boost

WSC concentrations and improve the ensiling of peanut haulms. Addition of corn meal to peanut haulm increased the lactic acid concentration by 43% and decreased proteolysis by 26% (Yang, 2005). For ensiling of whole-crop peanut (with nuts retained), addition of propionic acid reduced pH from 0.52 to 0.45, increased lactic acid from 0.9 to 4.0% DM and decreased butyric acid from 0.85 to 0.02% DM (Johnson *et al*., 1979). In this study, the concentration of lactic acid, the principal contributor to pH decline, was lower than the minimum concentration of 3.0% DM recommended for good quality silage (McDonald *et al*., 1991). Yang (2005) observed that because peanut haulm is a mature crop residue with hollow stems, the efficiency of fermentation can be suboptimal due to the challenges in excluding oxygen. Foster *et al*. (2011) proposed the ideal fermentation characteristics of a well-preserved silage as pH of ≤ 4.0, lactic: acetic ratio of < 2.0, butyric acid concentration of < 1.0% and ammonia-N concentration of below 10.0% of total N. Yang (2005) measured a pH of 4.7 in peanut haulm silage, a value lower than the 5.2 observed in our study, with both values being higher than that associated with good quality silage. Ammonia-N was also higher in silage than hay (17.0 vs 7.1% of total N).

In this study, the populations of yeasts and moulds were nearly 1 log_{10}CFU/g greater in silage than hay. Higher populations of yeasts and moulds are associated with silages of suboptimal quality. Another factor that could account for the higher concentrations of butyric acid and ammonia N in the silage was the higher moisture content (39.1% DM) of the un-conserved haulms. Johnson *et al*. (1979) ensiled whole peanut forage harvested at a DM content of 33.0% with or without propionic acid and proposed that it should be harvested at ~40.0% DM to obtain desirable quality silage. The higher CP content of the hay was not reflected in the TMR diets. Instead, the silage-based diet had higher CP than the hay-based diet. This paradox stems from significant leaf losses associated with handling peanut hay compared to silage during storage and diet preparation. Peanut forage contains more CP in the leaves than the stems (Larbi *et al*., 1999) and leaf shattering losses during storage and daily ration preparation can be very high. Johnson *et al*. (1979) proposed ensiling peanut haulms to reduce sun-curing losses in the field, but storage and handling losses prior to feeding should be given similar attention. Also, higher temperatures in tropical regions enhance proteolytic activity and therefore remain one of the reasons that fewer farmers conserve forages as silage in the tropics (Oude Elferink *et al*., 2000; Bernardes *et al*., 2018).

The depressions of DM intake of sheep fed the silage-based diet in this study suggest that the quality of the ensiled haulm was lower than the dried haulm as evidenced by the higher population of yeasts and moulds accompanied by higher concentration of ammonia and, acetic and butyric acids in silage as compared to hay. Significant reductions in DM intake of silage compared to hay conserved from forage of the same maturity has previously been reported in cattle fed perennial ryegrass (Thiago *et al*., 1992) and Timothy grass/alfalfa (Seoane *et al*., 1993). This suggests that end products of the ensiling process may limit intake. Voluntary intake of silage may be influenced by the end products of fermentation that exert this influence through a reduction in palatability (Buchanan-Smith, 1990). Even though the intake of the silage-based diet was 15% lower than the intake of the hay-based diet, the difference could be described as only marginally significant (P = 0.069). A reduction of 17% in silage intake compared to hay has been reported in cattle (Thiago *et al*., 1992). Even though Rook *et al.* (1990) identified butyric acid as the most important fermentation acid that depresses silage DM intake, they also acknowledged that it was also possible that some unmeasured metabolite from clostridial activity could be responsible for intake-depression of silages with high butyric acid concentration. Charmley (2001) reviewed data (1964–2000) on the effects of end products of silage fermentation on feed intake and concluded that whereas it was not possible to attribute the depression in silage intake to a single end product, ammonia was still ranked as the most frequent fermentation end product responsible for reduced silage DM intake. Other related indices can affect intake of silage-based diets. Dry matter content of alfalfa forage correlates linearly with proteolysis (Muck, 1987).

Feed efficiency of rams fed the silage-based diet was reduced by ensiling compared to drying the haulm as hay with the rate of gain of rams fed the hay being more than twice (83 vs. 40 g/d) that of the rams fed the silage-based diet. The differences in DM intake (1564.4 vs 1328.6 g/d) between sheep fed the hay-based and silage-based diets, respectively, could account for the difference in ADG. In this study, the sheep were intensively fed with only the TMR. The ADG obtained for sheep fed the hay-based diet in this study was 40.0 g/d and was comparable to those (40.0–40.2 g/d) reported for Oudah sheep fed bush hay and supplemented with varying levels of peanut hay (Ayantunde *et al*., 2007). Peanut silage increased DM intake of non-lactating heifers when it proportionately replaced half of a 100% corn silage diet (Johnson *et al*., 1979). Conservation and storage of peanut haulms in the rainy season is a major challenge to smallholder livestock-crop farmers in tropical Africa. To address this challenge, cultivation of late-maturing varieties should be timed so that harvesting can occur towards the end of the rainy season when drying and storage of the haulms will be more efficient and not impacted by rain.

CONCLUSION

The closest plant spacing did not only increase fodder and grain yields of peanut, but NDF digestibility also was higher at the narrowest row spacing and decreased linearly with wider row spacing. Lower concentration of WSC in peanut haulm and its associated poorer fermentation suggest that, under suitable tropical conditions, conserving peanut haulm as hay can improve the growth performance of sheep as compared to conserving it as silage. Under the conditions of the present study, it is more productive to conserve peanut haulm as hay for feeding sheep than as silage as the former has the potential to improve ADG of sheep in the dry season. Addition of microbial additives or readily fermentable substrates or sugar could be useful in providing fermentable substrates and improving the efficiency of fermentation of peanut haulm as silage.

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