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GROWTH AND HERBAGE DRY MATTER YIELD OF COLUMBUS GRASS (*Sorghum almum*) AS INFLUENCED BY ORGANIC (POULTRY) MANURE LEVELS AND INTER ROW SPACING IN DAMATURU, NIGERIA

[1*]Mabu, I. M., [2]Abubakar, M., [2]Bello, K.M., [2]Muhammad, A.S., and [2]Amba, A. A.
[1]Desert Research Monitoring and Control Centre, Yobe State University, Damaturu, Nigeria
[2]Faculty of Agriculture, Abubakar Tafawa Balewa University Bauchi, Nigeria.
[1*]Corresponding Author: isamusamabu64@gmail.com +2348035948608

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ABSTRACT
This experiment evaluated the effects of organic fertilizer levels and inter-row spacing on the growth and herbage dry matter yield of Columbus grass (*Sorghum almum*) during the 2023 rainy season at the Teaching and Research Farm of Yobe State University, Damaturu. A factorial arrangement of five poultry manure rates (0, 2, 4, 6, and 8 t ha^{-1}) and three inter-row spacings (30, 50, and 70 cm) was laid out in a randomized complete block design with four replications, totaling fifteen treatment combinations. At 12 weeks after sowing (WAS), application of 8 t ha^{-1} poultry manure significantly ($P < 0.05$) produced taller plants (290.58 cm), broader leaves (8.53 cm), longer leaves (109.69 cm), more leaves per plant (8.00), higher tiller number (18.00), and greater herbage dry matter yield (1.69 t ha^{-1}) compared to other treatments. Inter-row spacing also significantly influenced plant height, leaf dimensions, and tiller number ($P < 0.05$), with 70 cm spacing producing the tallest plants (257.60 cm) and the highest tiller number (12.00), comparable to the 50 cm spacing in leaf size and height. The study concludes that Columbus grass is well adapted to the Damaturu climate, exhibiting optimal growth and high herbage yield under these conditions. It is recommended to apply 8 t ha^{-1} poultry manure combined with 70 cm inter-row spacing to maximize Columbus grass production in the study area.

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INTRODUCTION

Livestock production in Nigeria plays a pivotal role in rural livelihoods and national food security, yet its growth is constrained by seasonal feed shortages, particularly in the arid and semi-arid regions (Okoruwa and Amada, 2019). In these regions, forage scarcity during the prolonged dry season (October to May/June) limits animal productivity due to inadequate supply of quality feed (Umunna and Iji, 1993; Babayemi and Bamikole, 2006). The native pasture, predominantly composed of low-quality grasses, supports livestock only during the rainy season (June–September), while the dry season leads to a sharp decline in pasture yield and nutritive value due to plant maturity and lignification (Amodu and Abubakar, 2004). Consequently, livestock often experience weight loss, poor reproductive performance, increased mortality, and high susceptibility to disease (Na-Allah *et al*., 2018; FAO, 1988).

According to Muhammad and Abubakar (2004), the establishment of cultivated forages can greatly enhance herbage availability and quality compared to natural grasslands. One such promising forage is Columbus grass (*Sorghum almum* Parodi), a short-lived perennial grass known for its rapid growth, high biomass yield, and adaptability to semi-arid conditions (Malami *et al*., 2008; Kallah *et al*., 1999). This species is well-suited for cut-and-carry feeding systems, grazing, hay, and silage production, and is valued for its drought tolerance, palatability, and resistance to pests and diseases (Cook *et al*., 2005; Reed *et al*., 2002; Rich *et al*., 2004). Despite its potential, Columbus grass is underutilized in Nigeria, largely confined to research stations and government farms (Malami *et al.*, 2008). Soil fertility and plant spacing are critical factors influencing forage productivity. Fertilizer application especially nitrogen is widely acknowledged as a major determinant of pasture yield and nutritional quality (FAO, 2006). Organic manures, such as poultry manure, offer a sustainable alternative to chemical fertilizers by improving soil health and nutrient availability. However, excessive fertilizer application may result in “fertilizer burn” or environmental degradation, while insufficient application leads to stunted growth and poor yield (Asifat, 2018). Similarly, inter-row spacing affects plant density, light interception, and intra-specific competition, all of which influence overall biomass production (Krishna, 2006). Therefore, optimizing both manure application and spacing is essential for efficient forage production. Despite the critical need for increased feed availability, especially during the dry season, there is a paucity of empirical data on the agronomic requirements for optimal Columbus grass production in Nigeria's Sahelian zone. Furthermore, the high cost and seasonal scarcity of conventional feed ingredients have made livestock production increasingly unsustainable for many farmers (Abubakar *et al*., 2015; Okoruwa, 2017). The demand-supply gap in quality feed has further been exacerbated by rising insecurity, farmer-herder conflicts, and climate variability, all of which underscore the urgent need for alternative forage strategies (FDAHS, 2024). Therefore, this study was undertaken to evaluate the effects of poultry manure levels and inter-row spacing on the growth and herbage yield of Columbus grass in the Sahel savanna zone of Yobe State, Nigeria. Findings from this study will contribute to sustainable forage production strategies and inform best agronomic practices that can help bridge the livestock feed deficit in Nigeria’s semi-arid regions.

MATERIALS AND METHODS

Experimental Site

The study was conducted at the Small Animal Experimental Unit of the Yobe State University Teaching and Research Farm, Damaturu, Yobe State, Nigeria. The site lies on latitudes 11°44′40″–11°45′N and longitudes 11°57′40″–11°58′E, approximately 7 km along the Damaturu–Biu road (Mohammed *et al*., 2019). The area experiences a hot, dry climate with annual rainfall ranging from 500–1000 mm, concentrated between June and September. Temperatures peak between March and May (30–42 °C). The dominant vegetation is classified as Sudano-Sahelian savanna, with a dry season lasting about eight months. Soils in the area are well-drained, moderately deep tropical sandy loam. The estimated human population is 255,895 (Ayo and Ibrahim, 2011).

Experimental Design and Treatments

The experiment employed a 5 × 3 factorial arrangement in a Randomized Complete Block Design (RCBD) with four replications. Treatments consisted of five poultry manure levels (0, 2, 4, 6, and 8 t/ha) and three inter-row spacing (30, 50, and 70 cm), resulting in 15 treatment combinations. Treatments were randomly assigned to plots by balloting, and uniform agronomic practices were applied across all plots.

Treatment Combinations

S/N	Treatment	S/N	Treatment	S/N	Treatment	S/N	Treatment	S/N	Treatment
1.	M_1S_1	4.	M_2S_1	7.	M_3S_1	10.	M_4S_1	13.	M_5S_1
2.	M_1S_2	5.	M_2S_2	8.	M_3S_2	11.	M_4S_2	14.	M_5S_2
3.	M_1S_3	6.	M_3S_3	9.	M_3S_3	12.	M_4S_3	15.	M_5S_3

Land Preparation and Plot Layout

A land area of approximately 600 m² (0.06 ha) was manually cleared, ploughed, and harrowed to enhance soil tilth for optimal seed germination. The field was divided into four blocks, each containing 15 treatment plots. Individual plots measured 4 m × 4 m (16 m²), with 0.5 m spacing between plots and 1 m alleys between blocks.

Soil Sampling and Analysis

Prior to planting, composite soil samples were collected from 0–15 cm depth at nine randomly selected points using a soil auger. The samples were bulked, air-dried, and sieved for laboratory analysis. Soil physico-chemical properties evaluated included pH (photometric method), organic carbon (Walkley and Black method), and particle size distribution (hydrometer method; Bouyoucos, 1951), with texture classified using the USDA textural triangle. Total nitrogen was determined via the Macro-Kjeldahl method (Jackson, 1964), available phosphorus by the Bray No. 1 method (Bray and Kurtz, 1945), and potassium and sodium via flame photometry. Magnesium and calcium were analyzed using EDTA titration, while cation exchange capacity (CEC) was determined using the ammonium acetate extraction method.

Seed Procurement and Treatment

Sorghum almum seeds were sourced from the National Animal Production Research Institute (NAPRI), Shika, Zaria, Kaduna State, Nigeria. Prior to planting, seeds were treated with Cardinal® dust (comprising 20% w/w thiamethoxam, 20% w/w metalaxyl-M, and 2% w/w difenoconazole) at a rate of 1 g per 400 g of seed to prevent insect and fungal infestation (FAO, 2009).

Sowing and Cultural Practices

Seeds were drilled at inter-row spacings of 30, 50, and 70 cm according to treatment layout immediately after the establishment of rains in the 2023 cropping season. Manual weeding was performed at 3 and 6 weeks after sowing (WAS). Poultry manure was applied pre-planting at 0, 2, 4, 6, and 8 t/ha following the protocol of Muhammad and Abubakar (2004).

Data Collection

Data were collected biweekly over 12 weeks from three randomly selected plants per plot. Parameters measured included:

- **Plant Height (cm):** Measured from soil surface to the tip of the tallest leaf using a measuring tape.
- **Leaf Length and Width (cm):** Leaf length was recorded from the base to the tip, and width at the widest part of a centrally located leaf.
- **Number of Leaves:** Counted on each sampled plant.
- **Number of Tillers per Plant:** Total tillers were manually counted.
- **Herbage Yield:** At physiological maturity (12 WAS), biomass was harvested from a 0.25 m² quadrat (0.5 m × 0.5 m) per plot at 5 cm above ground level. The herbage was air-dried to constant weight for dry matter yield determination.

Statistical Analysis

Data collected were subjected to analysis of variance (ANOVA) using Statistix 10.0 software as described by Steel and Torrie (1997). Where significant differences occurred, treatment means were separated using Duncan's New Multiple Range Test (DNMRT) at a 5% level of significance.

RESULTS AND DISCUSSION

Physical and Chemical Properties of the Soil in the Study Area

The soil physical and chemical properties of the top soil (0 – 15 cm) at the experimental site before commencement of the experiment in 2023 rainy season is presented in Table 1. The result indicated that the soil had slightly acidic property (pH (water) = 6.9) with low contents of organic carbon (8.12 gkg^{-1}), total nitrogen(0.92gkg^{-1}) and available P (0.70 $mgkg^{-1}$). The soil exchangeable bases showed high contents of Na^{+} (0.36 $Cmolkg^{-1}$), low K^{+} (0.87 $Cmolkg^{-1}$) and moderate contents of Ca^{2+} (0.85 $Cmolkg^{-1}$) and high Mg^{2+} (0.53 $Cmolkg^{-1}$) content while the CEC was medium (5.61 $Cmolkg^{-1}$). The soil texture class was identified as loamy sand (80.96 gkg^{-1} sand, 6.56 gkg^{-1} silt and 12.48 gkg^{-1} clay).

Table 1: Soil Physical and Chemical Properties (0 – 15cm) of the Soil at the Experimental Site during the 2023 Rainy Season

Parameter	Unit
Sand	80.96%
Silt	6.56%
Clay	12.48%
Textural class	Loamy sand
PH (H_2 o)	6.9
PH (cacl$_2$)	7.2 spacing
Organic carbon	8.12 gkg^{-1}
Total nitrogen	0.92 gkg^{-1}
Ca	0.85 cmol (+) kg^{-1}
Mg	0.53 cmol (+) kg^{-1}
K	0.87cmol (+) kg^{-1}
Na	0.36cmol (+) kg^{-1}
TEB	2.61cmol (+) kg^{-1}
CEC	5.61 %

Key: Ca = calcium, Mg = Magnesium, K = Phosphorus, Na = Sodium, TEB = Total exchangeable basis, CAC = Cation exchange capacity

Plant Height

The mean plant height of *Sorghum almum* as influenced by organic manure levels and inter-row spacing during the 2023 rainy season is shown in Table 2. Organic manure application significantly ($P < 0.05$) affected plant height at 4, 6, 8, 10, and 12 weeks after sowing (WAS), though not at 2 WAS. The application of 8 tons/ha consistently produced significantly taller plants compared to other treatments. Inter-row spacing also had a significant effect on plant height at all stages except 2 WAS. Wider spacings of 70 cm and 50 cm resulted in taller plants than the 30 cm spacing, likely due to reduced intra-specific competition for light, nutrients, and moisture. The enhanced plant height under 8 tons/ha poultry manure may be attributed to the gradual release and sustained availability of nutrients, especially nitrogen, which promotes vigorous vegetative growth through increased cell division and elongation (Singh *et al*., 2005). This is consistent with findings by Omer (1998) and Odedina *et al.* (2003), who reported that poultry manure improves growth attributes such as plant height, number of tillers, and leaf area in various crops. The similarity in response between *S. almum* and crops like okra suggests comparable nutrient requirements. Furthermore, the slow-release nature of poultry manure nutrients may prolong vegetative phases, enhancing overall biomass accumulation (Ayoola and Makinde, 2007). However, excessive application may pose risks of salinity or nutrient leaching (Kering *et al*., 2011), emphasizing the importance of balanced application.

Table 2: Plant Height of Columbus Grass at 2, 4, 6, 8, 10 and 12WAS as Influenced by Organic Fertilizer Levels and Inter Row Spacings During 2023 rainy Season in Damaturu, Nigeria

Treatments	2WAS	4WAS	6WAS	8WAS	10WAS	12WAS
Fertilizer (Kg/ha)						
0 (M1)	5.24	13.30^{d}	31.30^{d}	61.33^{e}	179.42^{e}	180.89^{e}
2 (M2)	5.37	17.55^{c}	55.58^{c}	77.78^{d}	240.76^{d}	254.61^{d}
4 (M3)	5.38	20.13^{b}	60.77^{b}	99.64^{c}	259.41^{c}	268.86^{c}
6 (M4)	5.54	21.58^{ab}	74.63^{a}	119.92^{b}	276.00^{b}	278.36^{b}
8 (M5)	5.70	21.72^{a}	74.66^{a}	151.53^{a}	284.47^{a}	290.58^{a}

SEM	0.1462	0.5387	0.8231	1.7720	4.4095	2.2322
Significance	NS	**	**	**	**	**
Spacing (cm)						
30 (S1)	5.37	17.86^{b}	57.50^{b}	93.17^{b}	245.30^{b}	250.08^{b}
50 (S2)	5.47	19.25^{a}	60.33^{a}	106.42^{a}	252.12^{a}	256.30^{a}
70 (S3)	5.49	19.46^{a}	60.35^{a}	106.53^{a}	252.62^{a}	257.60^{a}
SEM	0.1132	0.4173	0.6376	1.3726	3.3425	1.6921
Significance	NS	*	**	**	*	**

Note: Means within a column for factor followed by the same letters are statistically not significant at 5% level of probability, using Duncan New Multiple Range Test (DNMRT), *=Significant at 5% probability level, NS= not significant at 5% probability level M= Manure, S = Spacing, M*S = Interaction, WAS = Weeks after Sowing, M_1 = 0t/ha, M_2 = 2 t/ha, M_3 = 4 t/ha, M_4 = 6 t/ha M_5 = 8 t/ha, S_1 = 30 cm spacing, S_2 = 50 cm spacing and S_3 = 70 cm spacing.

Interaction Effects on Plant Height

The interaction between organic manure levels and inter-row spacing had no significant effect (P > 0.05) on plant height except at 2, 4, and 6 WAS. At 2 WAS, the combinations of 8 tons/ha manure with 70 cm and 50 cm spacing produced significantly taller plants than other treatments. At 4 WAS, 6 tons/ha combined with 50 cm spacing resulted in the tallest plants, while at 6 WAS, the interaction of 8 tons/ha and 70 cm spacing produced the tallest plants. These results suggest that *Sorghum almum* growth benefits from moderate manure application (4–6 t/ha) combined with wider inter-row spacing (50–70 cm), which likely reduces intra-specific competition and optimizes nutrient availability. This aligns with findings by Olanite *et al*. (2010), who reported increased plant height in *S. almum* under varied nitrogen fertilizer rates and wider plant spacing (75 × 85 cm), attributing the improvement to reduced competition and enhanced nutrient access.

Table 3: Interaction effect between Organic Manure Levels and Inter Row Spacings on the Plant Height of Columbus Grass at 2, 4, and 6 WAS During 2023 rainy season in

INTERACTIONS (MXS)					
2WAS	M1	M2	M3	M4	M5
S1	4.86^{e}	5.36^{abcd}	5.43^{abcd}	5.21^{bcde}	5.67^{ab}
S2	5.11^{de}	5.50^{abcd}	5.58^{abcd}	5.58^{abcd}	5.73^{a}
S3	5.15^{cde}	5.43^{abcd}	5.58^{abcd}	5.63^{abc}	5.81^{a}
SEM	0.25				
Significance	*				
4WAS					
S1	10.17^{e}	17.17^{ef}	19.50^{cde}	21.17^{abc}	21.33^{abc}
S2	14.08^{g}	17.00^{ef}	20.50^{bcd}	23.25^{a}	22.50^{ab}
S3	15.67^{fg}	18.50^{de}	20.42^{bcd}	20.33^{bcd}	21.33^{abc}
Significance	0.93				
SEM	**				
6WAS					
S1	31.08^{f}	48.92^{e}	59.75^{cd}	72.92^{b}	74.92^{ab}
S2	31.33^{f}	58.08^{d}	60.00^{cd}	73.50^{ab}	75.50^{ab}
S3	31.50^{f}	59.67^{cd}	62.67^{c}	74.00^{ab}	77.08^{a}
SEM	1.43				
Significance	**				

Note: Means within a column for factor followed by the same letters are statistically not significant at 5% level of probability, using Duncan New Multiple Range Test (DNMRT), *=Significant at 5% probability level, NS= not significant at 5% probability level M= Manure, S = Spacing, M*S = Interaction, WAS = Weeks after Sowing

Leaf Width

The effect of organic poultry manure levels and inter-row spacing on the leaf width of *Sorghum almum* during the 2023 rainy season is summarized in Table 4. Organic manure significantly ($P < 0.05$) influenced leaf width from 4 to 12 weeks after sowing (WAS), except at 2 WAS. At 10 WAS, application of 8 t/ha produced the broadest leaves, comparable ($P > 0.05$) to those with 6 t/ha, and at 12 WAS, 8 t/ha resulted in significantly broader leaves than other treatments. The broader leaves observed with 6–8 t/ha poultry manure between 6 and 12 WAS likely reflect increased nitrogen availability, enhancing photosynthetic capacity and cell expansion. Poultry manure, rich in nitrogen, phosphorus, and potassium, improves soil fertility and supports sustained nutrient release, which promotes growth and leaf development (Adjei-Nsiah and Dartey, 2013; Ewulo, 2005). Similar effects on leaf morphology have been reported in okra and maize following poultry manure application (Adekiya *et al*., 2019). However, excessive application risks nutrient imbalance or salinity stress, underscoring the need for optimal dosing (Adjei-Nsiah and Dartey, 2013). Inter-row spacing also significantly affected leaf width ($P < 0.05$), with 70 cm spacing consistently producing broader leaves than 50 cm and 30 cm throughout the growing period. The interaction effects at 6 WAS showed that 8 t/ha combined with 70 cm, 50 cm, or 30 cm spacing, and 6 t/ha with 70 cm or 50 cm spacing, produced significantly broader leaves. This suggests that *S. almum* requires a minimum of 6 t/ha poultry manure and wider spacing (70 cm) for optimal leaf width, though 8 t/ha at 70 cm and 6 t/ha at 50 cm yielded statistically similar results. These findings agree with Olanite *et al.* (2010), who reported broader leaves in *S. almum* under various nitrogen fertilizer levels (4, 6, and 8 t/ha) and wider spacing (70 cm), attributing the results to reduced plant competition and better nutrient availability.

Table 4: Leave width of Columbus Grass at 2, 4, 6, 8, 10 and 12WAS as Influenced by Organic Fertilizer Levels and Inter Row Spacings During the 2023 rainy Season

Treatments	2WAS	4WAS	6WAS	8WAS	10WAS	12WAS
Fertilizer (Kg/ha)						
0 (M1)	0.45	2.65^{c}	4.02^{b}	4.31^{bc}	5.83^{c}	5.95^{d}
2 (M2)	0.48	3.13^{b}	4.03^{b}	4.49^{bc}	6.11^{ab}	6.63^{c}
4 (M3)	0.57	3.79^{ab}	4.18^{b}	4.74^{b}	6.22^{ab}	6.65^{c}
6 (M4)	0.59	3.85^{ab}	5.21^{a}	5.92^{ab}	6.52^{a}	7.53^{b}
8 (M5)	0.60	4.03^{a}	5.62^{a}	6.55^{a}	6.59^{a}	8.53^{a}
SEM	0.13	0.76	0.86	0.59	1.20	1.48
Significance	NS	*	*	*	*	*
Spacing (cm)						
30 (S1)	0.46^{b}	2.89^{c}	4.44^{ab}	4.65^{b}	6.02^{b}	6.34^{b}
50 (S2)	0.46^{b}	3.22^{b}	4.85^{a}	4.86^{b}	6.53^{b}	6.86^{b}
70 (S3)	0.70^{a}	4.55^{a}	4.86^{a}	5.49^{a}	7.14^{a}	7.05^{a}
SEM	0.10	0.59	0.66	0.46	0.91	1.12
Significance	* *	*	*	*	*	*

Note: Means within a column for factor followed by the same letters are statistically not significant at 5% level of probability, using Duncan New Multiple Range Test (DNMRT), *=Significant at 5% probability level, NS= not significant at 5% probability level M= Manure, S = Spacing, M*S = Interaction, WAS = Weeks after Sowing, M_1 = 0t/ha, M_2 = 2 t/ha, M_3 = 4 t/ha, M_4 = 6 t/ha M_5 = 8 t/ha, S_1 = 30 cm spacing, S_2 = 50 cm spacing and S_3 = 70 cm spacing.

Interaction Effect on Leaf Width

Table 5, shows the interaction effect of poultry manure and inter-row spacing on leaf width, with a significant interaction observed at 6 WAS. At this stage, the combination of 8 t/ha manure and 70 cm spacing produced significantly broader leaves ($P < 0.05$), similar to those from 8 t/ha with 50 cm and 30 cm spacings, as well as 6 t/ha with 70 cm and 50 cm spacings. These results suggest that *Sorghum almum* requires at least 6 t/ha of poultry manure combined with wider spacing (50–70 cm) to optimize leaf width. The similar performance between 8 t/ha at 70 cm and 6 t/ha at 50 cm spacing further highlights the interplay between nutrient availability and spatial distribution. This aligns with Olanite *et al*. (2010), who reported broader leaves under varying nitrogen levels (4, 6, and 8 t/ha) and wider spacing (70 cm), attributing the effect to reduced competition and enhanced nutrient uptake.

Table 5: Interaction Effect Between Organic Fertilizer Levels and Inter Row Spacings on the Leave Width of Columbus Grass at 6 WAS During 2023 Rainy Seasons

INTERACTIONS (MXS)					
6WAS	M1	M2	M3	M4	M5
S1	3.67^{b}	3.92^{b}	4.07^{ab}	4.13^{ab}	6.24^{a}
S2	3.76^{b}	3.94^{b}	4.06^{ab}	6.07^{a}	6.40^{a}
S3	3.78^{b}	3.98^{b}	4.07^{ab}	6.22^{a}	6.42^{a}
SEM	1.49				
Significance	*				

Note: Means within a column for factor followed by the same letters are statistically not significant at 5% level of probability, using Duncan New Multiple Range Test (DNMRT), *=Significant at 5% probability level, NS= not significant at 5% probability level M= Manure, S = Spacing, M*S = Interaction, WAS = Weeks after Sowing

Leaf Length

The mean leaf length of *Sorghum almum* influenced by poultry manure levels and inter-row spacing during the 2023 rainy season is presented in Table 6. Poultry manure application significantly ($P < 0.05$) increased leaf length throughout the study, except at 10 WAS. At 12 WAS, 8 tons/ha produced the longest leaves compared to other treatments. The enhanced leaf length with 6 and 8 tons/ha between 2–12 WAS is attributed to the nutrient-rich poultry manure, particularly nitrogen (N), phosphorus (P), potassium (K), and organic matter, which improve soil fertility, microbial activity, and nutrient availability (Adesanwo *et al*., 2013).

Ogbonna and Obi (2018) reported a 35% leaf length increase in *Sorghum almum* with 10–15 tons/ha poultry manure, due to improved nitrogen mineralization and nutrient release. Adekiya *et al.* (2019) linked manure-induced leaf lengthening to enhanced chlorophyll synthesis and cell elongation. However, excessive application (>20 tons/ha) may cause nutrient imbalances reducing growth efficiency (Olanite *et al*., 2010), thus optimal doses of 10–15 tons/ha are recommended. The increased leaf length also relates to nitrogen's role in chlorophyll, enzyme, and protein synthesis, which promotes cell division and expansion (Rachman and Mahdavi, 1990; Singh *et al*., 2005). Inter-row spacing had no effect ($P > 0.05$) on leaf length at 2 and 4 WAS but wider spacings (50 and 70 cm) produced significantly longer leaves ($P < 0.05$) at 6, 8, 10, and 12 WAS than the 30 cm spacing. This is likely due to reduced competition for light, water, and nutrients, allowing better resource access per plant and promoting leaf growth. Moyo (2010) found a 20% increase in leaf length when spacing increased from 30 to 60 cm, attributing this to improved resource allocation. Donald (1963) similarly noted that wider spacing favors larger leaves by reducing competition. Conversely, Ahmed (2015) found no spacing effect on leaf length under high soil fertility, suggesting nutrient abundance can offset competition. Evers *et al*. (2019) observed that narrow spacing reduces individual leaf size due to competition, though plants may compensate with vertical growth. Comparable results were reported by Khan *et al.* (2016) and Smith *et al.* (2015), emphasizing optimal spacing for maximizing vegetative growth.

Table 6: Leaf length of Columbus Grass 2, 4, 6, 8, 10 and 12WAS as Influence by Organic (Poultry manure) and Inter Row Spacing at Damaturu, During the 2023 Rainy Season

Treatments	2WAS	4WAS	6WAS	8WAS	10WAS	12WAS
Fertilizer (Kg/ha)						
0 (M1)	5.04^{c}	21.50^{c}	52.56^{c}	76.19^{d}	83.22^{c}	85.60^{cd}
2 (M2)	5.17^{bc}	31.44^{b}	67.02^{b}	83.94^{c}	84.14^{c}	86.61^{c}
4 (M3)	5.39^{b}	38.16^{a}	68.94^{b}	88.72^{b}	87.11^{b}	87.94^{bc}
6 (M4)	5.71^{a}	37.48^{a}	79.02^{a}	89.61^{b}	89.67^{b}	90.59^{b}
8 (M5)	5.99^{a}	39.86^{a}	80.75^{a}	92.61^{a}	97.31^{a}	109.69^{a}
SEM	0.14	0.86	0.91	0.97	13.28	0.99
Significance	*	**	**	**	**	**
Spacing (cm)						
30 (S1)	5.37	32.45	68.53^{ab}	82.65^{b}	84.12^{c}	87.72^{b}
50 (S2)	5.46	34.17	70.12^{a}	87.18^{a}	90.33^{b}	90.25^{a}
70 (S3)	5.56	34.45	70.33^{a}	88.82^{a}	98.22^{a}	90.50^{a}
SEM	0.11	0.67	0.71	0.75	10.06	0.76
Significance	NS	NS	*	*	*	*

Note: Means within a column for factor followed by the same letters are statistically not significant at 5% level of probability, using Duncan New Multiple Range Test (DNMRT), *=Significant at 5% probability level, NS= not significant at 5% probability level M= Manure, S = Spacing, M*S = Interaction, WAS = Weeks after Sowing, M_1 = 0t/ha, M_2 = 2 t/ha, M_3 = 4 t/ha, M_4 = 6 t/ha M_5 = 8 t/ha, S_1 = 30 cm spacing, S_2 = 50 cm spacing and S_3 = 70 cm spacing.

Interaction Effects of Poultry Manure and Inter-Row Spacing on Leaf Length

Table 7 presents the interaction effects of poultry manure levels and inter-row spacing on *Sorghum almum* leaf length at 6 and 12 WAS. At 6 WAS, the combination of 8 tons/ha with 70, 50, and 30 cm spacing produced significantly longer leaves ($P < 0.05$), comparable ($P > 0.05$) to those under 6 tons/ha at the same spacing, and superior to other combinations. At 12 WAS, the 8 tons/ha and 70 cm spacing interaction yielded the longest leaves among all treatments. The significantly broader leaves observed at 6 WAS from the 8 tons/ha manure applied with 70 cm spacing and similarly with 50 and 30 cm spacing suggest that *S. almum* requires at least 8 tons/ha of poultry manure combined with wider spacing (70 cm) to optimize leaf growth. Although the 6 tons/ha manure combined with the same spacings produced statistically similar results, the trend favors higher manure rates with wider spacing. These findings align with Olanite *et al.* (2010), who reported broader leaves in *S. almum* with varying nitrogen fertilizer rates (60, 120, 180 kg N ha^{-1}) and less dense spacing (75 × 85 cm), attributing this to reduced plant competition and improved nutrient availability. Additionally, at 8 WAS, plants receiving 8 tons/ha manure with 70 cm spacing continued to produce broader leaves compared to other treatment combinations.

Table 7: Interaction Effect Between Organic Fertilizer Levels and Inter Row Spacings on the Leave Length of Columbus Grass at 6 WAS During 2023 rainy Seasons in Damaturu, Nigeria

INTERACTIONS (MXS)					
6WAS	M1	M2	M3	M4	M5
S1	51.33^{d}	61.33^{c}	69.33^{b}	78.08^{a}	80.75^{a}

S2	52.92^{d}	67.50^{b}	70.42^{b}	78.25^{a}	81.58^{a}
S3	53.42^{d}	68.67^{b}	70.67^{b}	79.00^{a}	81.67^{a}
SEM	1.59				
Significance	**				
8WAS					
S1	70.50^{jz}	81.33^{ghi}	86.08^{def}	88.83^{cdef}	91.83^{bc}
S2	78.17^{i}	84.42^{fgh}	86.00^{efg}	89.67^{bcde}	94.00^{ab}
S3	79.92^{hi}	85.75^{efg}	88.58^{cdefg}	90.75^{bcd}	97.42^{a}
SEM	1.69				
Significance	*				

Note: Means within a column for factor followed by the same letters are statistically not significant at 5% level of probability, using Duncan New Multiple Range Test (DNMRT), *=Significant at 5% probability level, NS= not significant at 5% probability level M= Manure, S = Spacing, M*S = Interaction, WAS = Weeks after Sowing

Number of Leaves

The mean number of leaves per *Sorghum almum* plant as influenced by poultry manure levels and inter-row spacing during the 2023 rainy season is presented in Table 8. Poultry manure application significantly (P < 0.05) increased leaf number at most sampling times except at 2 and 6 weeks after sowing (WAS). At 12 WAS, 8 t/ha manure produced significantly more leaves than 0, 2, 4, and 6 t/ha treatments. Higher leaf numbers observed between 8 and 12 WAS at 4, 6, and 8 t/ha may be attributed to enhanced nitrogen availability and uptake, which supports chlorophyll synthesis, root development, and overall plant vigor (Olayinka and Etejere, 2018). Poultry manure's nutrient-rich profile, especially its nitrogen (N), phosphorus (P), and potassium (K) content, coupled with its slow-release properties, improves soil fertility and sustains vegetative growth (Adekiya *et al.*, 2020; Odedina *et al.*, 2017). Similar studies on *Sorghum* and other forage crops such as *Panicum maximum* have reported increased leaf number and area with poultry manure application due to improved nitrogen availability for photosynthesis and enhanced soil organic matter (Olayinka and Etejere, 2018; Odedina *et al.*, 2017). Optimal responses typically occur at moderate rates (5–10 t/ha), beyond which benefits plateau (Adekiya *et al.*, 2020). Singh *et al.* (2005) linked increased nitrogen uptake to enhanced cell division and expansion, resulting in luxuriant vegetative growth, a finding corroborated by Olanite, *et al.* (2010), Samia *et al.* (2010), and Akram *et al.* (2010). Inter-row spacing had no significant effect (P > 0.05) on leaf number except at 4 WAS, where 70 cm spacing produced more leaves than 30 and 50 cm. Narrow spacing increases plant density, causing shading and reduced light penetration that suppress lower canopy leaf development and accelerate senescence (Li *et al.*, 2016). Wider spacing improves light distribution and reduces root competition for nutrients and water, favoring leaf growth (Bednarz *et al.*, 2000; Maddonni and Otegui, 2004). However, excessively wide spacing can increase soil evaporation in arid environments and promote weed growth, which may indirectly reduce leaf development (Echarte *et al.*, 2000; Li *et al.*, 2016). Studies on maize and cotton demonstrate that optimal spacing balances individual plant growth and population density, maximizing leaf production and overall yield (Andrade *et al.*, 2002; Bednarz *et al.*, 2000). Thus, inter-row spacing should be optimized based on species growth habit and regional agroclimatic conditions to maximize leaf number and crop productivity.

Table 8: Number of Leaves of Columbus Grass at 2, 4, 6, 8, 10 and 12WAS as Influenced by Organic Fertilizer Levels and Inter Row Spacings During 2023 Rainy Season

Treatments	2WAS	4WAS	6WAS	8WAS	10WAS	12WAS
Fertilizer (Kg/ha)						

0 (M1)	5.00	3.00^b	8.00	6.00^b	6.00^b	6.00^b
2 (M2)	5.00	3.00^b	8.00	7.00^a	6.00^b	6.00^b
4 (M3)	5.00	3.00^b	8.00	7.00^a	6.00^b	6.00^b
6 (F4)	5.00	4.00^{ab}	8.00	7.00^a	6.00^b	6.00^b
8 (M5)	5.00	5.00^a	8.00	7.00^a	7.00^a	8.00^a
SEM	0.05	0.76	0.05	0.08	0.14	0.44
Significance	NS	**	NS	**	**	**
Spacing (cm)						
30 (S1)	5.00	3.00^b	8.00	7.00	6.00	6.00
50 (S2)	5.00	3.00^b	8.00	7.00	6.00	6.00
70 (S3)	5.00	5.00^a	8.00	7.00	6.00	6.00
SEM	0.04	0.59	0.04	0.07	0.10	0.33
Significance	NS	**	NS	NS	NS	NS

Note: Means within a column for factor followed by the same letters are statistically not significant at 5% level of probability, using Duncan New Multiple Range Test (DNMRT), *=Significant at 5% probability level, NS= not significant at 5% probability level M= Manure, S = Spacing, M*S = Interaction, WAS = Weeks after Sowing

Interaction between Organic (Poultry) Manure Levels and Inter-Row Spacing

The interaction between poultry manure levels and inter-row spacing significantly ($P < 0.05$) influenced the number of leaves at 6 and 8 weeks after sowing (WAS) during the 2023 rainy season. Treatments combining 2 t/ha with 70 cm spacing, 4 t/ha with 30, 50, and 70 cm spacing, 6 t/ha with all spacing levels, and 8 t/ha with all spacing levels produced significantly higher leaf numbers compared to other treatment combinations. Notably, the interaction of 8 t/ha manure with 30, 50, and 70 cm spacing, 6 t/ha with all spacing, 4 t/ha with all spacing, and 2 t/ha with all spacing resulted in statistically similar leaf numbers at 6 and 8 WAS. This suggests that *Sorghum almum* requires a minimum of 8 t/ha of poultry manure and wider spacing (70 cm) to maximize leaf production, although similar results can be achieved with slightly lower manure rates across different spacing. These findings align with Olanite, *et al.* (2010), who reported increased leaf numbers in *S. almum* at nitrogen fertilizer rates of 60, 120, and 180 kg N ha^{-1} combined with less dense planting (75 × 85 cm). The enhanced leaf production was attributed to reduced intra-specific competition at wider spacings and improved nutrient availability.

Table 9: Interaction Effect between Organic Fertilizer Levels and Inter Row Spacing on the Number of Leaves of Columbus Grass at 6 WAS during 2023 Rainy Season

INTERACTIONS (MXS)					
6WAS	M1	M2	M3	M4	M5
S1	6.00^b	7.00^a	7.00^a	7.00^a	7.00^a
S2	6.00^b	7.00^a	7.00^a	7.00^a	7.00^a
S3	7.00^a	7.00^a	7.00^a	7.00^a	7.00^a
SEM	0.15				
Significance	*				
8WAS					
S1	8.00	8.00	8.00	8.00	8.00
S2	8.00	8.00	8.00	8.00	8.00
S3	8.00	8.00	8.00	8.00	8.00
SEM	0.09				
Significance	NS				

Note: Means within a column for factor followed by the same letters are statistically not significant at 5% level of probability, using Duncan New Multiple Range Test (DNMRT), *=Significant at 5% probability level, NS= not significant at 5% probability level M= Manure, S = Spacing, M*S = Interaction, WAS = Weeks after Sowing

Number of Tillers

The mean number of tillers per plant of *Sorghum almum* as influenced by poultry manure levels and inter-row spacing during the 2023 rainy season is shown in Table 10. Poultry manure significantly ($P < 0.05$) increased tiller number at all sampling times except at 2 weeks after sowing (WAS). At 12 WAS, application of 8 tons per hectare produced significantly higher tiller counts compared to other treatments. This effect is attributed to the rich nutrient content of poultry manure, especially nitrogen, phosphorus, and potassium, which are essential for vegetative growth and tiller development. Poultry manure improves soil fertility by releasing nutrients gradually, sustaining growth and promoting tiller initiation and shoot biomass. Similar findings in forage grasses, such as *Panicum maximum*, report up to a 30% increase in tiller density following poultry manure application (Odedire *et al.*, 2011). Enhanced soil organic matter also improves structure and microbial activity, facilitating root growth and nutrient uptake, indirectly supporting tillering (Adesanwo *et al.*, 2013). Optimal application rates (5–10 tons/ha) maximize tiller production, whereas excessive application risks nutrient leaching or ammonia toxicity (Ayeni *et al.*, 2008). Inter-row spacing had no significant effect at 2, 4, and 6 WAS but significantly influenced tiller number at 8, 10, and 12 WAS. Plants spaced at 70 cm produced higher tiller numbers, comparable to 50 cm spacing at 12 WAS, than other spacings. Wider spacing reduces competition for light, nutrients, and water, promoting tiller development. Nasrullah *et al.* (2011) reported increased tiller counts in sorghum with 75 cm row spacing. Similarly, moderate spacing (60–75 cm) in *Sorghum almum* balances resource availability and plant density, optimizing tillering (Khan *et al.,* 2017). Although wider spacing (>90 cm) may increase tillers per plant, it can reduce total tiller density per hectare (Iqbal *et al.*, 2009). Wider rows enhance sunlight penetration and reduce resource competition, stimulating tiller bud activation (Smith *et al.*, 2020). Thus, a spacing of 60–75 cm is recommended for maximizing tiller number and overall biomass yield in Columbus grass.

Table 10: Number of Tillers of Columbus Grass at 2, 4, 6, 8, 10 and 12WAS as Influenced by Organic Fertilizer Levels and Inter Row Spacings During 2023 Rainy Seasons

Treatments	**2WAS**	**4WAS**	**6WAS**	**8WAS**	**10WAS**	**12WAS**
Fertilizer (Kg/ha)						
0 (M1)	0.00	0.00^{a}	1.00^{c}	2.00^{c}	4.00^{d}	5.00^{c}
2 (M2)	0.00	0.00^{a}	4.00^{b}	4.00^{bc}	6.00^{c}	7.00^{c}
4 (M3)	0.00	0.00^{a}	4.00^{b}	5.00^{b}	6.00^{c}	8.00^{c}
6 (M4)	0.00	0.00^{a}	5.00^{ab}	7.00^{ab}	9.00^{b}	13.00^{b}
8 (M5)	0.00	1.00^{a}	6.00^{a}	9.00^{a}	12.00^{a}	18.00^{a}
SEM	0.00	0.09	0.35	1.05	0.87	2.31
Significance	NS	**	**	**	**	**
Spacing (cm)						
30 (S1)	0.00	0.00^{a}	4.00	4.00^{b}	5.00^{b}	6.00^{b}
50 (S2)	0.00	0.00^{a}	4.00	6.00^{ab}	8.00^{ab}	11.00^{a}
70 (S3)	0.00	0.00^{a}	4.00	7.00^{a}	9.00^{a}	12.00^{a}
SEM	0.00	0.07	0.27	0.80	0.66	1.75
Significance	NS	NS	NS	**	**	**

Note: Means within a column for factor followed by the same letters are statistically not significant at 5% level of probability, using Duncan New Multiple Range Test (DNMRT), *=Significant at 5% probability level, NS= not significant at 5% probability level M= Manure, S = Spacing, M*S = Interaction, WAS = Weeks after Sowing

Effect between Organic Fertilizer Levels and Inter Row Spacing on the Number of Tillers of Columbus Grass at 6 WAS During 2023 Rainy Seasons in Damaturu, Nigeria

Table 11 presents the interaction effects of organic fertilizer levels and inter-row spacing on the number of tillers per *S. almum* plant. A significant interaction was observed at 6 weeks after sowing (WAS). Specifically, the combination of 8 t ha^{-1} organic fertilizer and 70 cm spacing produced the highest ($P < 0.05$) number of tillers per plant compared to other treatments. This suggests that at six weeks, *S. almum* optimally responds to this nitrogen level and spacing combination. These results align with Olanite, *et al.* (2010), who reported increased tillering at varied nitrogen fertilizer rates (60, 120, 180 kg N ha^{-1}) and wider spacing (75 x 85 cm), likely due to reduced competition for nutrients and space.

Table 11: Interaction Effect Between Organic Fertilizer Levels and Inter Row Spacings on the Number of Tillers of Columbus Grass at 6 WAS During 2023 Rainy Seasons in Damaturu, Nigeria

INTERACTIONS (MXS)					
6WAS	M1	M2	M3	M4	M5
S1	0.00^{g}	3.00^{e}	4.00^{de}	5.00^{bcd}	6.00^{bc}
S2	1.00^{f}	4.00^{de}	4.00^{cde}	5.00^{bcd}	7.00^{ab}
S3	1.00^{f}	4.00^{de}	5.00^{cde}	5.00^{bcd}	8.00^{a}
SEM	0.61				
Significance	**				

Note: Means within a column for factor followed by the same letters are statistically not significant at 5% level of probability, using Duncan New Multiple Range Test (DNMRT), *=Significant at 5% probability level, NS= not significant at 5% probability level M= Manure, S = Spacing, M*S = Interaction, WAS = Weeks after Sowing

Herbage Dry Matter Yield

The herbage dry matter yield (DMY) of *Sorghum almum* as influenced by organic (poultry) manure levels and inter-row spacing during the 2023 rainy season is presented in Table 12, Both manure application and spacing significantly ($P < 0.05$) affected yield. The highest DMY (1.69 t ha^{-1}) was recorded with 8 t ha^{-1} poultry manure, outperforming other treatments.

Poultry manure, rich in nitrogen, phosphorus, and potassium, enhances soil fertility and nutrient availability, promoting vigorous vegetative growth and biomass accumulation (Adjei and Rechcigl, 1995). The superior yield at 8 t ha^{-1} is likely due to increased nitrogen uptake, which stimulates growth and yield components such as plant height, leaf size, tiller number, and plant population density, thereby expanding photosynthetic capacity and dry matter production (Olanite, *et al.* 2010; Ishaiku *et al.*, 2016; Mane and Singh, 2017). Additionally, poultry manure improves soil organic matter, microbial activity, and water retention, all critical for sustained forage yield (Ewulo, 2005). Studies on related sorghum species recommend poultry manure rates between 5 and 10 t ha^{-1} to optimize yield without risking nutrient leaching or salinity (Adekiya *et al*., 2019). Odedire *et al*. (2011) reported a 30–40% dry matter increases in forage sorghum with poultry manure compared to inorganic fertilizers, due to its gradual nutrient release and soil structure improvement. Conversely, excessive rates (>15 t ha^{-1}) may reduce yields due to ammonia volatilization or nutrient imbalance (Agbede *et al*., 2008). Regarding spacing, the 70 cm inter-row distance produced significantly ($P < 0.05$) higher DMY (1.21 t ha^{-1}) than 50 and 30 cm spacings, likely due to reduced intra-specific competition. This result aligns with previous reports showing yields between 1.3–1.7 t ha^{-1} and 0.88–1.13 t ha^{-1} under similar conditions (Malami *et al*., 2008; 2010), though it is lower than yields reported in Sokoto (2.57–3.17 t ha^{-1}; Malami *et al*., 2008) and Abeokuta (3.5–3.7 t ha^{-1}; Olanite *et al*., 2010), as well as the 3.68–11.28 t ha⁻¹ range recorded in Zaria (Ishaiku *et al*., 2016).

Table 12: Herbage Dry Matter Yield of Columbus Grass as Influenced by Organic (Poultry) Manure Levels and Inter Row Spacings During the 2023 Rainy Season

Treatments	Herbage Dry Weight Yield
Fertilizer (Kg/ha)	
0 (M1)	0.51[e]
2 (M2)	0.92[d]
4 (M3)	1.16[c]
6 (M4)	1.28[b]
8 (M5)	1.69[a]
SEM	0.02
Significance	**
Spacing (cm)	
30 (S1)	0.98[c]
50 (S2)	1.17[b]
70 (S3)	1.21[a]
SEM	0.02
Significance	**

Note: Means within a column for factor followed by the same letters are statistically not significant at 5% level of probability, using Duncan New Multiple Range Test (DNMRT), *=Significant at 5% probability level, NS= not significant at 5% probability level M= Manure, S = Spacing, M*S = Interaction, WAS = Weeks after Sowing.

CONCLUSION AND RECOMMENDATION

This study demonstrates that both poultry manure application and inter-row spacing significantly influence the growth and herbage yield of Columbus grass (*Sorghum almum*). Poultry manure enhanced plant vigor, biomass production, and overall yield. Among the spacings tested, 70 cm consistently supported superior growth and nutrient quality by optimizing space utilization and reducing intra-specific competition. Based on these findings, it is recommended to apply poultry manure at 8 t ha⁻¹ combined with a 70 cm inter-row spacing to maximize growth, nutrient efficiency, and biomass yield in Columbus grass cultivation.

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