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Effect of plant spacing and nitrogen fertilizer levels on the growth, dry-matter yield and nutritive quality of Columbus grass (*Sorghum almum* stapf) in southwest Nigeria

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Abstract

A field experiment was conducted in 2006 and 2007 to determine the agronomic performance and nutritive value of *Sorghum almum* for introduction in the derived savannah area of Nigeria. The experiment was arranged in a 2×4 factorial design with 2 plant spacings ($0{\cdot}5 \times 0{\cdot}5$ m and $1{\cdot}0 \times 1{\cdot}0$ m) and 4 nitrogen (N) fertilizer levels (0, 60, 120 and 180 kg N ha^{-1}). Plant height, tiller number, leaf proportion, biomass yield and nutritive value of the herbage were evaluated as part of the search for alternatives (especially drought tolerant) to local forages for dry season feeding of ruminants. Herbage yield data were tested for linear, quadratic and cubic trends to identify the optimal fertilizer levels for both spacings. Spacing × N interactions ($P < 0{\cdot}05$) were observed for plant height and tiller number in both years. Agronomic performance was marginally better in 2007 compared with 2006. The maximum dry-matter (DM) yield of 3500 and 3740 kg ha^{-1} for the more dense row spacing ($0{\cdot}5 \times 0{\cdot}5$ m) was achieved at N fertilizer levels of 144 and 149 kg N ha^{-1} for 2006 and 2007 respectively. For the less dense ($1{\cdot}0 \times 1{\cdot}0$ m) row spacing, the maximum DM yield of 3020 and 3240 kg ha^{-1} was achieved at 51 and 97 kg N ha^{-1} for 2006 and 2007 respectively. The crude protein content of the grass ranged from 61 to 89 g kg^{-1} DM, while the neutral detergent fibre (NDF) content ranged from 700 to 734 g kg^{-1} DM. The ability of *S. almum* to persist into the second year in this region is seen as a promising index as persistence is one of the characteristics of a good forage plant. Considering the exorbitant price of N fertilizer, less dense row spacing with N fertilizer rate in the range of 50–100 kg N ha^{-1} is hereby recommended for this region.

Keywords: dry-matter yield, grass, humid savannah, nitrogen fertilizer, nutritive value

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Introduction

Grasses are important in ruminant animal nutrition in tropical countries as they supply the main grazing resource in the wet season, thereby supplying the bulk of the energy in the diet of the animals. This underscores the enormous attention paid to evaluation of grasses in Nigeria in the past decades (Ademosun, 1973; Akinyemi and Onayinka, 1982). From the earlier evaluations, many grasses, such as *Panicum maximum*, *Pennisetum purpureum*, *Andropogon gayanus*, *A. tectorum*, *Cynodon nlemfuensis*, *C. dactylon*, assumed prominence in forage research and livestock production. Most of these grasses usually occur as components of natural vegetation that constitute the grazing resource to ruminant animals in the country (Mohammed-Saleem, 1994). The intake of animals on the natural vegetation is high during the growing season as the plants produce fresh and succulent leaves and stems that could be efficiently grazed and utilized. Consequently, this is accompanied by reasonable live-weight gains and improved general performance. As the plants mature, all the quality indices depreciate rapidly and further aggravated by the approaching dry season. Animal intake, digestibility and utilization also progressively decrease to the extent that depending on the severity of the dry season, considerable proportion of the weight earlier gained by the

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animal is lost and the general animal performance plummets.

Columbus grass (*Sorghum almum*) originated in Argentina and the latitudinal range of the grass is 25°N to 30°S. It can be found at elevations between sea level and 700 m (Duke, 1983). It is a promising forage crop with a high potential for integration into Nigerian livestock production systems. Ease of establishment, drought and salt resistance, rapid growth and reasonable high yields (4000–12000 kg ha^{-1}) indicate it may be a suitable forage crop for silage production during the rainy season while permitting regrowth for hay production or in situ grazing of the standing crop. *Sorghum almum* can reach a height of 4·5 m with its short rhizomes reaching as deep as 50 cm. It can withstand heavy grazing but not heavy trampling.

Sorghum almum did not feature in the early evaluations of grasses, at least in southwest Nigeria. Meanwhile, preliminary studies in northern Nigeria (Muhammad, 1993; Muhammad *et al.*, 1997) indicated that the grass is promising in terms of drought tolerance and dry-matter yield. Elsewhere, the response of the grass to nitrogen (N) fertilizer for dry-matter yield and nutritive quality is also documented (Narayanam and Dabadghao, 1977). Forage species that show encouraging performances in the northern part of Nigeria may not necessarily do well in the south because of vast differences in climatic and soil factors. This study therefore aimed at evaluating the forage potential of *S. almum* in the southern part of the country with the view to recommending it as a feed resource in the area.

Materials and methods

Experimental site

The experiment was conducted at the University of Agriculture Teaching and Research farm, Alabata Abeokuta, Ogun State Nigeria (7°58′N; 3°20′E; 75 m above sea level) in the derived savannah area of Nigeria, which is a zone of transition between the humid forest to the further south and the west moist subhumid guinea savannah to the north. The area receives a mean annual rainfall of about 1230 mm in bimodal distribution with peaks in June ⁄ July and September ⁄ October with a break of about 2–3 weeks in August and a major dry season between November and March. Temperatures are fairly uniform with daytime values of 28–30°C during the rainy season and 30–34°C during the dry season with lowest night temperature of around 24°C during the harmattan period between December and February. Relative humidity is high during the rainy season with values between 63 and 96% when compared to dry season values of 55–84%. The temperature of the soil ranges from 24 to 31°C, measured at the meteorological station at the University of Agriculture, Abeokuta.

A total land area measuring 448 m^2 used for the experiment was divided into four replicates with each replicate subdivided into eight equal plots of 3×4 m (12 m^2) each after clearing, ploughing and harrowing to obtain a clean and well-levelled seedbed followed by planting in July 2006. The seeds were subjected to germination test in the laboratory to ascertain viability before planting on the field. On the field, the seeds were drilled in rows at predetermined spacing of $0{\cdot}5 \times 0{\cdot}5$ and $1{\cdot}0 \times 1{\cdot}0$ m at the rate of 45 kg ha^{-1} to compensate for the high level of impurity in the seeds. At this seed rate, each 12 -m^2 plot received seeds weighing 54 g and each 1 m^2 had 4·5 g seed or approximately 60 seeds.

Experimental design

The experiment was laid out in a 2×4 factorial design arrangement using two plant spacings ($0{\cdot}5 \times 0{\cdot}5$ m and at 1×1 m) and four rates of urea fertilizer (0 (control), 60, 120 and 180 kg ha^{-1}). The fertilizer was applied 2 weeks after planting as a single-dose application, and the plots weeded as required at 4 weeks after planting. Seed germination was estimated at 4 weeks after planting by counting the seedlings inside a 1×1 m quadrat.

Data collection

Growth parameters such as plant height, tiller number, tiller density, stem girth, proportion of leaf and regrowth after cutting were evaluated. Forage samples were harvested at 12 weeks after planting (using a 1×1 m quadrat) for the estimation of dry-matter yield and forage quality. Forage samples were harvested to 15 cm above ground to ensure maximum regrowth. The regrowth potential of the grass was estimated in the early rains of the 2007 by counting the number of stems that sprouted after the main dry season of the year followed by dry-matter yield and quality estimations after 8 weeks.

Chemical analyses

The samples (comprising leaves and stem) were analysed for crude protein (CP), neutral detergent fibre (NDF) and acid detergent fibre (ADF). Total N was estimated by combustion assay (LECO Instrument, Monchengladbach, Germany); CP was expressed as $N \times 6{\cdot}25$. Calcium (Ca) and phosphorus (P) were analysed according to standard methods of AOAC (2000). The NDF and ADF were determined according to Van Soest *et al.* (1991); the NDF was determined without use of α-amylase or sodium sulphite. Both NDF and ADF were expressed with residual ash.

Soil parameters were measured following the standard methods Kalra and Maynard (1991). Soil pH was determined in a 2:1 0·01 M NH_4Cl to oven-dry weight soil ratio (vol wt^{-1}). Soil pH was measured using pH meter (model 744 Metrohm, Switzerland). Total C and total N concentrations were analysed by dry combustion using a C–N analyser (Elementar; GmbH, Hanau, Germany). Exchangeable cations (Na, K, Ca, Mg) were estimated in soil extracts prepared in 1·0 M NH_4Cl solution using a mechanical vacuum extractor. Available *P* was determined in soil solution (mg kg^{-1} dry soil) using 0·5 M $NaHCO_3$ as an extractant. Sodium (Na) and K were determined using Flame Photometer (model CL-360; Elico, Hyderabad, India), and Ca, Mg and other metals were determined using atomic absorption spectrometer (model Analyst-300; Perkins Elmer, Palo Alto, CA, USA). Particle size distribution of air-dried soil was determined by hydrometer method.

Table 1 Physicochemical characteristics of the composite soil samples taken from the experimental site at 0 to 15 cm and 15 to 30 cm depths before planting of grasses in the year 2006.

Chemical properties	0–15 cm	15–30 cm
pH (H_2O)	5·8	5·8
Total N (g kg^{-1})	1·3	1·2
Organic C (g kg^{-1})	36·9	36·9
C:N ratio	28·4	28·6
Available P (mg kg^{-1})	84	81
Acidity (cmol kg^{-1})	0·2	0·3
CEC	1·8	1·8
Exchangeable cations (cmol kg^{-1})		
Na	0·2	0·2
K	0·2	0·2
Ca	0·9	0·6
Mg	0·5	0·4
Particle size		
Sand (%)	94·3	92·8
Silt (%)	4·4	5·9
Clay (%)	1·3	1·3

Statistical analysis

Data were subjected to analysis of variance using the GLM procedure of SAS (2002) in a 2 × 4 factorial experiment with four replicates. The model was

$$Y_{ijk} = \mu + S_i + F_j + (SF)_{ij} + \varepsilon_{ijk}$$

where Y_{ijk} = observation, μ = population mean, S_i = spacing effect (I = 1–2), F_j = fertilizer effect (J = 1–4), $(SF)_{ij}$ = interaction between spacing and fertilizer level and ϵ_{ijk} = residual error. Means were compared by applying the probability of difference (PDIFF) option of the least squares means statement in the GLM procedure. In addition, the herbage yield data were tested for linear, quadratic and cubic trends to identify the optimal fertilizer rates for both spacings using the equation:

$$Y = \alpha + \beta_1 x + \beta_2 x^2 + \beta_3 x^3$$

where Y = yield, α = intercept, β_1, β_2 and β_3 are regression coefficients, x is the independent variable (fertilizer rate). Differences between means with $P < 0{\cdot}05$ were accepted as representing statistically significant differences. Probability values <0·001 are expressed as '$P < 0{\cdot}001$' rather than the actual value.

Results and discussion

The physicochemical characteristics of the composite soil samples taken from 0 to 15 cm and 15 to 30 cm depths of the experimental site are shown in Table 1. Typically with tropical soils, the soil of the experimental site was low in both total N (1·3 and 1·2 g kg^{-1}) and available P (84 and 81 mg kg^{-1}). These two mineral elements are the major determinants of soil fertility, forage yield and quality. Low levels of these elements in most tropical soils have been the major cause of the low dry-matter yields of tropical forages and have prompted attention to fertilizer trials in Nigeria. Meanwhile, available reports indicate that *S. almum* could do well in low-fertility soils having produced good yield of dry matter in the semiarid area of northern Nigeria (Muhammad *et al.*, 1994, 2005).

The estimated germination of the grass seed on the field ranged between 60 and 80%, which was generally similar to the result of pre-planting germination test that recorded 85% germination. Meanwhile, the level of germination recorded was adequate for the observed satisfactory establishment of the grass on the field. The seed rate used in this study (45 kg ha^{-1}) was almost three times as high as the 16·5 kg ha^{-1} used by Muhammad *et al.* (2005). The pure germinable seed in the planting material used by Muhammad *et al.* (2005) was 84·5%, whereas that of the stock planted in this study was 35% and so the seed rate was increased to compensate for the high-quantity thrash in the seed stock. In addition, the seed had been stored under room temperature for about 12 months before planting which could have resulted in reduced viability as indicated by the germination test.

Interaction effect between plant spacing and N levels on the various growth parameters and dry-matter yield of *S. almum* in 2006 and 2007 are shown in Table 2. Spacing × N fertilizer interactions were observed for the plant height and tiller number in 2006, also for

Table 2 Interaction effect between plant spacing and N fertilizer levels on growth parameters of *Sorghum almum* in 2006 and 2007.

	0·5 × 0·5 m				1·0 × 1·0 m							
	0	60	120	180	0	60	120	180	SEM	P value†	P value‡	P value§
2006												
Plant density (number per m^2)	45	38	42	41	48	45	41	39	2·53	ns	ns	ns
Plant height (cm)	137^d	153^c	153^c	185^{ab}	147^{cd}	181^b	190^{ab}	196^a	2·65	***	***	***
Tiller no/plant	4·5^c	4·8^c	5·5^{bc}	4·9^c	4·8^c	6·5^b	8·2^a	8·3^a	0·28	***	***	***
Stem girth (cm)	3·0	4·8	5·7	5·9	5·7	6·0	6·9	6·9	0·39	***	***	ns
Leaf (%)	48	52·7	55·7	56·6	54·1	58·6	58·8	59·5	2·82	*	ns	ns
2007												
Plant density (number per m^2)	32^{bc}	31^c	33^{bc}	34^{bc}	45^a	44^a	39^{ab}	37^{ab}	1·61	***	ns	*
Plant height (cm)	145^d	169^c	193^b	202^{ab}	151^d	199^{ab}	209^a	210^a	2·94	***	***	**
Tiller no/plant	6·9^c	7·7^c	9·8^b	7·6^c	7·4^c	10·2^b	14·5^a	14·3^a	0·41	***	***	***
Stem girth (cm)	4·5	6·0	8·7	8·5	7·9	9·6	10·9	9·8	0·57	***	***	ns
Leaf (%)	47·9	53·4	57·8	57·4	55·3	57·8	64·6	62·5	3·57	*	*	ns

Means with different superscript along rows are significantly different.
†*P* value for spacing.
‡*P* value for fertilizer level.
§*P* value for interaction between spacing and level of fertilizer application.
ns, non-significant; *, $P < 0·05$; **, $P < 0·01$; ***, $P < 0·001$.

regrowth, plant height and tiller number in 2007. Plants that received N at the various levels generally performed better than the control (i.e. zero N fertilizer) for all the growth parameters under the two plant spacing arrangements. Plant height and tiller number were greater at less dense row spacing that received 120 and 180 kg N ha^{-1}. The growth parameters were constantly greater under 1·0 × 1·0 m than 0·5 × 0·5 m spacing. Plant heights, tiller number, stem girth and leaf number of *S. almum* were greater in 2007 compared with figures recorded in 2006. The ability of *S. almum* to persist into the second year is promising as persistence is one of the characteristics of a good forage plant. This shows that *S. almum* can also perform well in the humid savannah zone of Nigeria.

Interactions between spacing and N fertilizer levels observed for the dry-matter (DM) yields of *S. almum* had linear, quadratic and cubic relationships that were highly significant (P_L, P_Q, $P_C < 0·001$) (Table 3). Analyses of the DM yields of *S. almum* revealed curvilinear relationships as shown in Figures 1 and 2. Total biomass yield was greater under the less dense row spacing. The DM yield of the grass did not follow the same trend observed in the total biomass yield with values being fairly greater under the more dense row spacing.

The maximum DM yields of *S. almum* at more dense row spacing were 3500 kg ha^{-1} at optimum fertilizer level of 144 kg N ha^{-1} and 3740 kg ha^{-1} at optimum fertilizer level of 149 kg N ha^{-1} in 2006 and 2007 respectively. The maximum DM yields of *S. almum* at less dense row spacing were 3020 kg ha^{-1} at optimum fertilizer level of 51 kg N ha^{-1} and 3240 kg ha^{-1} at optimum fertilizer level of 97 kg N ha^{-1} in 2006 and 2007 respectively.

Table 3 Maximum yields and optimum fertilizer levels of the total and component dry-matter yields (kg ha^{-1}) of *Sorghum almum* in 2006 and 2007.

	Maximum yield (kg ha^{-1})		Optimum fertilizer levels (kg N ha^{-1})		Spacing × fertilizer interaction			
	0·5 m	1·0 m	0·5 m	1·0 m	R^2	L	Q	C
2006								
Total biomass*	3600	3970	145	33	0·96	***	***	***
S. almum	3500	3020	144	51	0·99	***	***	***
2007								
Total biomass*	3920	4090	157	180	0·98	***	**	**
S. almum	3740	3240	149	97	0·99	***	***	***

*This includes weeds.
L, Q and C are linear, quadratic and cubic effects of the interaction between spacing and fertilizer levels.
**$P < 0·01$; ***$P < 0·001$.

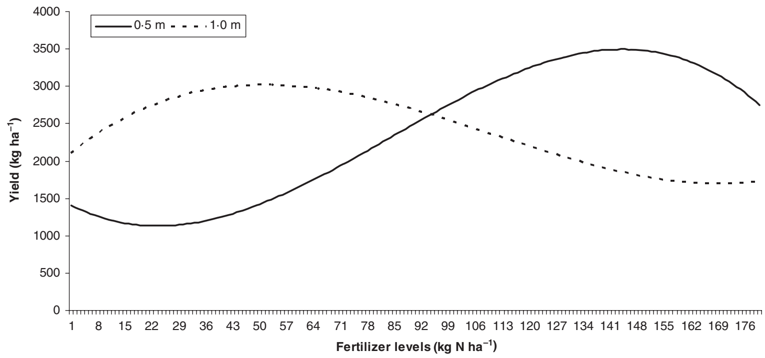

Figure 1 Effect of spacing and fertilizer levels on the herbage yield of *S. almum* in 2006.

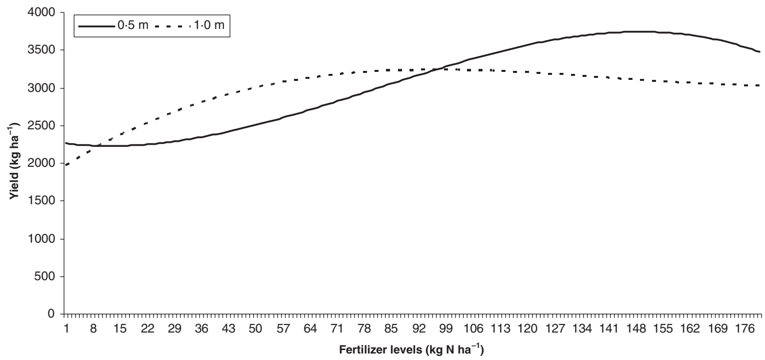

Figure 2 Effect of spacing and fertilizer levels on the herbage yield of *S. almum* in 2007.

The difference between optimum fertilizer levels for the less and more dense row spacing was almost three times higher in 2006 and 53% higher in 2007 for more dense row spacing. The corresponding yield of *S. almum* at more dense row spacing with its greater fertilizer levels was about 16 and 15% more in 2006 and 2007 respectively. The increased yield at more dense row spacing in both years was not significant to justify the quantity of fertilizer. As a result, less dense row spacing at lower fertilizer rate of 50–100 kg N ha^{-1} is best suited for *S. almum* production in this region.

The herbage yields recorded for *S. almum* in this study (1527–4269 kg ha^{-1}) was <11000–19600 kg ha^{-1} reported for the grass when irrigated in the late dry season (March–June) in the Sudan savannah of Nigeria (Muhammad *et al.*, 2005). Greater yields were also reported for the grass by Omokanye *et al.* (2001); Kallah *et al.* (1999); Muhammad *et al.* (1997) and Muhammad (1993) from rain-fed planting in the northern guinea savannah zone of Nigeria. The modest yields recorded for the grass in this study may be attributed to the vast differences in climatic (temperature, sunshine, cloudiness, etc.) and soil (soil fertility, pH, etc.) conditions between northern and southern Nigeria.

In contrast to the nutrient content of *S. almum* in 2006, interaction between spacing and fertilizer levels occurred for the CP, Ca and P contents of *S. almum* in 2007. There were slight increases in the values of CP, Ca and P and a reduction in the values of ADF and NDF of *S. almum* in 2007 (Table 4). The time of harvest may be responsible for the differences in the chemical composition of *S. almum* in 2006 and 2007. The plants were harvested for chemical analysis at 12 weeks after planting in 2006, while this was carried out at approximately 8 weeks after the initial regrowth in 2007.

The CP range of 61·7–88·9 g kg^{-1} DM recorded for *S. almum* during the 2-year study period is above the critical limit below which intake of forages by ruminants and rumen microbial activity would be adversely affected (Van Soest, 1994). These values were within the range of values reported earlier for *S. almum* grown in northern guinea savannah of Nigeria (Muhammad, 1993; Kallah *et al.*, 1999; Muhammad *et al.*, 2005). The NDF content of *S. almum* ranged from 722 to 734 g kg^{-1} in 2006 with slightly lower values in 2007.

Calcium and phosphorus make up to 70% of the total mineral elements in the body and have vital functions in almost all tissues in the body and must be available to livestock in proper quantities and ratio. They play special role in the proper functioning of the rumen microorganisms especially those which digest plant cellulose, utilization of energy from feeds, protein

Table 4 Effect of plant spacing and N levels on the nutrient concentration (g kg^{-1} DM unless stated) of *Sorghum almum* in 2006 and 2007.

	0·5 × 0·5 m				1·0 × 1·0 m							
	0	60	120	180	0	60	120	180	SEM	*P* value†	*P* value‡	*P* value§
2006												
CP	64·0	67·8	69·0	69·0	63·7	70·0	69·7	68·7	2·69	ns	ns	ns
NDF	732	734	731	726	727	727	733	722	9·82	ns	ns	ns
ADF	406	409	408	407	412	409	409	407	5·01	ns	ns	ns
Ca (mg kg^{-1} DM)	6·2	6·1	5·7	4·9	5·9	6·0	5·3	5·8	0·36	ns	ns	ns
P (mg kg^{-1} DM)	1·9	1·4	1·8	1·5	1·6	1·9	1·5	1·9	0·21	ns	ns	ns
2007												
CP	68·5^{c}	86·7^{a}	87·4^{a}	87·3^{a}	69·4^{c}	88·9^{a}	83·4^{ab}	79·7^{ab}	2·83	*	**	**
NDF	722	713	707	710	715	700	712	722	13·02	ns	ns	ns
ADF	400	399	397	389	401	380	391	407	8·33	ns	ns	ns
Ca (mg kg^{-1} DM)	8·1^{a}	7·9^{a}	6·8^{abc}	6·1^{bc}	7·8^{a}	6·5^{bc}	7·3^{ab}	5·8^{c}	0·28	ns	***	*
P (mg kg^{-1} DM)	4·5^{ab}	3·7^{ab}	3·9^{ab}	3·6^{b}	4·7^{a}	4·3^{ab}	4·8^{a}	2·0^{c}	0·23	ns	***	***

Means with different superscript along rows are significantly different.

†*P* value for spacing

‡*P* value for fertilizer level

§*P* value for interaction between spacing and level of fertilizer application.

CP, crude protein; NDF, neutral detergent fibre; ADF, acid detergent fibre; ns, non-significant; **P* < 0·05; ***P* < 0·01; ****P* < 0·001.

metabolism among other functions (McDowell *et al.*, 1993). The range of values recorded for Ca in this study is >0·7–0·9 g kg^{-1} DM reported earlier (Muhammad *et al.*, 2005) but above the critical level of 3 g kg^{-1} DM recommended for ruminant needs in the warm wet climates (McDowell *et al.*, 1993). The P level in this study is both above the critical level of 2·5 g kg^{-1} DM for ruminant animals and a mean value of 1·2 g kg^{-1} DM reported by Muhammad *et al.* (2005). Calcium is considered in conjunction with P as Ca:P ratio; the recommended lower and upper critical dietary Ca:P ratios are 1:1 to 1:7 in the tropics (McDowell *et al.*, 1993). The mean Ca:P ratio of 1:4 obtained in this study is within the recommended range and would meet the Ca:P ratio requirement for ruminant livestock.

Conclusion

This experiment showed that *S. almum* produced sufficient biomass under less dense row spacing with less N fertilizer. Considering the exorbitant price of N fertilizer, less dense row spacing with N fertilizer rate in the range of 50–100 kg N ha^{-1} is hereby recommended. The mean Ca:P ratio obtained in this study is within the recommended range and would meet the Ca:P ratio requirement for ruminant livestock. These attributes underscore the importance of this grass as alternative forage species for dry season feeding of ruminant animals in southwest Nigeria.

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