



**PRODUCTIVITY OF FINGER MILLET (*Eleusine coracana* L.) GAERTN AND
GROUNDNUT (*Arachis hypogaea* L.) INTERCROP AS INFLUENCED BY RABBIT
MANURE AND ROW ARRANGEMENT IN SUDAN SAVANNA ECOLOGY,
NIGERIA**

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ABSTRACT

The study investigated the effects of rabbit manure (RM) and row arrangement (RA) on the growth and yield of finger millet-groundnut intercrops at two locations in Kano State, Nigeria, during the 2019 rainy season. Field trials employed a split-plot design with six row arrangements (1:1, 1:2, 2:1, 2:2, 2:4 as main plot, and alternate stand) and four RM levels (0, 1.5, 2.5, and 3.5 t ha⁻¹) plus NPK fertilizer as sub plot. Soil analysis revealed sandy loam textures with low organic carbon and nitrogen at both sites, with Dawakin Kudu (DWK) exhibiting higher fertility than BUK. Results indicated that RM significantly influenced finger millet straw weight, 1000 seed weight, and grain yield, particularly at DWK, with higher RM rates and NPK enhancing these parameters. Groundnut canopy height, leaf area, and leaf area index were also significantly impacted by RM, with NPK and 2.5 t ha⁻¹ RM showing the most significant increases. Row arrangement did not significantly affect yields of either crop, though interactions between RM and RA significantly impacted groundnut canopy height and chlorophyll content at DWK. Intercropping indices, including Land Equivalent Ratio (LER), Area Time Equivalent Ratio (ATER), and Land Use Efficiency (LUE), were significantly influenced by RM, demonstrating intercropping's yield advantage over sole cropping. LER values exceeded 1.0 in most treatments, with the highest LER (2.80 and 2.33) observed at 0.0 t ha⁻¹ at BUK and NPK at DWK. Aggressivity values revealed competitive interactions between finger millet and groundnut. This study underscores the potential of RM to enhance intercropping productivity, highlighting the importance of site-specific factors and nutrient management in optimizing intercropping systems.

Keywords: Arrangement, Groundnut, Intercropping, Millet and Productivity

INTRODUCTION

Global food security faces unparalleled pressure and challenges due to an expanding population, environmental pollution, and climate change (Li *et al.*, 2021; Chen *et al.*, 2024). In the Sudan Savanna of Nigeria, ensuring sustainable agricultural productivity remains a critical concern, particularly for staple crops such as finger millet (*Eleusine coracana* L.) and groundnut (*Arachis hypogaea* L.). The research community has been striving to develop sustainable agricultural practices that enhance crop production while minimizing environmental impacts (Chen *et al.*, 2021; Liu and Zhao, 2023; Yan *et al.*, 2023).

Intercropping, which involves cultivating two or more crops in the same field simultaneously, has been recognized as a viable strategy to improve crop productivity and yield stability by increasing crop diversity and resource utilization efficiency (Raza *et al.*, 2023; Li *et al.*, 2021). Additionally, intercropping can enhance soil fertility, reduce soil erosion, and decrease the prevalence of pests, diseases, and weeds (Chadfield *et al.*, 2022; Secco *et al.*, 2023). Given the constraints of low-input farming systems, small land areas, and lower yields, intercropping has been widely adopted as an intensification practice in many regions, including the Sudan Savanna (Ma *et al.*, 2022; Mudare *et al.*, 2022). However, optimizing intercropping efficiency requires understanding the influence of different management practices, such as manure application and row arrangement. Rabbit manure, as an organic amendment, offers a

sustainable alternative to synthetic fertilizers, improving soil structure and nutrient availability (Ibrahim *et al.*, 2024; Ekwere *et al.*, 2024). Despite its potential, limited research has explored the combined effects of rabbit manure and row arrangement on finger millet-groundnut intercropping systems. This study aims to assess how these factors influence crop productivity, resource efficiency, and sustainability in the Sudan Savanna of Nigeria.

Low soil fertility and erratic rainfall are key challenges limiting crop productivity in the Sudan Savanna of Nigeria. Reliance on synthetic fertilizers raises economic and environmental concerns, highlighting the need for sustainable alternatives such as rabbit manure. However, research on its optimal application rates and the role of row arrangements in finger millet-groundnut intercropping remains limited. While organic manures have been shown to improve crop performance (Mahadi *et al.*, 2018; Wu *et al.*, 2021), gaps persist regarding their effects in intercropped systems and how spatial configurations influence light use, competition, and yield. This study therefore evaluates the effects of rabbit manure and row arrangements on finger millet-groundnut intercrops, focusing on growth, yield, and land equivalent ratio. The objective is to identify optimal manure rates and planting configurations that enhance productivity while promoting sustainable and economically viable intercropping practices in the Sudan Savanna.

MATERIALS AND METHODS

The study Area

Field trials were conducted during the 2019 rainy season at the Research and Training Farm of the Centre for Dryland Agriculture, Bayero University Kano (11°58'N, 8°26'E, 475 m asl) and at a community-based demonstration farm in Dawakin Kudu (11°84'N, 8°59'E), Kano State, Nigeria. Both sites are sandy loam soils with annual rainfall of 400-650 mm.

Experimental Design

Treatments consisted of six row arrangements (1:1, 1:2, 2:1, 2:2, 2:4, and alternate stand) and four rabbit manure (RM) rates (0, 1.5, 2.5, and 3.5 t ha⁻¹), alongside one NPK fertilizer level. The experiment was laid out in a split-plot design with three replications, assigning row arrangement to the main plots and RM to the subplots.

The finger millet variety used was *Chabrown* (Ex-Jos), a red-seeded type maturing in 90-120 days with yields of 580-785 kg ha⁻¹. Groundnut variety SAMNUT 23 was sown, characterized by early maturity (80-100 days), kernel yield of 2.0-2.5 t ha⁻¹, fodder yield of 2.0 t ha⁻¹, and 56% oil content. Land preparation involved clearing, harrowing, and ridging. RM was incorporated into 15 cm-deep grooves and covered for seven days before sowing. Finger millet was dibbled at 75 × 10 cm spacing, five seeds per hole thinned to two plants at 4 WAS, while groundnut was planted at 75 × 30 cm spacing, three seeds per hole thinned to two at 2 WAS.

Fertilizer application followed crop-specific requirements: finger millet received 60 kg N, 30 kg P₂O₅, and 30 kg K₂O ha⁻¹ (half NPK 15-15-15 at 2 WAS, remaining N as urea at 6 WAS), while groundnut received 20 kg N, 54 kg P₂O₅, and 20 kg K₂O ha⁻¹ (supplied through NPK and SSP). Weeds were manually controlled at 3 and 6 WAS, and insect pests were removed by hand. Finger millet was harvested at physiological maturity when panicles turned brown and threshed after drying. Groundnut was harvested upon leaf yellowing or pod maturity, confirmed by pod inspection.

Data Collection

Data were collected on growth and yield traits of both crops using five randomly tagged plants per plot, following standard agronomic procedures. For finger millet, observations

included plant height, leaf area, leaf area index (LAI), chlorophyll content, plant dry matter, and crop growth rate (CGR). For groundnut, data included canopy height, leaf area, LAI, chlorophyll content, and plant dry matter. Yield and yield-related traits were also measured: straw weight, 1000-seed weight, and grain yield ($t\ ha^{-1}$) for finger millet, and fodder weight, 100-seed weight, and kernel yield for groundnut. In addition, intercropping indices such as land equivalent ratio (LER) and other efficiency measures were computed using standard formulas as shown below.

The **Land Equivalent Ratio (LER)** was computed to assess the advantage of intercropping over sole cropping. Relative yield was first determined as the ratio of each crop's intercrop yield to its corresponding sole crop yield. This metric reflects how efficiently intercropping utilizes resources compared to sole stands (Dhima et al., 2007; Takim, 2012).

The overall LER was then derived as the sum of the relative yields of the component crops, expressed mathematically as:

$$LER = LA + LB = \frac{Y_a}{S_b} + \frac{Y_b}{S_a} \quad \dots(1)$$

In the LER formula, LA and LB represent the partial land equivalent ratios of the individual crops, while Y_a and Y_b denote their intercrop yields, and S_a and S_b their respective sole crop yields. An $LER > 1.0$ indicates that intercropping is more efficient than sole cropping, whereas an $LER < 1.0$ reflects a disadvantage. According to Willey (1985), an LER of 1.25 suggests a 25% yield advantage under intercropping, or alternatively, that a monocrop system would require 25% more land to achieve the same yield.

Aggressivity

This is a function which measures the intercrop competition by relating yield changes of both component crops. Aggressivity was calculated mathematically as follows:

$$A_{ab} = \frac{Y_{ab}}{Y_{aa} \times Z_{ab}} - \frac{Y_{ba}}{Y_{bb} \times Z_{ba}} \quad \dots(2)$$

$$A_{ab} = \frac{Y_{ba}}{Y_{bb} \times Z_{ba}} - \frac{Y_{ab}}{Y_{aa} \times Z_{ab}} \quad \dots(3)$$

Where;

Y_{ab} and Y_{ba} are the individual yield of crop a and b in mixture respectively,

Y_{aa} and Y_{bb} are the sole yield of crops a and b respectively,

Z_{ab} and Z_{ba} are the sown proportion of crop a and b respectively (Mc Gilchrist, 1965)

Area Time Equivalent Ratio (ATER)

Area time equivalent ratio was calculated using the expression:

$$ATER = \frac{(R_{ya} \times t_a) + (R_{yb} \times t_b)}{T} \quad \dots(4)$$

Where;

R_{ya} and R_{yb} = relative yield of crop a and b respectively

t_a and t_b = duration (days) for crop a and b respectively

T = duration (days) of intercropping system (Hiebsch and Mccollum, 1987)

Land use efficiency (LUE)

System productivity was calculated using the expression below

$$LUE = LER + \frac{ATER}{2} \times 100 \quad \dots(5)$$

Where; LER = land equivalent ratio

ATER = Area time equivalent ratio

Data Analysis

Analysis of variance (ANOVA) was done using JMP 2017. Significant treatment means were compared using student Newman-Keuls test (SNK) at 5% level of probability. The Land Equivalent Ratio (LER) was used to determine the intercrop advantage.

RESULTS AND DISCUSSION

The physical and chemical properties of the soils at the experimental sites are shown in Table 1. At BUK, the soil is predominantly sandy (64.67%), with moderate silt (22.17%) and clay (13.16%), classifying it as sandy loam. Similarly, Dawakin Kudu (DWK) soil is sandy (55.18%) but contains more silt (33.62%) and a comparable clay fraction (11.20%), also falling under sandy loam. The higher silt content in DWK suggests slightly better moisture retention than BUK. Soil pH values were slightly acidic to neutral in BUK (6.77) and DWK (5.91), though DWK was more acidic, potentially reducing nutrient availability since most crops thrive at pH 6.0-7.0 as reported by Weil and Brady (2017). Both soils showed low organic carbon (0.47% in BUK, 0.48% in DWK) and nitrogen (0.041% and 0.046%, respectively), typical of tropical and semi-arid soils, which may limit fertility and water-holding capacity. Phosphorus was higher in DWK (7.35 mg kg⁻¹) than in BUK (4.94 mg kg⁻¹), while DWK also recorded a greater effective cation exchange capacity (3.46 cmol kg⁻¹) compared to BUK (2.10 cmol kg⁻¹), suggesting better nutrient-holding capacity. Micronutrients (Fe, Mg, Zn) and exchangeable bases (Ca, Mg, K, Na) were generally higher in DWK, indicating comparatively greater fertility despite both soils being nutrient-limited.

Rabbit manure (RM), though slightly acidic (pH 5.64), contained higher organic carbon (0.55%), nitrogen (0.056%), phosphorus (7.75 mg kg⁻¹), and favorable ECEC (3.36 cmol kg⁻¹), alongside beneficial Ca and Mg levels. These attributes underscore its potential as a natural soil amendment to improve fertility and crop performance in both sites (Jones *et al.*, 2013; Havlin *et al.*, 2016; Lal, 2004).

Table 1: The physical and chemical properties of soil of experimental sites and rabbit manure during 2019 rainy season

Properties	BUK	Dawakin Kudu	Rabbit manure
Particle size distribution (g kg⁻¹)			
Sand	646.7	551.8	
Silt	221.7	336.2	
Clay	131.6	112.0	
Chemical properties			
pH (1:1)	6.77	5.91	5.64
Organic Carbon	0.47	0.48	0.55
Total Nitrogen	0.041	0.046	0.056
Available Phosphorus (mg kg ⁻¹)	4.94	7.35	7.75
Fe	287.89	170.61	139.38
Mg	0.40	0.57	0.73
Zn	4.25	6.37	4.44
Exchangeable bases (cmo kg⁻¹)			
Ca	1.36	1.50	2.26
Mg	0.40	0.57	0.73
K	0.21	0.43	0.28
Na	0.09	0.09	0.19
ECEC	2.10	3.46	3.36

Source: Soil Science laboratory of Centre for Dryland Agriculture (CDA), Bayero University Kano.

Plant height and leaf area of finger millet in finger millet-groundnut intercrop as influenced by rabbit manure and row arrangement.

Table 2 shows the effects of rabbit manure (RM) and row arrangement (RA) on plant height, and leaf area (LA) of finger millet intercropped with groundnut at BUK and DWK. Plant height was not significantly affected by RM at BUK (6 and 8 WAS) or at 6 WAS in DWK. However, at 8 WAS in DWK, RM application significantly increased plant height, with 2.5 and 3.5 t ha⁻¹ producing taller plants, though comparable with 1.5 t ha⁻¹, while the control consistently produced shorter plants. Leaf area was also significantly ($P < 0.05$) influenced by RM at 8 WAS in both locations, where higher RM rates produced broader leaves similar to those under NPK, contrasting with the control which had narrower leaves.

Row arrangement (RA) showed no significant effects on plant height or LA across sites and sampling times, and no significant RM \times RA interaction was observed. These findings highlight RM as a key factor in improving vegetative traits, particularly plant height and leaf area, while RA had little influence on crop growth performance under the tested conditions. The significant effect of RM on leaf area, and to a lesser extent on plant height at DWK, underscores the role of nutrients in enhancing vegetative growth, photosynthesis, and productivity. Similar growth improvements with RM were reported in zucchini by Adi *et al.* (2020). The marked impact on plant height at 8 WAS at DWK suggests that the response required time to become evident, aligning with findings by Li *et al.* (2022). Meanwhile, the stronger effect on leaf area compared to the non-significant impact on LAI indicates that RM mainly promoted leaf enlargement rather than leaf density. This suggests plants responded to improved nutrient supply by increasing leaf size instead of producing more leaves, consistent with Mousavi *et al.* (2020).

Table 2: Plant height and leaf area of finger millet intercrop with groundnut as influenced by rabbit manure and row arrangement at 6 and 8 WAS at BUK and Dawakin Kudu in 2019 rainy season

Season	Plant height (cm)				Leaf area plant ⁻¹ (cm ²)			
	BUK		DWK		BUK		DWK	
	Sampling period (WAS)							
Treatment	6	8	6	8	6	8	6	8
Rabbit Manure (RM) (t ha⁻¹)								
0.0	23.53	32.85	30.74	26.15 ^b	30.01	26.36 ^b	47.48	30.52 ^b
1.5	23.59	36.06	29.40	33.73 ^{ab}	30.78	35.30 ^{ab}	50.06	41.99 ^{ab}
2.5	21.47	29.48	25.69	34.76 ^a	28.97	36.53 ^{ab}	42.60	44.68 ^a
3.5	21.34	40.36	25.93	38.73 ^a	28.60	39.99 ^a	47.18	46.43 ^a
NPK	16.18	23.95	20.24	38.48 ^a	20.79	38.66 ^a	34.21	41.97 ^{ab}
P of F	0.078	0.076	0.073	0.013	0.058	0.020	0.086	0.015
SE±	0.041	4.220	2.731	2.769	2.608	3.035	4.297	3.435
Row arrangement (RA)								
1:1	23.48	33.69	24.86	35.26	29.80	38.66	45.94	45.02
1:2	17.65	38.41	26.70	33.79	25.59	33.11	45.23	39.23
2:1	24.57	33.60	27.27	36.67	33.86	40.83	47.94	46.88
2:2	20.34	30.22	25.90	33.30	28.55	37.16	48.02	44.02
2:4	17.82	27.54	24.15	31.81	23.64	31.53	35.59	36.07
AS	20.03	36.54	27.87	36.10	28.26	35.38	41.39	40.96
P of F	0.296	0.831	0.994	0.980	0.516	0.626	0.634	0.569
SE±	2.581	5.338	3.455	3.503	3.298	3.838	5.435	4.345
Interaction								
RM x RA	0.420	0.787	0.793	0.357	0.722	0.667	0.341	0.589

Means followed by the same letter(s) in the column within a treatment group are not significantly different at 5% level of probability using SNK. AS= alternate stand.

Leaf chlorophyll content, plant dry matter, and crop growth rate in finger millet-groundnut intercrop as influenced by rabbit manure and row arrangement

Increasing RM application up to 1.5-2.5 t ha⁻¹ significantly improved chlorophyll content compared to the control (0 t ha⁻¹) at both sites and sampling times (Table 3). Higher rates (3.5 t ha⁻¹ and NPK) did not consistently enhance chlorophyll and, in some cases, resulted in slightly lower values than the optimal RM rates. This indicates that RM enhances photosynthetic capacity, supporting earlier reports where RM improved maize silage yield (Wysokiński and Kozuchowska, 2024) and boosted fiber content in fodder grass due to its high nitrogen content (Suganthi *et al.*, 2022). The results suggest that 1.5-2.5 t ha⁻¹ is the most effective range, as excessive application may lead to nutrient imbalance or environmental risks. Crop growth rate (CGR) were not significantly ($P > 0.05$) affected by RM across locations and sampling times. Similarly, RA showed no significant effect on chlorophyll content, dry matter, or CGR at BUK, but at DWK the 1:1 RA significantly improved CGR compared to other arrangements at both sampling periods. No significant RM \times RA interaction was observed.

The contrasting responses between BUK and DWK emphasize the influence of local environmental conditions, such as rainfall, temperature, and soil properties on treatment outcomes, as also noted by Viana *et al.* (2022). The superior performance of the 1:1 RA at DWK suggests it provided a balanced competitive environment for finger millet and groundnut, enhancing crop growth. Hence, a 1:1 row arrangement appears particularly beneficial for DWK farmers, offering a strategy to optimize growth without being constrained by RM levels.

Table 3: Leaf chlorophyll content and crop growth rate of finger millet intercrop with groundnut as influenced by rabbit manure and row arrangement at 6 and 8 WAS at BUK and Dawakin Kudu in 2019 rainy season

Treatment	BUK		DWK		BUK		DWK	
	Chlorophyll content (SPAD)				Crop growth rate (g wk ⁻¹)			
	Sampling period (WAS)							
	6	8	6	8	6	8	6	8
Rabbit Manure (RM) (t ha ⁻¹)								
0.0	34.19 ^{ab}	40.33 ^b	27.41 ^b	26.23 ^b	0.11	0.24	0.19	0.21
1.5	65.41 ^a	59.36 ^a	40.28 ^a	40.23 ^a	0.10	0.22	0.18	0.19
2.5	55.08 ^a	55.57 ^a	36.97 ^a	35.21 ^a	0.10	0.21	0.19	0.20
3.5	55.12 ^a	56.58 ^a	32.96 ^{ab}	35.88 ^a	0.09	0.18	0.18	0.18
NPK	67.46 ^a	62.98 ^a	34.19 ^{ab}	36.71 ^a	0.08	0.18	0.13	0.14
P of F	0.001	0.028	0.025	0.008	0.181	0.236	0.075	0.057
SE±	4.892	5.115	2.792	2.704	0.010	0.021	0.018	0.018
Row arrangement (RA)								
1:1	61.18	60.55	37.99	37.03	0.11	0.22	0.24 ^a	0.25 ^a
1:2	52.63	52.01	35.23	34.57	0.11	0.24	0.16 ^{bc}	0.18 ^{bc}
2:1	62.40	56.73	34.19	35.01	0.11	0.25	0.16 ^{bc}	0.17 ^{bc}
2:2	59.46	59.72	32.23	33.03	0.10	0.19	0.16 ^{bc}	0.17 ^{bc}
2:4	54.14	47.57	31.49	33.06	0.08	0.16	0.16 ^{bc}	0.16 ^{bc}
AS	56.55	58.88	34.35	35.16	0.09	0.19	0.20 ^{ab}	0.21 ^{ab}
P of F	0.861	0.765	0.760	0.903	0.188	0.078	0.007	0.016
SE±	6.188	6.470	3.532	3.420	0.013	0.027	0.023	0.023
Interaction								
RM x RA	0.160	0.510	0.255	0.146	0.481	0.291	0.390	0.200

Means followed by the same letter(s) in the column within a treatment group are not significantly different at 5% level of probability using SNK. AS= alternate stand.

Canopy height, leaf area and leaf area index of groundnut intercropped with finger millet as influenced by rabbit manure and row arrangement.

Table 4 presents the canopy height, leaf area (LA), and leaf area index (LAI) of groundnut at 6 and 8 WAS in BUK and DWK. Results showed that row arrangement (RA) was not significant ($P > 0.05$) across locations and sampling periods, while rabbit manure (RM) had a consistent effect on canopy height. Higher RM rates (2.5 t ha^{-1} and NPK) produced taller canopies compared to the control, particularly at DWK, while at BUK, NPK and RM also enhanced canopy height relative to 0 t ha^{-1} . This indicates that RM promotes vertical growth in groundnut, with effects comparable to synthetic fertilizers, aligning with reports by Zhang *et al.* (2023; 2024). RM also significantly influenced LA and LAI across locations and sampling times, with 2.5 t ha^{-1} and NPK producing larger leaf areas and higher LAI than the control. This suggests that RM improved both leaf size and density, thereby increasing photosynthetic capacity, light interception, and carbon assimilation, as similarly noted by Durand *et al.* (2021).

The interaction of $\text{RM} \times \text{RA}$ was not significant for LA and LAI but was significant ($P < 0.05$) for canopy height. At 6 WAS in BUK, where $\text{NPK} \times \text{alternate stand (AS)}$ produced the tallest canopy (20.44 cm), while $1.5 \text{ t ha}^{-1} \text{ RM} \times 2:2 \text{ RA}$ recorded the shortest (1.78 cm). At DWK, $2.5 \text{ t ha}^{-1} \text{ RM} \times 2:2 \text{ RA}$ produced the tallest canopy, contrasting with $0 \text{ t ha}^{-1} \text{ RM} \times 2:4 \text{ RA}$, which had the lowest (Figure 1 & 2). At 8 WAS, higher RM rates ($2.5\text{-}3.5 \text{ t ha}^{-1}$) and NPK generally resulted in taller canopies, especially under AS and 2:2 arrangements (Figure 3 & 4). These findings suggest that RM enhances canopy development in groundnut-finger millet intercrops, with AS and 2:2 row configurations supporting optimal growth. This aligns with Htet *et al.* (2017) and Bugilla *et al.* (2023), who highlighted the role of planting patterns in maize-based intercrops. The differences between BUK and DWK further emphasize the influence of site-specific environmental conditions on crop performance.

Chlorophyll content, plant fresh weight and dry matter content of groundnut intercrop with finger millet as influenced by rabbit manure and row arrangement

Table 5 presents the effects of rabbit manure (RM) and row arrangement (RA) on chlorophyll content, fresh weight, and dry weight of groundnut in finger millet intercrop. Most variables were not significantly affected by RM or RA across both locations, except chlorophyll content at DWK, which was significantly influenced by RM at 6 and 8 WAS. NPK application produced the highest chlorophyll values compared to the control (0 t ha^{-1}), though results were statistically similar to those from higher RM rates.

The $\text{RM} \times \text{RA}$ interaction was also significant for chlorophyll content at DWK (Table 8). At 6 WAS, the combination of $3.5 \text{ t ha}^{-1} \text{ RM} \times 2:1 \text{ RA}$ yielded the highest chlorophyll content (22.72), while $0 \text{ t ha}^{-1} \text{ RM} \times 2:2 \text{ RA}$ recorded the lowest. At 8 WAS, $3.5 \text{ t ha}^{-1} \text{ RM} \times 1:1 \text{ RA}$ produced the highest chlorophyll concentration (73.47), in contrast to $0 \text{ t ha}^{-1} \text{ RM} \times 2:2 \text{ RA}$, which had the lowest (7.11). Other treatment combinations were statistically similar. The lower chlorophyll concentrations in 2:2 and 2:4 row arrangements, particularly without manure, suggest heightened resource competition that may have reduced photosynthetic capacity. These results highlight the importance of both nutrient supply and spatial arrangement in mitigating stress and sustaining crop vigor under intercropping systems.

Table 4: Canopy height, leaf area and leaf area index of groundnut-finger millet intercrop in finger millet-groundnut intercrop as influenced by rabbit manure and row arrangement at 6 and 8 WAS at BUK and Dawakin Kudu in 2019 rainy season

Treatment	BUK		DWK		BUK		DWK		BUK		DWK	
	Canopy height (cm)		Canopy height (cm)		Leaf area plant ⁻¹ (cm)		Leaf area plant ⁻¹ (cm)		Leaf area index (LAI)		Leaf area index (LAI)	
	Sampling period (WAS)		Sampling period (WAS)		Sampling period (WAS)		Sampling period (WAS)		Sampling period (WAS)		Sampling period (WAS)	
	6	8	6	8	6	8	6	8	6	8	6	8
Rabbit Manure (RM) (t ha⁻¹)												
0.0	13.05 ^c	18.67 ^c	17.22 ^{ab}	21.36 ^{ab}	22.97 ^{ab}	17.59 ^b	22.63 ^b	11.83 ^c	0.88 ^{bc}	0.68 ^b	0.85 ^b	0.48 ^{ab}
1.5	14.11 ^{bc}	19.61 ^{bc}	14.82 ^b	18.75 ^b	21.72 ^b	16.64 ^b	21.43 ^b	12.38 ^{bc}	0.82 ^c	0.63 ^b	0.79 ^b	0.45 ^b
2.5	16.89 ^{ab}	23.34 ^{ab}	18.45 ^a	23.21 ^a	27.68 ^a	24.52 ^a	25.68 ^b	15.94 ^a	1.17 ^{ab}	1.06 ^a	1.08 ^{ab}	0.68 ^a
3.5	15.52 ^{abc}	21.59 ^{ab}	14.43 ^b	18.47 ^b	20.31 ^b	16.09 ^b	19.59 ^b	12.56 ^{abc}	0.86 ^{bc}	0.68 ^b	0.83 ^b	0.51 ^{ab}
NPK	17.79 ^a	24.59 ^a	18.98 ^a	24.29 ^a	27.15 ^a	21.20 ^{ab}	32.76 ^a	15.27 ^{ab}	1.21 ^a	0.94 ^a	1.48 ^a	0.68 ^a
P of F	0.018	0.031	0.037	0.022	0.021	0.024	0.003	0.048	0.0067	0.0217	0.0006	0.0131
SE±	1.089	1.479	1.262	1.496	1.878	2.071	2.464	1.205	0.094	0.072	0.134	0.059
Row arrangement (RA)												
1:1	16.99	23.44	16.79	21.60	25.82	19.33	24.74	13.45	1.11	0.83	1.05	0.58
1:2	15.36	21.14	16.55	20.88	23.73	17.96	23.06	12.40	0.99	0.75	0.95	0.52
2:1	15.74	22.98	17.92	22.41	25.72	20.02	25.08	14.37	1.08	0.84	1.05	0.61
2:2	13.47	19.50	16.84	20.28	19.66	21.21	26.67	12.15	0.79	0.90	1.13	0.49
2:4	14.16	19.46	15.28	19.62	22.80	17.79	23.38	13.02	0.90	0.71	0.93	0.51
AS	17.28	23.14	19.27	23.91	26.28	20.54	25.16	16.07	1.08	0.85	1.03	0.67
P of F	0.477	0.679	0.487	0.523	2.429	0.940	0.951	0.631	0.453	0.945	0.929	0.668
SE±	1.378	1.871	1.597	1.892	2.375	2.619	3.117	1.525	0.121	0.139	0.154	0.076
Interaction												
RM x RA	0.007	0.005	0.016	0.013	0.048	0.098	0.086	0.073	0.323	0.434	0.182	0.370

Means followed by the same letter(s) in the column within a treatment group are not significantly different at 5% level of probability using SNK. AS= alternate stand

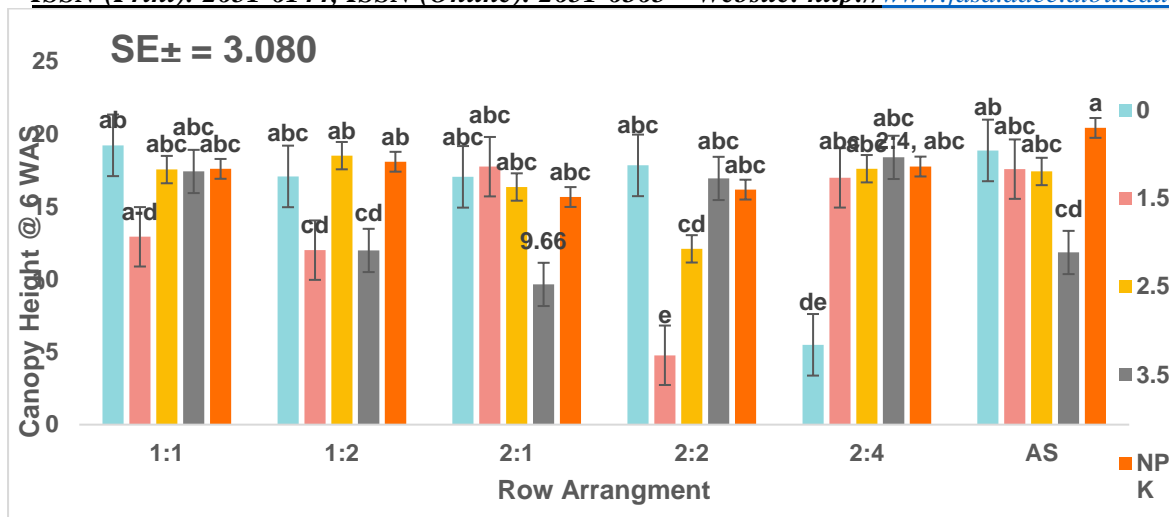


Figure 1: Interaction of rabbit manure and row arrangement on canopy height of groundnut in finger millet intercrop at 6 WAS in BUK.

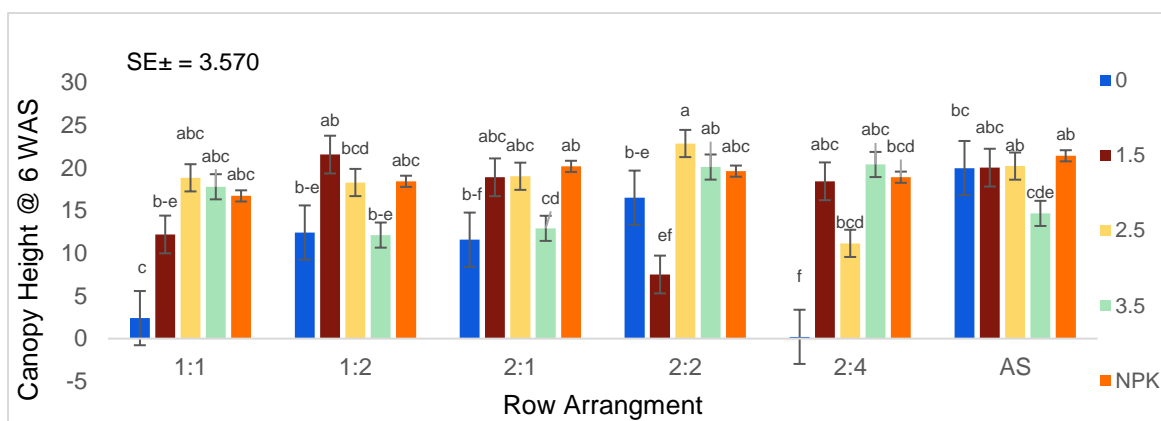


Figure 2: Interaction of rabbit manure and row arrangement on canopy height of groundnut in finger millet intercrop at 6 WAS in Dawakin Kudu

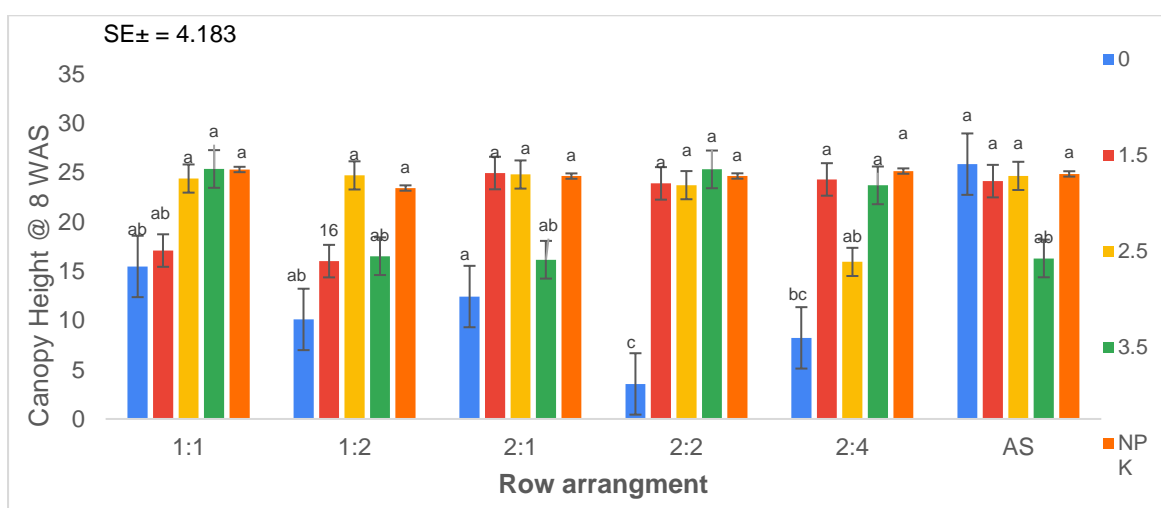


Figure 3: Interaction of rabbit manure and row arrangement on canopy height of groundnut in finger millet intercrop at 8 WAS in BUK.

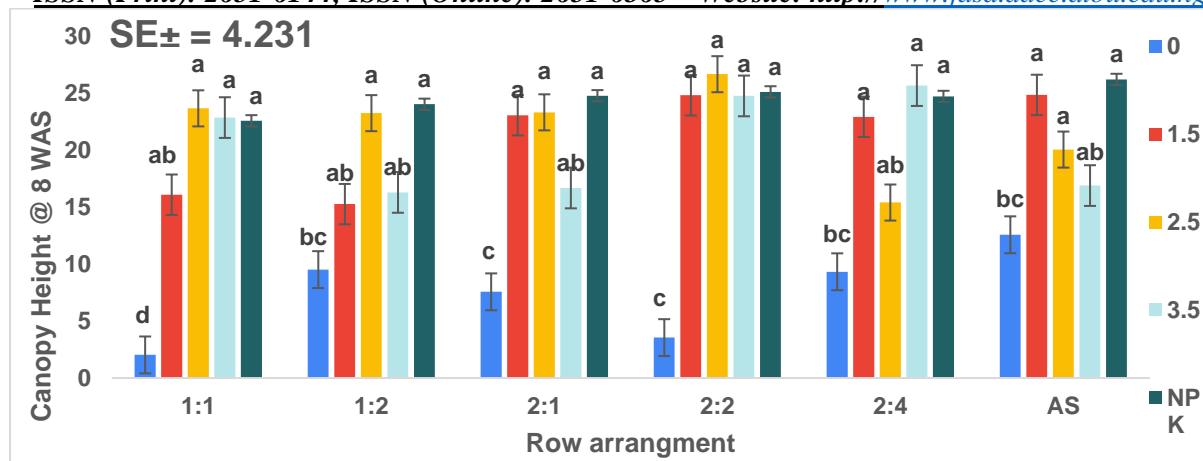


Figure 4: Interaction of rabbit manure and row arrangement on canopy height of groundnut in finger millet intercrop at 8 WAS in DWK.

Table 5: Chlorophyll content, plant fresh weight and dry matter content of groundnut in finger millet -groundnut intercrop as influenced by rabbit manure and row arrangement at 6 and 8 WAS at BUK and Dawakin Kudu in 2019 rainy season

Treatment	BUK		DWK		BUK		DWK		BUK		DWK	
	Chlorophyll content (SPAD)				Plant fresh weight (g)				Dry matter content (g)			
					Weeks after sowing (WAS)							
	6	8	6	8	6	8	6	8	6	8	6	8
Rabbit manure (RM) (t ha⁻¹)												
0.0	43.52	48.73	30.41 ^c	15.20 ^c	27.30	34.18	29.97	32.23	13.56	18.90	12.03	14.30
1.5	40.39	42.24	34.93 ^{bc}	17.46 ^{bc}	27.38	33.07	29.19	33.33	13.22	17.90	11.93	15.24
2.5	44.80	48.10	40.45 ^{ab}	18.42 ^{abc}	30.23	37.76	35.45	38.13	15.35	20.91	14.05	17.55
3.5	38.61	37.85	36.84 ^{abc}	20.23 ^{ab}	26.28	31.64	28.47	30.82	12.67	16.80	11.59	13.58
NPK	50.86	50.91	42.65 ^a	21.33 ^a	29.88	37.64	36.71	39.52	14.84	20.44	14.70	17.94
P of F	0.270	0.180	0.013	0.013	0.8647	0.5580	0.3233	0.2575	0.706	0.471	0.452	0.126
SE±	4.111	4.239	2.596	1.298	3.0792	3.1631	3.5130	3.2726	1.531	1.813	0.464	1.426
Row arrangement (RA)												
1:1	51.27	55.73	38.77	19.39	34.37	40.25	38.49	41.31	16.30	20.80	15.02	17.86
1:2	40.44	42.39	37.29	18.64	23.75	31.87	27.37	29.96	12.63	17.97	10.55	13.45
2:1	49.44	47.21	39.37	19.68	27.73	35.72	35.25	38.14	13.73	19.55	13.99	16.91
2:2	39.37	43.88	34.16	17.08	26.70	33.27	34.20	36.27	13.34	17.78	13.79	16.34
2:4	42.52	41.31	32.43	16.21	25.60	30.96	29.23	31.92	12.50	17.42	11.78	14.60
AS	48.21	47.8	40.33	20.16	28.41	34.94	35.51	37.54	13.99	19.63	14.83	16.78
P of F	0.432	0.068	0.496	0.497	0.6444	0.7341	0.4328	0.4270	0.904	0.941	0.484	0.682
SE±	5.200	5.362	3.283	1.642	3.8949	4.001	4.4435	4.1396	1.936	2.293	1.852	1.804
Interaction												
RM x RA	0.069	0.055	0.005	0.005	0.4311	0.2011	0.4284	0.1707	0.479	0.318	0.452	0.147

Means followed by the same letter(s) in the column within a treatment group are not significantly different at 5% level of probability using SNK. AS= alternate stand

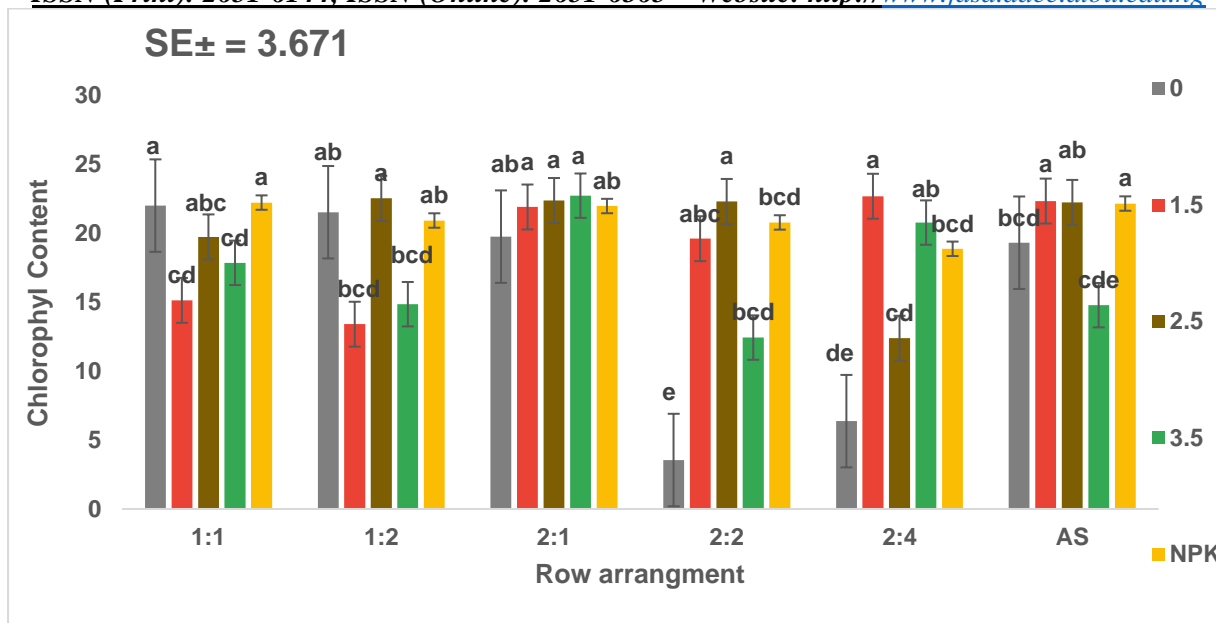


Figure 5: Interaction of rabbit manure and row arrangement on chlorophyll content of groundnut intercropped with finger millet at 6 in DWK.

Means followed by the same letter(s) across column and rows are not significantly different at 5% level of probability using SNK. AS= alternate stand

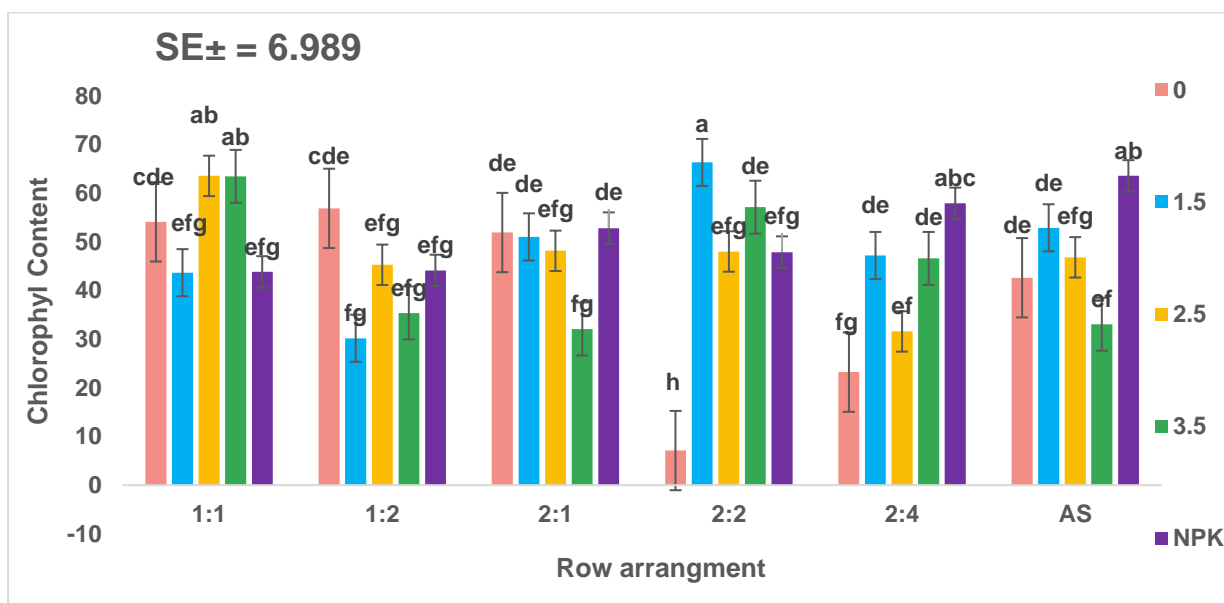


Figure 6: Interaction of rabbit manure and row arrangement on chlorophyll content of groundnut intercropped with finger millet at 8 in DWK.

Means followed by the same letter(s) across column and rows are not significantly different at 5% level of probability using SNK. AS= alternate stand

Straw weight, 1000 seed weight and grain yield of finger millet in groundnut intercrop as influenced by rabbit manure and row arrangement.

Table 9 shows the effects of rabbit manure (RM) and row arrangement (RA) on straw weight, 1000-seed weight, and grain yield of finger millet intercropped with groundnut at BUK and Dawakin Kudu. Application of RM (1.5-3.5 t ha⁻¹) and NPK significantly increased straw weight, 1000-seed weight at both sites, and grain yield at DWK, compared to the control (0.0

t ha⁻¹), which consistently recorded the lowest values. These positive effects of RM are linked to its ability to enhance soil fertility, nutrient availability, and soil structure, thereby supporting seed development. Similar benefits of RM on crop yield have been reported by Medyńska-Juraszek *et al.* (2022) and Li *et al.* (2022). In contrast, RA had no significant ($P > 0.05$) influence on any of the measured variables, suggesting that finger millet is relatively tolerant to variations in row arrangements within this intercropping system. Likewise, the interaction between RM and RA was not significant, indicating that their effects were independent.

Fodder weight, 100 seed weight and kernel yield of groundnut in finger millet intercrop at BUK and Dawakin Kudu in 2019 season.

Table 10 presents the effects of rabbit manure (RM) and row arrangement (RA) on fodder weight, 100-seed weight, and kernel yield of groundnut intercropped with finger millet at BUK and Dawakin Kudu. RM application did not significantly ($P > 0.05$) affect fodder weight or kernel yield at either site, nor 100-seed weight at BUK. However, at DWK, RM significantly influenced 100-seed weight, with NPK producing the highest value, though statistically similar to other RM rates while 3.5 t ha⁻¹ RM recorded the lowest. Neither RA nor the RM \times RA interaction had significant effects on groundnut performance. This may be attributed to a mismatch between the timing of nutrient release from RM and groundnut nutrient requirements, as well as competition with finger millet for soil resources.

Table 9: Straw weight, 1000 seed weight and grain yield of finger millet in groundnut intercrop as influenced by rabbit manure and row arrangement at BUK and Dawakin Kudu in 2019 rainy season

Treatment	Straw weight (kg ha ⁻¹)		1000 seed weight (g)		Grain yield (kg ha ⁻¹)	
	BUK	DWK	BUK	DWK	BUK	DWK
Rabbit Manure (RM) (t ha⁻¹)						
0.0	0.43 ^b	0.58 ^b	1.36 ^b	1.36 ^b	232.45	206.01 ^b
1.5	1.17 ^a	1.18 ^a	2.07 ^a	2.04 ^a	409.87	369.69 ^{ab}
2.5	0.82 ^a	1.06 ^a	1.78 ^a	1.71 ^{ab}	483.09	375.56 ^{ab}
3.5	0.98 ^a	1.08 ^a	1.83 ^a	1.75 ^{ab}	591.85	486.74 ^a
NPK	1.02 ^a	1.11 ^a	1.99 ^a	1.86 ^a	590.83	483.70 ^a
P of F	0.003	0.035	0.004	0.023	0.060	0.028
SE \pm	0.135	0.145	0.135	0.145	23.299	19.351
Row arrangement (RA)						
1:1	0.78	0.94	1.95	1.76	109.37	106.53
1:2	0.70	0.91	1.85	1.83	104.73	120.94
2:1	1.14	0.88	1.97	1.89	191.73	103.03
2:2	1.29	0.87	1.76	1.70	132.88	102.39
2:4	0.66	0.92	1.67	1.61	119.51	99.52
AS	0.69	1.15	1.73	1.71	102.77	109.03
P of F	0.100	0.677	0.788	0.785	0.416	0.316
SE \pm	0.171	0.183	0.171	0.183	29.471	24.477
Interaction						
RM \times RA	0.3237	0.2353	0.197	0.450	0.716	0.375

Means followed by the same letter(s) in the column within a treatment group are not significantly different at 5% level of probability using SNK. AS= alternate stand

Table 10: Fodder weight, 100 seed weight and kernel yield of groundnut in finger millet intercrop at BUK and Dawakiwn Kudu in 2019 season

Treatment	Fodder weight (kg ha ⁻¹)		100 kernel weight (g)		Kernel yield (kg ha ⁻¹)	
	BUK	DWK	BUK	DWK	BUK	DWK
Rabbit Manure (RM) (t ha⁻¹)						
0.0	0.78	0.64	25.42	29.23 ^{abc}	214.57	229.48
1.5	0.71	0.67	21.73	26.63 ^{bc}	171.30	216.70
2.5	0.76	0.76	24.66	30.94 ^{ab}	175.68	228.94
3.5	0.65	0.54	21.11	24.50 ^c	201.73	189.00
NPK	0.84	0.79	27.78	32.61 ^a	270.78	238.37
P of F	0.668	0.345	0.076	0.034	0.211	0.774
SE±	0.092	0.092	1.852	1.966	32.726	28.726
Row arrangement (RA)						
1:1	0.67	0.51	29.23	30.75	269.16	205.86
1:2	0.72	0.67	23.17	29.05	167.00	210.38
2:1	0.76	0.71	23.33	31.54	128.24	234.73
2:2	0.77	0.54	23.08	25.61	282.33	190.91
2:4	0.87	0.77	21.26	26.39	200.57	264.56
AS	0.75	0.79	25.83	29.82	193.67	232.89
P of F	0.864	0.252	0.214	0.508	0.101	0.170
SE±	0.117	0.117	2.342	2.487	9.395	8.336
Interaction						
RM x RA	0.066	0.093	0.059	0.104	0.431	0.098

Means followed by the same letter(s) in the column within a treatment group are not significantly different at 5% level of probability using SNK. AS= alternate stand.

Intercropping indices

Table 11 presents the Land Equivalent Ratio (LER), Area Time Equivalent Ratio (ATER), Land Use Efficiency (LUE) and aggressivity of finger millet-groundnut intercrop as influenced by rabbit manure and row arrangement in BUK and Dawakin Kudu. The results indicate that rabbit manure application significantly influences intercropping indices such as LER, ATER, and LUE. The highest LER values were observed at 0.0 t ha⁻¹ (2.80) at BUK and NPK (2.33) at DWK, indicating superior resource utilization efficiency under no manure application. Generally, most of the RM and RA had LER of >1 which could be attributed to efficient use growth resources by the component crop. Thus, the result of land equivalent ratio (LER) indicates that intercropping had yield advantage over sole cropping. However, ATER values peaked at 2.5 t ha⁻¹, suggesting optimal temporal resource use. Similarly, LUE values were highest at 1:1 and 2:2 row arrangements, demonstrating efficient land use. Aggressivity values showed a competitive interaction between intercrop components. Negative values in certain row arrangements (1:1 and 1:2) indicate that groundnut was less dominant, while positive values in others (2:1 and 2:2) suggest greater competitiveness of finger millet. These findings align with previous research that suggests organic manure enhances soil properties, improving intercropping benefits (Dong *et al.*, 2024; Li *et al.*, 2023).

CONCLUSION AND RECOMMENDATIONS

The study demonstrated that rabbit manure (RM) significantly enhanced the growth and yield of finger millet-groundnut intercrops, particularly in terms of finger millet straw weight, 1000 seed weight, and grain yield, as well as groundnut canopy height, leaf area, and leaf area index. Higher RM rates and NPK fertilizer consistently resulted in improved performance, indicating the importance of adequate nutrient availability. While row arrangement (RA) did not significantly affect yields independently, interactions between RM and RA influenced groundnut canopy height and chlorophyll content, especially at Dawakin Kudu (DWK), emphasizing the complex interplay between nutrient management and spatial arrangement.



Intercropping proved advantageous over sole cropping, as evidenced by Land Equivalent Ratio (LER) values exceeding 1.0 in most treatments. The study also highlighted the importance of site-specific factors, with DWK generally showing higher fertility and more pronounced responses to RM compared to BUK. Overall, RM application, particularly at rates of 2.5 t ha⁻¹ and above, combined with NPK fertilizer, offers a viable strategy for enhancing intercropping productivity in semi-arid regions.



Table 11: Land equivalent ratio, area time equivalent ratio, land use efficiency and aggressivity of finger millet-groundnut intercrop as influenced by rabbit manure and row arrangement in BUK and Dawakin Kudu

Treatment	Land equivalent ratio (LER)		Area time equivalent ratio (ATER)		Land use efficiency (LUE)		Aggressivity	
	BUK	DKD	BUK	DKD	BUK	DKW	BUK	DKD
Rabbit Manure (RM) (t ha⁻¹)								
0.0	2.80	2.06	2.439	2.39	261.95	222.60	-	-
1.5	1.93	1.96	2.363	2.61	214.65	228.49	-	-
2.5	2.25	2.24	2.500	2.65	237.50	244.33	-	-
3.5	1.74	1.74	2.195	2.39	196.75	206.71	-	-
NPK	1.60	2.33	2.552	2.05	207.60	219.21	-	-
P of F	0.398	0.839	0.7986	0.883	56.815	86.080	-	-
SE±	0.388	0.564	1.0359	1.077	71.195	52.070	-	-
Row arrangement (RA)								
1:1	3.04	1.69	2.412	2.29	272.60	198.94	-0.058	-0.061
1:2	1.79	2.82	2.007	2.41	189.85	261.52	-0.017	-0.023
2:1	2.11	2.79	2.479	2.31	229.45	255.31	0.045	-0.074
2:2	2.77	2.54	2.586	2.21	267.80	237.48	-0.013	0.012
2:4	1.33	2.09	2.218	2.39	177.40	223.89	-0.021	-0.032
AS	2.69	1.64	2.110	2.38	240.00	201.18	-0.002	0.002
P of F	0.185	0.177	0.7739	0.951	47.935	56.405	0.00001	0.0003
SE±	0.597	0.487	1.1211	1.193	85.905	83.995	0.0005	0.0014
Interaction								
RM x RA	0.762	0.066	0.1042	0.0571	0.6723	0.0567	0.1542	0.1250

Means followed by the same letter(s) in the column within a treatment group are not significantly different at 5% level of probability using SNK. AS= alternate stand



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