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OPTIMIZING SORGHUM–ROSELLE INTERCROPPING AND WEEDING REGIMES FOR ENHANCED PRODUCTIVITY AND WEED SUPPRESSION IN THE NIGERIAN SUDAN SAVANNA

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ABSTRACT

Intercropping offers a viable pathway toward sustainable intensification of agricultural systems, particularly in resource-constrained environments such as Nigeria's Sudan Savanna. This study evaluated the effects of row arrangement (RA) and weeding frequency (WF) on the growth, yield, weed suppression, and intercropping efficiency of sorghum (*Sorghum bicolor* L.) and roselle (*Hibiscus sabdariffa* L.) during the 2023 wet season in BUK and Dutsin-Ma. A split-plot design was used, comprising four row arrangements (1S:1R, 2S:1R, 1S:2R, and 2S:2R) and four weeding regimes (weedy check, 3 WAS, 3 and 6 WAS, and 3, 6 and 9 WAS), replicated three times, with RA assigned to main plots and WF to subplots. Results showed that the 1S:1R configuration consistently enhanced crop performance across locations. It produced the tallest sorghum plants (183.57 cm at BUK), longest panicles (30.48 cm), highest grain yield (1863.33 kg ha^{-1}), and roselle calyx yield (829.33 kg ha^{-1}). At Dutsin-Ma, similar trends were observed, with the 1S:1R treatment achieving a grain yield of 1651.5 kg ha^{-1} and calyx yield of 1494.5 kg ha^{-1}. Frequent weeding at 3, 6 and 9 WAS significantly improved growth traits and yield, and reduced weed density to as low as 19.22 plants m^{-2}, while increasing weed control efficiency (WCE) to 86.23%. No significant RA × WF interaction was observed, indicating their independent influence on system performance. The 1S:1R configuration also recorded the highest Land Equivalent Ratio (1.81) and System Productivity Index (8.11), reflecting superior land-use efficiency. Aggressivity values showed that sorghum was the dominant species, particularly under balanced spatial arrangements.These findings highlight that optimized spatial design and weed management in sorghum–roselle intercropping can improve yield, suppress weeds, and promote sustainable agricultural intensification in dryland farming systems.

Keywords: Intercropping systems, Sorghum–roselle productivity, Row arrangement, Weeding frequency, Land equivalent ratio, Sustainable intensification

INTRODUCTION

Intercropping is a sustainable agricultural practice that enhances land-use efficiency, improves crop productivity, and reduces pest and weed infestation (Matusso *et al*., 2021). Sorghum (*Sorghum bicolor* L.) and roselle (*Hibiscus sabdariffa* L.) are important crops in the Sudan Savanna of Nigeria, valued for their roles in food security, income generation, and industrial applications (Oluwasusi and Akanni, 2020). However, suboptimal planting configurations and intense weed competition constrain their productivity by limiting the efficient use of light, water, and nutrients (Ibrahim *et al*., 2022).

Row arrangement and weeding frequency significantly affect intercrop performance by influencing canopy structure, weed suppression, and resource allocation (Mao *et al.,* 2023). Although sole cropping is still widespread among smallholder farmers, evidence suggests that intercropping sorghum and roselle using efficient spatial designs can yield significant productivity gains (Ajeigbe *et al.,* 2021). Despite this potential, there is limited research on optimal row arrangements and weeding regimes specifically for sorghum/roselle systems in the Sudan Savanna.

Sorghum and roselle yields in the region are adversely affected by poor agronomic practices, particularly inefficient row spacing and inadequate weed management (Kamara et al., 2021). According to Oyege *et al*. (2022), uncontrolled weeds can reduce yields by 30–60%, and improper row arrangements may either intensify competition or underutilize space (Zhang *et al.,* 2023). Most existing research has focused on sole crops or cereal-legume combinations, leaving a knowledge gap on best practices for sorghum/roselle intercropping (Abdullahi *et al.,* 2020). Addressing this gap is essential to enhance productivity and sustainability for smallholder systems in the region.

Improving sorghum and roselle productivity through optimized intercropping aligns with Nigeria's goals of agricultural diversification and food security (FAO, 2023). Efficient row arrangements enhance light interception and suppress weeds, while timely weeding reduces yield losses (Tofa *et al.,* 2021). This study provides empirical evidence to support agronomic decisions that promote sustainable intensification in the Sudan Savanna. Results will inform farmers, extension agents, and policymakers on climate-smart practices that enhance land and labor productivity (Vanlauwe *et al.,* 2022). The study aims at evaluating the effect of different row arrangements on the growth and yield of sorghum/roselle intercrops as well as to determine the influence of weeding frequency on weed suppression and crop productivity.

MATERIALS AND METHODS

Experimental Sites

The field trials were conducted during the 2023 wet season at two locations: Bayero University, Kano Teaching and Research Farm (Lat. 11°58'N, Long. 8°26'E, 460 m above sea level) and Federal University Dutsin-ma Teaching and Research Farm, Katsina (Lat. 12°08'N, Long. 8°32'E, 500 m above sea level). Both sites are situated in the Sudan Savanna agroecological zone of Nigeria, characterized by a unimodal rainfall pattern (800–1,000 mm annually), sandy loam soils, and average temperatures of 28–34°C. Soil analysis revealed a slightly acidic pH (5.8–6.2), low organic carbon (1.2–1.8%), and moderate nitrogen content (0.5–0.8 g kg^{-1}).

Treatments and Experimental Design

The experiment consisted of six sorghum (S) and roselle (R) planting configurations: sole sorghum (S_1:R_0), sole roselle (S_0:R_1), and four intercropping arrangements (S_1:R_1, S_1:R_2, S_2:R_1, and S_2:R_2). In addition, four weeding regimes were tested: no weeding (weedy check), weeding at 3 weeks after sowing (WAS), weeding at 3 and 6 WAS, and weeding at 3, 6, and 9 WAS. The experiment was laid out in a split-plot design with three replications. Row arrangement was assigned to the main plots, while weeding frequency was allocated to the subplots. The sole crops were included primarily for comparative purposes, particularly for calculating the land equivalent ratio (LER) and other intercropping indices.

Varietal traits and Source

The sorghum variety used in the trial was *cv. Deko*, a medium-maturing (90–100 days), drought-tolerant cultivar with a yield potential of 1,889–3,000 kg ha^{-1}. It was obtained from the Department of Agronomy, Bayero University Kano (BUK). The roselle used was a high-yielding, dark-purple calyx variety, well adapted to arid environments, and sourced from Dawanau International Grain Market, Kano.

Cultural Practices

Land Preparation

The field was cleared, plowed, harrowed, and ridged at 0.75 m spacing. Experimental plots were demarcated with a gross plot size of 12 ridges × 3 m in length (27 m^2), while the net plot comprised two inner rows measuring 3 m × 1.5 m (4.5 m^2). Alleys were maintained at 1.0 m between main plots, 0.5 m between sub-plots, and 1.5 m between replications.

Sowing

Sorghum was sown at a spacing of 75 cm × 30 cm (inter- × intra-row), with four seeds per hole, later thinned to two plants per stand at 2 weeks after sowing (WAS). Roselle was sown simultaneously at the same spacing.

Fertilizer Application

Sorghum received 64 kg N ha^{-1}, 32 kg P_2O_5 ha^{-1}, and 32 kg K_2O ha^{-1} in the form of NPK (15:15:15) at sowing. The remaining nitrogen was top-dressed at 6 WAS. For roselle, 150 kg ha^{-1} of Single Super Phosphate (SSP) was applied at 3 WAS.

Weed and Pest Control

Weeding was done according to the respective treatment schedules. Insect pests were controlled using Karate EC (7.5% pirimicarb) applied at two-week intervals starting from flowering.

Harvesting

Each crop was harvested separately at physiological maturity from the net plot area. Roselle plants were harvested when mature, sun-dried to constant weight, threshed, and weighed to determine calyx yield. Sorghum was harvested by cutting stems just above ground level when partially dried in the field using a machete. Panicles were then sun-dried to constant weight, threshed, and weighed to determine grain yield.

Data Collection

Data were collected on both growth and yield parameters for the component crops.

Sorghum

Plant height, leaf number, Panicle count, panicle weight, 1000-grain weight, grain yield (kg ha^{-1}).

Roselle

Plant height, number of leaves per plant, number of branches per plant, calyx count per plot, calyx yield and seed yield (kg ha^{-1}).

Weed Parameters

Weed density (n m^{-2}), weed dry weight (g m^{-2}), and weed control efficiency (WCE%).

Intercropping Efficiency

Land Equivalent Ratio (LER): Calculated as:

$$LER = \frac{\text{Ysorghum intercrop}}{\text{Ysorghum sole}} + \frac{\text{Yroselle intercrop}}{\text{Yroselle sole}}$$

Aggressivity:

This was a function which measures the inter crop competition by relating yield changes of both components crops. Aggressively was mathematically calculated as Aggressivity of crop "a" with "b"

$$Aab = \frac{Yab}{Yaa \times Zab} - \frac{Yba}{Ybb \times 2ba}$$

$$Aab = \frac{Yba}{Ybb \times Zab} - \frac{Yba}{Yaa \times 2ab}$$

Where,

Y_{ab} and Y_{ba} were the individual yield crop "a" and "b" in mixture respectively, Y_{aa} and Y_{bb} were the sole yield of crops "a" and "b" respectively, Zab and Zba were the swon proportion of crop "a" and "b" respectively (Mc Gildirist, 1965).

Data Analysis

Data collected were subjected to analysis of variance (ANOVA) using GENSTAT (17th edition), and significant treatment means were compared using the Student–Newman–Keuls (SNK) test at the 5% probability level.

RESULTS AND DISCUSSION

Plant height and Number of leaves per plant of sorghum

Table 1 presents the effect of row arrangement (RA) and weeding frequency (WF) on plant height and number of leaves per plant of sorghum at physiological maturity in BUK and Dutsin-Ma during the 2023 wet season. The effect of row arrangement was highly significant ($p < 0.001$) on plant height at both locations. The 1S:1R configuration consistently produced the tallest plants (183.57 cm in BUK and 180.22 cm in Dutsin-Ma) significantly higher than other arrangements. Conversely, the 2S:2R configuration resulted in the shortest plants at both sites. Regarding leaf number, RA had a significant effect ($p < 0.05$) in both locations. At Dutsin-Ma, the 1S:2R arrangement produced the highest number of leaves (13.00), while other treatments had statistically similar but slightly lower values. In BUK, although 1S:1R had the highest leaf number (13.17), the difference was not statistically distinct from other arrangements.

The effect of weeding frequency on plant height was not significant ($p > 0.05$) in either location. However, it significantly influenced the number of leaves in BUK ($p < 0.001$), with the highest leaf number (13.13) observed in the 3, 6, and 9 WAS weeding regime, while the weedy check had the lowest (11.07). No significant effect was observed in Dutsin-Ma for leaf number. The interaction between RA and WF had no significant effect ($p > 0.05$) on either parameter in both locations. These findings confirm that spatial arrangement plays a critical role in sorghum growth, particularly in enhancing plant height and leaf production. The superior performance of the 1S:1R arrangement suggests reduced interspecific competition and better resource utilization. Similar trends were reported by Abba et al. (2024), where a 2:1 sorghum–groundnut row arrangement effectively reduced weed density and improved sorghum yield in the Sudan Savanna.

Table 1: Effect of row arrangement and weeding frequency on plant height and number of leaves per plant of Sorghum at physiological maturity at BUK and Dutsin-Ma during 2023 wet season

Treatment	BUK Plant height (cm)	Dutsin-Ma Number of leaves per plant	BUK Plant height (cm)	Dutsin-Ma Number of leaves per plant
Row Arrangement (RA)				
1S:1R	183.57a	13.17a	180.22a	12.32ab
2S:1R	175.61bc	11.83ab	170.93c	12.32ab
1S:2R	171.94cd	12.66ab	168.84b	13.00a
2S:2R	168.40d	12.00ab	167.01b	12.33ab
P. value	<0.001	0.050	<0.001	0.005
SE±	1.26879	04346	1.000	0.224
Weeding frequency (WF)				
Weedy check	172.743	11.066c	171.342	11.11
Weeding @ 3 weeks	173.40	11.87bc	174.223	12.22
Weeding @ 3 & 6 weeks	175.79	12.80ab	175.43	12.33
Weeding @ 3, 6, & 9 weeks	175.27	13.13a	175.44	12.02
P. value	0.1573	<.0001	0.1695	1.000
SE±	1.2687	0.388	1.1348	0.201
Interaction				
RA x WF	1.000	0.091	1.000	1.000

Means in the same column followed by the same letter(s) are not significantly different at the 5%level of probability using the SNK test. 1S:1R = 1 row of Sorghum to 1 row of Roselle, 2S:1R = 2Rows of Sorghum 1 row of Roselle, 1S:2R = 1 row of Sorghum to 2 rows of Roselle, 2S:2R = 2 rows of Sorghum to 2 rows of Roselle.

Although weeding frequency had no significant effect on plant height, its influence on leaf number, especially in BUK, underscores the importance of weed control for maintaining healthy foliage development. This is consistent with findings from Baker *et al.* (2021), where increased weeding frequency significantly enhanced leaf development in dry bean intercrops, though plant height remained relatively unaffected. This suggests that leaf production may be more sensitive to weed stress than stem elongation, depending on crop and environment.

The lack of significant interaction between RA and WF implies that the two factors influence plant traits independently. This indicates that once an optimal row configuration is identified, adding more intensive weeding strategies may yield limited additional benefits, particularly under moderate weed pressure. These insights align with observations by Cheriere *et al.* (2020), who found that row arrangement had a stronger influence than weeding on overall crop performance in soybean-based intercrops.

Yield and yield related components of sorghum

The effect of RA and WF on yield and yield components of sorghum including panicle length, panicle weight per plant, 1000-seed weight, and grain yield at BUK and Dutsin-Ma during the 2023 wet season is presented in Table 2. Results reveal that RA had a significant influence on most yield parameters. At BUK, RA had a highly significant ($p < 0.001$) effect on panicle length, 1000-seed weight, and grain yield, and a significant ($p < 0.05$) on panicle

Table 2: Effect of row arrangement and weeding frequency on yield and yield attributes of Sorghum at BUK and Dutsin-ma during the 2023 wet season

	BUK				DUTSIN-MA			
Treatment	Panicle length (cm)	Panicle weight $plant^{-1}$ (g)	1000 seed weight (g)	Grain yield (kg ha^{-1})	Panicle length (cm)	Panicle weight $plant^{-1}$ (g)	1000 seed weight (g)	Grain yield (kg ha^{-1})
Row arrangement (RA)								
1S:1R	29.43b	133.51a	37.57a	1863.33a	27.52	132.33a	28.676a	1651.5
2S: 1R	24.87c	110.32b	33.99b	1617.00b	27.63	105.33b	26.621b	1636.4
1S: 2R	30.02a	104.10b	33..58b	1445.33c	27.99	107.33b	26.33bc	1573.1
2S :2R	30.48a	105.12b	32.15c	1382.33d	27.40	98.667c	25.511c	1372.2
P. Value	<.0001	0.004	<.0001	<.0001	0.7224	<.0001	<.0001	0.0590
SE±	2.249	5.603	2.957	5.216	1.250	0.887	0.3554	133.479
Weeding frequency (WF)								
Weedy check	28.75	110.60	27.43b	1704.93	20.21c	44.98c	26.93	1565.1
Weeding @ 3 weeks	29.67	113.01	33.02ab	1703.51	23.97b	107.67b	26.93	1661.2
Weeding @ 3 & 6 weeks	30.22	114.52	34.20ab	1704.77	26.19a	114.35a	26.52	1698.6
Weeding @ 3, 6, & 9 weeks	30.77	114.63	40.51a	1704.82	27.44a	113.90a	26.67	1628.1
P.value	0.907	0.935	0.013	1.000	0.004	0.002	1.000	0.879
SE±	2.0119	5.0110	2.645	4.665	1.1184	0.7941	0.317	119.387
Interaction								
RA x WF	0.939	0.978	0.984	1.000	1.000	1.000	1.000	0.0727

Means in the same column followed by the same letter(s) are not significantly different at the 5%level of probability using the SNK test. 1S:1R = 1 row of Sorghum to 1 row of Roselle, 2S:1R = 2 Rows of Sorghum to 1 row of Roselle, 1S:2R = 1 row of Sorghum to 2 rows of Roselle, 2S:2R = 2 rows of Sorghum to 2 rows of Rosel weight. The 1S:1R configuration recorded the highest panicle weight (133.51 g) and grain yield (1863.33 kg/ha), producing longer and heavier panicles than all other arrangements. In contrast, the 2S:2R configuration resulted in the lowest grain yield and smallest panicle size. At Dutsin-Ma, RA significantly ($p < 0.001$) affected panicle weight v and 1000-seed weight, though its effect on grain yield was not statistically significant ($p > 0.05$). However, as observed in BUK, the 1S:1R and 2S:1R configurations consistently produced higher values for yield traits, with 1S:1R outperforming other treatments in panicle weight and seed mass.

These results emphasize the advantage of the 1S:1R spatial configuration, likely due to more efficient utilization of light, nutrients, and water, which promotes better panicle development and seed filling. Comparable results were reported by Abba et al. (2024), who found that a 2:1 sorghum–groundnut row arrangement significantly enhanced sorghum yield in the Sudan Savanna. Similarly, Ibrahim et al. (2024) observed yield improvement from optimized row arrangement in a finger millet–groundnut intercropping system under the same ecological conditions.

On the other hand, WF had variable effects across sites and yield traits. At BUK, WF had a highly significant effect ($p < 0.001$) on 1000-seed weight but did not significantly influence grain yield or panicle traits. The highest seed weight (40.51 g) was recorded under the 3, 6, & 9 WAS weeding regime, while the weedy check resulted in the lowest (27.43 g). This indicates that extended weed control enhances seed filling, likely by reducing competition during critical grain development stages. At Dutsin-Ma, WF had a significant impact ($p < 0.001$) on both panicle length and panicle weight. The best performance was observed under 3 & 6 WAS and 3, 6, & 9 WAS weeding schedules, whereas the weedy check again resulted in the lowest values for these traits. These findings demonstrate that frequent weeding supports reproductive development, especially panicle formation and seed weight, by minimizing resource competition during key stages of crop growth. Similar outcomes were reported by Yumbya (2025), who found that improved weeding schedules enhanced yield performance in green gram–sorghum systems. Iqbal et al. (2019) also confirmed that better weed suppression leads to improved yield components in cereal–legume intercrops. There was no significant interaction between RA and WF observed for any of the measured parameters at either BUK or Dutsin-Ma, suggesting that row arrangement and weeding frequency influence yield traits independently.

Growth characters of Roselle

Table 3 presents the effect of RA and WF on roselle plant height, number of leaves per plant, and number of branches per plant at BUK and Dutsin-Ma during the 2023 wet season. Results show that at BUK, RA had a significant ($p < 0.05$) effect on the number of branches per plant, while its effects on plant height and leaf number were not statistically significant. The 1S:1R configuration produced the highest number of branches (13.83), whereas the 2S:2R arrangement recorded the lowest (9.20).

At Dutsin-Ma, RA significantly ($p < 0.001$) influenced the number of leaves per plant with 1S:1R yielding the highest leaf count (68.99). However, RA had no significant effect on plant height and number of branches per plant at this location. These findings suggest that more balanced spatial arrangements, such as 1S:1R, can enhance roselle vegetative growth by minimizing competition for light and space. This aligns with intercropping studies that have shown how spatial configuration strongly influences crop vigor and structure, even when no interaction effects are present *(Berdjour et al.,* 2020).

Weeding frequency, on the other hand, had a more pronounced effect, particularly on plant height. At BUK, WF had a highly significant ($p < 0.001$) effect on roselle height. The 3, 6, &

Table 3: Effect of row arrangement and weeding frequency on Plant height, Number of leaves per plant and Number of branches per plant of Roselle at BUK and Dutsin-Ma during the 2023 wet season

	BUK			DUTSIN-MA		
Treatment	Plant height (cm)	Number of leaves per plant (#)	Number of branches per plant (#)	Plant height (cm)	Number of leaves per plant (#)	Number of branches per plant (#)
Row arrangement (RA)						
1S:1R	28.12	62.78	13.83ab	62.49	68.99a	11.65
2S:1R	23.96	66.26	11.93b	59.84	61.44a	10.27
1S: 2R	25.15	65.45	11.07b	54.95	60.19a	10.73
2S :2R	26.10	64.41	9.20b	49.57	46.83b	10.37
P. value	0.929	0.899	0.008	0.357	0.004	0.714
SE±	1.820	6.572	0.952	4.848	4.122	0.772
Weeding frequency (WF)						
Weedy check	17.73c	62.37	13.03	44.97a	61.38	10.57
Weeding @ 3 weeks	24.57b	65.27	12.20	55.33bc	60.75	10.51
Weeding @ 3 & 6 weeks	27.87b	68.38	12.85	60.11ab	64.35	10.91
Weeding @ 3,6, & 9 weeks	35.64a	67.41	13.16	69.11a	57.84	10.79
SE±	2.001	0.893	0.633	4.336	0.669	0.973
Interaction						
RA x WF	0.5746	7.268	1.052	0.8592	3.669	0.691

Means in the same column followed by the same letter(s) are not significantly different at the 5%level of probability using the SNK test. 1S:1R = 1 row of Sorghum to 1 row of Roselle, 2S:1R = 2 Rows of Sorghum to 1 row of Roselle, 1S:2R = 1 row of Sorghum to 2 rows of Roselle, 2S:2R = 2 rows of Sorghum to 2 rows of Roselle.

9 WAS treatment produced the tallest plants (35.64 cm), while the weedy check yielded the shortest (17.73 cm).

However, leaf and branch numbers were not significantly affected by WF. At Dutsin-Ma, WF also had a significant effect on plant height ($p < 0.001$), with the 3, 6, & 9 WAS treatment again producing the tallest roselle plants (69.11 cm). Similar to BUK, the effects on leaf and branch numbers were not statistically significant. These results confirm that timely and consistent weed control enhances roselle's vegetative growth particularly height by reducing early-stage competition for essential resources. With less competition, the plant can allocate more energy toward canopy and stem development. This finding is consistent with Shittu et al. (2023), who observed that hoe weeding at 3 and 6 WAS significantly improved roselle growth traits compared to unweeded controls.

No significant RA × WF interaction was observed for all the measured traits at either location, indicating that row arrangement and weeding frequency operate independently. This suggests that each practice can be optimized separately to improve roselle vegetative performance.

Yield and yield related traits of Roselle

The effect of RA and WF on the number of calyces per plot, calyces yield, and seed yield of roselle at BUK and Dutsin-Ma during the 2023 wet season is shown in Table 4. At BUK, RA had a significant ($p < 0.05$) effect on calyces yield and seed yield, but not on the number of calyces per plot. The 1S:1R configuration produced the highest calyces (829.33 kg/ha) and seed yields

Table 4: Effect of row arrangement and weeding frequency on Number of calyces per plot, Calyces yield and seed yield of Roselle at BUK and Dutsin-Ma during the 2023 wet season

	BUK			DUTSIN-MA		
Treatment	Number of calyces per plot	Calyces yield (kg ha^{-1})	Seed yield (kg ha^{-1})	Number of calyces per plot	Calyces yield (kg ha^{-1})	Seed yield (kg ha^{-1})
Row arrangement (RA)						
1S:1R	3960.3	829.33a	1008a	3380.0b	1494.5a	1065.6
2S: 1R	3812.4	806.11b	988b	2708.3c	1250.8b	1005.0
1S: 2R	2885.3	705.25b	746c	1871.7d	1117.7c	1055.5
2S :2R	3435.1	691.67c	644d	2610.0	1126.1b	1003.2
P. value	0.784	0.004c	0.022	<.0001	<.0001	0.765
SE±	472.803	30.67	64.462	188.188	56.130	73.357
Weeding frequency (WF)						
Weedy check	3162.4	674.20c	631c	2020.0b	726.1c	679.89c
Weeding @ 3 weeks	3419.2	715.40c	900b	3170.7a	1061.3b	1055.85b
Weeding @ 3 & 6weeks	3954.1	821.47b	970a	3480.0a	1063.4b	1089.54a
Weeding @ 3, 6, & 9 weeks	3102.5	934.53a	972a	3305.3a	1390.8a	1227.35a
P. value	0.318	0.003	0.0319	<.0001	0.023	<.0001
SE±	522.885	27.840	44.612	168.320	95.36	65.612
Interaction						
RA x WF	0.593	0.8059	0.8121	0.2747	0.9982	0.410

Means in the same column followed by the same letter(s) are not significantly different at the 5%level of probability using the SNK test. 1S:1R = 1 row of Sorghum to 1 row of Roselle, 2S:1R = 2 Rows of Sorghum to 1 row of Roselle, 1S:2R = 1 row of Sorghum to 2 rows of Roselle, 2S:2R = 2 rows of Sorghum to 2 rows of Roselle.

(1008 kg/ha), while the 2S:2R arrangement recorded the lowest (691.67 kg/ha and 644 kg/ha, respectively). At Dutsin-Ma, RA had highly significant effects ($p < 0.001$) on both number of calyces per plot and calyces yield, with 1S:1R again showing superior performance. Seed yield differences were not significant. These results highlight the advantage of the 1S:1R arrangement, likely due to better light interception and less interspecific competition, which enhances both calyx development and seed set. This is consistent with findings by Jabereldar *et al*. (2023), who reported significantly higher calyx yield and number of calyces per plant in roselle when intercropped in a 2:2 arrangement with cowpea in Sudan. Their study confirmed that row spacing and crop pairing significantly influence roselle reproductive output.

Weeding frequency on the other hand, significantly influenced roselle yield components at both locations At BUK, WF had a highly significant ($p <0.001$) effects on calyces yield and significant ($p < 0.05$) effect on seed yield, but not on the number of calyces per plot. The 3, 6, & 9 WAS treatment recorded the highest calyces yield (934.53 kg/ha) and seed yield (972 kg/ha), while the weedy check had the lowest in both traits. At Dutsin-Ma, WF had a highly significant effect ($p < 0.0001$) on number of calyces per plot and seed yield ($p < 0.0001$). The most frequent weeding (3, 6, & 9 WAS) again led to the best performance, producing 3305.3 calyces per plot and 1227.35 kg/ha seed yield. The weedy check was consistently the lowest across all parameters. These findings affirm that frequent weeding enhances roselle productivity, especially when done during early and mid-growth stages. Removing weed competition allows for improved nutrient uptake and reproductive success. This mirrors results from Aneke et al. (2023), who demonstrated that healthier and more productive calyces are obtained from roselle under optimal field conditions of adequate spacing and weed-free environments especially for high anthocyanin content and biomass accumulation. Equally there was no significant ($p > 0.05$) RA × WF interaction for any trait at either location, suggesting that row arrangement and weeding frequency independently affect roselle yield performance. Thus, farmers can manage each factor separately for effective yield improvement.

Weed characters

Table 5 presents the effect of RA and WF on weed density, weed biomass, and weed control efficiency in the sorghum–roselle intercropping system at BUK and Dutsin-Ma during the 2023 wet season. At BUK, RA significantly ($p < 0.05$) influenced weed density and highly significant ($p < 0.001$) on weed biomass, where the 1S:1R configuration recorded the lowest weed density (20.10 m^{-2}) and highest weed biomass (188.32 g/m^2), while 2S:2R had a similarly low weed density but much higher biomass (672.65 g/m^2), indicating poor suppression despite plant spacing. At Dutsin-Ma, RA also significantly ($p < 0.0001$) affected both weed density and biomass with 1S:1R again providing the lowest weed density (20.69 m^{-2}) and lowest weed biomass (181.22 g/m^2). The 1S:2R and 2S:2R configurations performed poorly in suppressing weeds, with the highest weed biomass observed in these treatments. These results confirm that closer and more balanced row arrangements improve weed suppression by promoting faster canopy closure and minimizing light availability for weed growth. Similar outcomes were reported by Ibrahim et al. (2023), who found that intercropping sorghum with sunflower on broad beds significantly reduced weed density compared to sole cropping systems, highlighting the importance of spatial arrangements in integrated weed management.

Weeding frequency had a highly significant ($p < 0.001$) effect on all weed control metrics at both locations. At BUK, the weedy check showed the highest weed density (66.12 m^{-2}) and weed biomass (914.47 g/m^2), with the lowest weed control efficiency (19.19%).

Table 5: Effect of Row arrangement and Weeding frequency on Weed density, Weed biomass and Weed control efficiency of Sorghum Roselle intercropping system at BUK and Dutsin-Ma during the 2023 wet season

	BUK			DUTSIN-MA		
Treatment	Weed density (n/m^2)	Weed biomass (g/m^2)	Weed control efficiency (%)	Weed density (n/m^2)	Weed biomass (g/m^2)	Weed control efficiency (%)
Row arrangement (RA)						
1S:1R	20.10c	188.32a	68.4	20.69c	181.22a	34.23
2S: 1R	23.17ab	165.94b	64.87	25.27ab	101.48b	42.11
1S: 2R	23.19ab	84.38c	59.56	26.62ab	882.40c	46.45
2S :2R	20.10c	672.65	61.19	22.52b	822.82	38.45
P. value	0.0264	<.0001	0.863	<.0001	<.0001	0.386
SE±	1.386	51.467	5.456	1.386	52.993	4.521
Weeding frequency (WF)						
Weedy check	66.12a	914.47a	19.19c	56.09a	924.39a	27.34c
Weeding @ 3 weeks	37.14b	211.22b	79.54b	45.34b	208.88a	81.23ab
Weeding @ 3 & 6weeks	22.21c	181.48b	84.45ab	20.87c	92.13c	84.01b
Weeding @ 3, 6, &9 weeks	21.12c	92.40c	86.23a	19.22c	76.72d	86.02a
P. value	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
SE±	1.343	0.0548	3.773	1.2432	47.398	3.289
Interaction						
RA x WF	0.2513	0.6935	6.0054	0.34212	0.0662	5.901

Means in the same column followed by the same letter(s) are not significantly different at the 5%level of probability using the SNK test. 1S:1R = 1 row of Sorghum to 1 row of Roselle, 2S:1R = 2 Rows of Sorghum to 1 row of Roselle, 1S:2R = 1 row of sorghum to 2 rows of Roselle, 2S:2R = 2 rows of sorghum to 2 rows of Roselle.

The most effective treatment was weeding at 3, 6, & 9 WAS, which reduced weed density to 21.12 m^{-2} and increased weed control efficiency to 86.23%. At Dutsin-Ma, the same trend was observed, with the 3, 6, & 9 WAS treatment resulted in the lowest weed density (19.22 m^{-2}), lowest biomass (76.72 g/m^2), and highest weed control efficiency (86.02%), while the weedy check had the lowest performance. These findings underline the importance of frequent and timely weeding to maintain low weed pressure. The results are in line with Patra et al. (2025), who demonstrated that hand weeding and sorghum-based mulching achieved the highest weed control efficiency and lowest biomass in field pea systems. Similarly, Chavda et al. (2024) found that hand weeding and tank-mixed herbicides in sorghum significantly reduced weed biomass and improved crop yield. There was no significant RA × WF interaction observed for any of the parameters at either location.

Intercropping indices

Land Equivalent Ratio (LER) and System Productivity Index (SPI)

The effects of RA on the LER, SPI, and Aggressivity indices (Aab for sorghum and Aba for roselle) in sorghum–roselle intercropping at BUK and Dutsin-Ma during the 2023 wet season is shown in Table 6. At both locations, the 1S:1R configuration recorded the highest LER values (1.81 at BUK and 1.62 at Dutsin-Ma), indicating superior land-use efficiency compared to other arrangements. This configuration also had the highest SPI (8.03 at BUK and 8.11 at Dutsin-Ma), showing better system productivity overall. These results highlight the advantage of balanced intercropping structures in maximizing total yield and efficient resource use. Similar trends were observed by Tesfaye (2024), who found that intercropping sorghum with cowpea improved land productivity by 23–36% compared to monocultures, with LER values exceeding 1.30, confirming land-saving advantages.

On the other hand, the aggressivity values show that sorghum was the dominant crop across all arrangements, indicated by positive Aab and negative Aba values. The highest aggressivity of sorghum (+1.3 at BUK) was observed in the 1S:1R configuration, suggesting stronger competitive ability over roselle in that setup. These results align with the findings of Feng et al. (2022), who reported that dominant crop species in optimized row arrangements (2:4 maize–soybean) expressed higher nutrient aggressivity and contributed more to total yield. In both studies, the dominant crop influenced the overall productivity and resource capture. Additionally, Gebremichael et al. (2020) found that sorghum intercropped with legumes consistently showed higher aggressivity and LER values, supporting its adaptability and competitive strength in intercrop systems.

Table 6: Land Equivalent Ratio, System Productivity Index, Aggressivity of Sorghum/Roselle intercropped as influenced by Row Arrangement and Weeding Frequency at BUK and Dutsin-Ma during 2023 wet season.

	BUK				DUTSIN-MA			
Treatment	LER	SPI	Aab	Aba	LER	SPI	Aab	Aba
Row arrangement (RA)								
1S:1R	1.81	8.03	+1.3	-1.3	1.62	8.11	+1.02	-1.02
2S: 1R	1.06	6.22	+0.9	-0.9	1.22	7.01	+0.47	-0.47
1S: 2R	1.43	7.00	+0.8	-0.8	1.13	6.32	+0.82	-0.82
2S :2R	1.21	3.51	+0.7	-0.7	1.40	5.10	+0.44	-0.44

1S:1R = 1 row of Sorghum to 1 row of Roselle, 2S:1R = 2 Rows of Sorghum to 1 row of Roselle, 1S:2R = 1row of sorghum to 2 rows of Roselle, 2S:2R = 2 rows of sorghum to 2 rows of Roselle.
LER: Land Equivalent Ratio
SPI: System Productivity Index
Aab: Aggressivity of Sorghum
Aba: Aggressivity of Roselle

CONCLUSION

The study concludes that the 1S:1R sorghum–roselle intercropping arrangement, combined with timely weeding at 3, 6, and 9 weeks after sowing (WAS), significantly enhances crop growth, yield, and weed suppression, while also improving land-use efficiency and overall system productivity. Although row arrangement and weeding frequency influenced performance independently, their combined application produced consistently positive results across both study locations.

To promote sustainable food production and efficient land use in the Sudan Savanna agroecology, it is recommended that farmers adopt the 1S:1R intercropping system along with a three-stage weeding schedule (3, 6, and 9 WAS). These practices should be incorporated into climate-smart agricultural extension programs and supported through relevant policy initiatives. Further research is encouraged to evaluate the long-term economic benefits and soil health impacts of this intercropping model across different seasons and agro-ecological zones.

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