



Effects of Planting Patterns and NPK Fertilizer Rates on the Growth, Yield and Economic Performance of Sorghum (*Sorghum bicolor* L.) Varieties in the Sudan Savanna of Nigeria

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KEYWORDS

Sorghum Varieties,
Plant Density,
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Grain Yield,
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ABSTRACT

Sorghum (*Sorghum bicolor* L.) is a major cereal crop supporting food security and livelihoods in the Sudan Savanna of Nigeria. However, yields remain low due to inappropriate agronomic practices, declining soil fertility, and limited adoption of improved varieties. Field experiments were conducted during the 2023 rainy season at Dutsin-Ma (Katsina State) and Kazaure (Jigawa State), Nigeria, to evaluate the effects of planting pattern and NPK fertilizer rates on the growth, yield, and economic performance of sorghum varieties. Treatments consisted of three sorghum varieties (SAMSORG KSV 400, SAMSORG CSR 01, and a local KAURA variety), two planting patterns (single-row and double-row planting on ridges), and four NPK fertilizer rates (0, N30:P30:K30, N60:P30:K30, and N90:P30:K30) arranged in a factorial combination using a randomized complete block design with three replications. Growth parameters, yield components, grain yield, and economic returns were assessed. Results showed significant ($p \leq 0.05$) effects of variety, planting pattern, and NPK rate on most measured parameters. SAMSORG KSV 400 produced the highest grain yield across locations, while double-row planting significantly outperformed single-row planting. Grain yield increased progressively with increasing NPK rates, with N90:P30:K30 producing the highest yield and gross margin. Significant interaction effects among variety, planting pattern, and fertilizer rate indicated the importance of integrated agronomic management. The combination of SAMSORG KSV 400, double-row planting, and N90:P30:K30 fertilizer emerged as the most productive and economically viable option for sorghum production in the Sudan Savanna. Adoption of these practices could substantially enhance sorghum productivity and farmer income in northern Nigeria. It is therefore recommended that, SAMSORG KSV 400 variety, Double-row planting pattern on ridge with application of N90: P:30 K30 fertilizer, should be used in Sudan Savanna region due its higher productivity.

CITATION

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INTRODUCTION

Sorghum (*Sorghum bicolor* L.) is one of the most important cereal crops globally, ranking fifth after maize, rice, wheat, and barley. It is particularly important in semi-arid and arid regions due to its tolerance to drought, high temperature, and low soil fertility (Borrell et al., 2014). In Nigeria, sorghum is a staple food crop cultivated predominantly in the Sudan and Sahel Savanna agro-ecological zones, where it contributes significantly to household food security, livestock feed, and agro-industrial raw materials (Hakeem et al., 2020).

Despite its importance, sorghum productivity in Nigeria remains low compared with its potential yield. Average yields of smallholder farmers rarely exceed 1.5–2.0 t ha⁻¹, far below the achievable yields of improved cultivars under optimal management (Mundia et al., 2019). Major constraints to sorghum production include low soil fertility, poor agronomic practices, inappropriate plant population, and limited use of improved varieties and fertilizers (Bationo et al., 2018).

Planting pattern is a critical agronomic factor that determines plant population density, light interception, root distribution, and nutrient uptake. Suboptimal planting patterns can lead to excessive competition among plants or inefficient use of available land and resources (Ingle et al., 2023). In cereal crops, optimized row configuration has been shown to enhance canopy architecture, radiation-use efficiency, and yield (Kumar et al., 2018). However, farmers in the Sudan Savanna often rely on traditional planting methods that may not maximize yield potential. Nutrient management, particularly nitrogen (N), phosphorus (P), and potassium (K), is another major determinant of sorghum productivity. Soils of the Sudan

Savanna are typically low in organic matter and total nitrogen due to continuous cultivation, erosion, and limited residue return (Bationo et al., 2018). Although fertilizer recommendations exist, they are often generalized and do not account for varietal differences or interactions with planting pattern. Balanced fertilization tailored to crop demand and soil conditions is therefore essential for sustainable sorghum production.

Several studies have independently examined the effects of planting density or fertilizer application on sorghum yield. However, information on the combined effects of sorghum variety, planting pattern, and NPK fertilizer rate under Sudan Savanna conditions remains limited. Understanding these interactions is crucial for developing location-specific and economically viable recommendations for farmers.

Therefore, this study aimed to (i) evaluate the effects of planting pattern and NPK fertilizer rates on the growth and yield of different sorghum varieties, (ii) assess the interaction effects among variety, planting pattern, and fertilizer rate, and (iii) determine the economic profitability of different treatment combinations under the Sudan Savanna conditions of Nigeria.

MATERIALS AND METHODS

Description of the Experimental Sites

Field experiments were conducted during the 2023 rainy season at two locations: the Teaching and Research Farm of the Federal University Dutsin-Ma, Katsina State, and Sabuwar Jawo village in Kazaure Local Government Area of Jigawa State, Nigeria. Both locations lie within the Sudan Savanna agro-ecological zone, characterized by a uni-modal rainfall pattern, with annual rainfall ranging from 600 to 900 mm and mean daily temperatures of 25–35 °C.

Table 1: Description of Sorghum Varieties

S/No	Variety	Outstanding Characteristics	Agro-ecological Adaptation	Maturity
1	Samsorg KSV 400	Dwarf small seeds Compact, cream color Tolerant to <i>striga</i> Resistant to major leaf disease	Sudan and Sahel Savannah	Early maturing (75 85 days)
2	Samsorg CSR 01	Semi-dwarf Head is semi-compact and ecliptically shaped	Sudan and Sahel Savannah	90-100 days
3	Local KAURA	Tall stalk Long panicle Seeds are yellow and medium size	Sudan and Sahel savannah	120-140 days

Handbook on Improved Agronomic Practices of Sorghum Production in Northern Nigeria. (Salisu, 2023)

Soil Sampling and Analysis

Composite soil samples were collected from the 0–30 cm depth before planting at both locations. Samples were air-

dried, sieved, and analyzed for physical and chemical properties using standard laboratory procedures. Soil texture was determined by the hydrometer method, soil pH

was measured in water (1:2.5 soil–water ratio), organic carbon by the Walkley–Black method, total nitrogen by the Kjeldahl method, available phosphorus by the Bray-1 method, and exchangeable bases by ammonium acetate extraction.

Experimental Design and Treatments

The experiment consisted of a 3 × 2 × 4 factorial combination of treatments arranged in a randomized complete block design with three replications. The factors included three sorghum varieties (SAMSORG KSV 400, SAMSORG CSR 01, and local KAURA), two planting patterns (single-row and double-row planting on ridges), and four NPK fertilizer rates (0, N30:P30:K30, N60:P30:K30, and N90:P30:K30).

Crop Establishment and Management

Land preparation involved ploughing, harrowing, and ridging at 75 cm spacing. Sorghum seeds were sown manually and thinned to two plants per stand at two weeks after sowing. Fertilizer was applied in split doses according to treatment specifications, with nitrogen applied in two splits while phosphorus and potassium were applied at planting. Weeds were controlled manually, and other cultural practices were uniformly applied across treatments.

Data Collection

Growth parameters, including plant height, number of leaves, stem girth, tiller number, and leaf area index, were recorded at 4, 6, 8, and 10 weeks after sowing. At harvest,

yield components such as panicle length, panicle weight, 1000-grain weight, total dry matter, harvest index, and grain yield were determined. Grain yield was adjusted to standard moisture content and expressed in kg ha⁻¹.

Economic Analysis

Economic analysis was conducted using partial budget analysis following CIMMYT (1988) procedures. Gross revenue, total variable cost, gross margin, and return per naira invested were calculated to assess the profitability of each treatment combination.

Statistical Analysis

Data were subjected to analysis of variance (ANOVA) using standard statistical procedures. Treatment means were separated using Duncan’s Multiple Range Test at the 5% probability level. All statistical analyses were performed separately for each location and combined where appropriate.

RESULTS AND DISCUSSION

Soil Physical and Chemical Properties

Soils at both locations were sandy loam to loamy sand in texture, with slightly acidic to neutral pH. Organic carbon and total nitrogen contents were low, while available phosphorus was moderate as presented in table 2. These characteristics are typical of Sudan Savanna soils and indicate a need for external nutrient inputs to sustain crop productivity.

Table 2: Physical and Chemical Properties of Soils at the Experimental Sites during the 2023Rainy Seasons

Soil Composition	Depth of Soil (0 – 30cm)	
	Dutsin-Ma	Kazaure
Particle size distribution (g kg⁻¹)		
Sand	780	620
Silt	130	280
Clay	90	100
Texture Class	Sandy-Loam	Loam-Sand
Chemical Composition		
pH in H ₂ O (1:2.5)	7.44	.573
pH in 0.01M CaCl ₂ (1:2.5)	6.56	6.49
Organic Carbon (g kg ⁻¹)	12.51	1.91
Total Nitrogen (g kg ⁻¹)	1.62	1.74
Available Phosphorus (mg kg ⁻¹)	15.43	16.00
Exchangeable cations (cmol kg⁻¹)		
Calcium (Ca ²⁺)	2.97	3.11
Magnesium (Mg ²⁺)	0.53	0.38
Potassium (K ⁺)	0.20	0.23
Sodium (Na ⁺)	0.14	0.16
Aluminum and Hydrogen (Al ³⁺⁺ H ⁺)	0.2	0.3
Effective Cation Exchange Capacity (C.E.C)	4.04	4.02

(Salisu, 2023)

All the parameters were analyzed at the Department of Agronomy, Ahmadu Bello University Zaria

Effects of Variety, Planting Pattern, and NPK Fertilizer on Growth Parameters

Sorghum varieties differed significantly ($p \leq 0.05$) in growth parameters across both locations table 3 to 8. The local KAURA variety produced the tallest plants, while

SAMSORG KSV 400 exhibited moderate height but superior canopy development. Double-row planting slightly reduced plant height but improved leaf area index compared with single-row planting.

Table 3: Effect of Sorghum Varieties, Planting Pattern and Rate of NPK Fertilizer Application on Plant Height at Dutsin-Ma and Kazaure during 2023 Rainy Season

Treatment	Plant Height (cm)							
	Dutsin-Ma				Kazaure			
	4WAS	6WAS	8WAS	10WAS	4WAS	6WAS	8WAS	10WAS
Varieties (V)								
Samsorg KSV 400	12.13 ^c	36.52 ^c	67.83 ^c	107.51 ^c	12.39 ^c	24.42 ^c	76.98 ^c	116.80 ^c
Samsorg CSR 01	13.19 ^b	42.45 ^b	88.82 ^b	126.68 ^b	12.86 ^b	32.62 ^b	84.06 ^b	129.01 ^b
Local Kaura	15.99 ^a	55.11 ^a	103.72 ^a	142.49 ^a	15.31 ^a	47.50 ^a	109.53 ^a	142.85 ^a
SE±	0.018	0.048	0.061	0.067	0.018	0.07	0.111	0.115
Planting Pattern (P)								
Single row	14.06 ^a	45.61 ^a	88.82 ^a	127.89 ^a	14.36 ^a	37.07 ^a	95.38 ^a	135.12 ^a
Double row	13.48 ^b	43.77 ^b	84.75 ^b	123.23 ^b	12.68 ^b	32.62 ^b	85.00 ^b	123.98 ^b
SE±	0.012	0.032	0.041	0.045	0.012	0.046	0.074	0.077
N.P.K rate (F)								
0	9.46 ^d	30.33 ^d	50.99 ^d	81.47 ^d	9.87 ^d	27.28 ^d	65.24 ^d	93.41 ^d
N ₃₀ P ₃₀ K ₃₀	12.04 ^c	37.78 ^c	78.45 ^c	121.12 ^c	11.65 ^c	33.85 ^c	86.59 ^c	125.19 ^c
N ₆₀ P ₃₀ K ₃₀	15.33 ^b	49.03 ^b	96.17 ^b	136.11 ^b	14.97 ^b	36.31 ^b	96.87 ^b	137.82 ^b
N ₉₀ P ₃₀ K ₃₀	18.25 ^a	61.62 ^a	121.53 ^a	163.53 ^a	17.59 ^a	41.94 ^a	112.06 ^a	161.79 ^a
SE±	0.024	0.064	0.082	0.089	0.025	0.093	0.148	0.153
Interaction								
V*P	NS	NS	NS	NS	*	**	NS	NS
V*F	**	**	**	**	**	**	**	**
P*F	NS	**	NS	**	**	NS	**	NS
V*P*F	NS	NS	NS	NS	NS	NS	NS	NS

(Salisu, 2023)

Means followed by the same letters within column in each treatment group are not significant different at 5% probability level according to Duncan Multiple Range Test (DMRT)

WAS= Week after sowing; NS= Not Significant at 5% level of probability

* = Significant at 5% level of probability

** = Significant at 1% level of probability

SE = Standard error

Table 4: Interaction between Sorghum Varieties and Planting Pattern on Plant Height of Sorghum during 2023 Rainy Season at Kazaure

Treatment	Planting Pattern	
	Single row	Double row
	4WAS	
Varieties		
Samsorg KSV 400	13.05 ^d	11.73 ^f
Samsorg CSR 01	13.64 ^c	12.08 ^e
Local Kaura	16.39 ^a	14.23 ^b
SE±		0.128
		6WAS
Samsorg KSV 400	25.79 ^e	23.04 ^f
Samsorg CSR 01	34.42 ^c	30.82 ^d
Local Kaura	51.00 ^a	44.00 ^b
SE±		0.482

(Salisu, 2023)

Means followed by the same letters are not significant different at 5% probability level according to Duncan Multiple Range Test (DMRT)

Table 5: Interaction between Sorghum Varieties and N.P.K Fertilizer Rate on Plant Height of Sorghum during 2023 Rainy Season at Dutsin-Ma

Treatment	N.P.K Fertilizer Rate			
	Control	N30 P30 K30	N60 P30 K30	N90 P30 K30
4WAS				
Varieties				
Samsorg KSV 400	8.88 ^l	10.32 ⁱ	13.58 ^g	15.75 ^d
Samsorg CSR 01	9.52 ^k	11.33 ^h	14.70 ^e	17.22 ^c
Local Kaura	9.98 ^j	14.47 ^f	17.72 ^b	21.78 ^a
SE±			0.173	
6WAS				
Samsorg KSV 400	25.02 ^k	28.52 ^j	39.15 ^g	53.38 ^d
Samsorg CSR 01	29.15 ⁱ	36.88 ^h	47.07 ^f	56.68 ^c
Local Kaura	36.82 ^h	47.95 ^e	60.87 ^b	74.80 ^a
SE±			0.470	
8WAS				
Samsorg KSV 400	42.38 ^l	53.60 ^j	69.28 ^h	106.03 ^d
Samsorg CSR 01	52.20 ^k	84.70 ^g	99.92 ^e	118.45 ^c
Local Kaura	58.38 ⁱ	97.05 ^f	119.32 ^b	140.12 ^a
SE±	0.602			
10WAS				
Samsorg KSV 400	68.97 ^l	99.25 ⁱ	112.52 ^h	149.30 ^d
Samsorg CSR 01	80.53 ^k	122.53 ^g	143.10 ^e	160.53 ^b
Local Kaura	94.90 ^j	141.58 ^f	152.72 ^c	180.77 ^a
SE±			0.658	

(Salisu, 2023)

Means followed by the same letters are not significant different at 5% probability level according to Duncan Multiple Range Test (DMRT)

Table 6: Interaction between Sorghum Varieties and N.P.K Fertilizer Rate on Plant Height of Sorghum during 2023 Rainy Season at Kazaure

Treatment	N.P.K Fertilizer Rate			
	Control	N30 P30 K30	N60 P30 K30	N90 P30 K30
4WAS				
Varieties				
Samsorg KSV 400	8.37 ^l	11.18 ⁱ	13.68 ^f	16.32 ^c
Samsorg CSR 01	9.07 ^k	10.42 ^j	14.07 ^e	16.88 ^b
Local Kaura	12.17 ^h	13.35 ^g	16.15 ^d	19.58 ^a
SE±			0.181	
6WAS				
Samsorg KSV 400	21.67 ^l	25.42 ^j	24.45 ^k	26.13 ⁱ
Samsorg CSR 01	27.17 ^h	34.80 ^e	32.13 ^g	36.37 ^d
Local Kaura	33.00 ^f	41.33 ^c	52.35 ^b	63.32 ^a
SE±			0.681	
8WAS				
Samsorg KSV 400	56.72 ^l	73.50 ^j	78.72 ^h	99.00 ^d
Samsorg CSR 01	63.28 ^k	83.07 ^g	92.43 ^f	97.45 ^e
Local Kaura	75.72 ⁱ	103.22 ^c	119.45 ^b	139.73 ^a
SE±			1.087	
10WAS				
Samsorg KSV 400	83.62 ^j	107.67 ^g	126.62 ^f	149.30 ^c
Samsorg CSR 01	92.02 ⁱ	127.07 ^f	136.85 ^e	160.00 ^b
Local Kaura	104.60 ^h	140.83 ^d	150.00 ^c	175.97 ^a
SE±			1.127	

(Salisu, 2023)

Means followed by the same letters are not significant different at 5% probability level according to Duncan Multiple Range Test (DMRT)

Table 7: Interaction between Planting Pattern and N.P.K Fertilizer Rate on Plant Height of Sorghum during 2023 Rainy Season at Dutsin-Ma

Treatment	N.P.K Fertilizer Rate			
	Control	N30 P30 K30	N60 P30 K30	N90 P30 K30
6WAS				
Planting pattern				
Single row	30.90 ^g	38.10 ^e	49.82 ^c	63.61 ^a
Double row	29.76 ^h	37.47 ^f	48.23 ^d	59.63 ^b
SE±			0.384	
10WAS				
Single row	82.44 ^g	123.33 ^e	139.86 ^c	165.92 ^a
Double row	80.49 ^h	118.91 ^f	132.37 ^d	161.14 ^b
SE±			0.537	

(Salisu, 2023)

Means followed by the same letters are not significant different at 5% probability level according to Duncan Multiple Range Test (DMRT)

Table 8: Interaction between Planting Pattern and N.P.K Fertilizer Rate on Plant Height of Sorghum during 2023 Rainy Season at Kazaure

Treatment	N.P.K Fertilizer Rate			
	Control	N30 P30 K30	N60 P30 K30	N90 P30 K30
4WAS				
Planting pattern				
Single row	10.32 ^g	12.12 ^e	16.53 ^c	18.47 ^a
Double row	9.41 ^h	11.18 ^f	13.40 ^d	16.72 ^b
SE±			0.148	
8WAS				
Single row	66.87 ^f	91.23 ^c	105.09 ^b	118.33 ^a
Double row	63.62 ^g	82.96 ^e	88.64 ^d	105.79 ^b
SE±			0.888	

(Salisu, 2023)

Means followed by the same letters are not significant different at 5% probability level according to Duncan Multiple Range Test (DMRT)

Increasing NPK fertilizer rates significantly enhanced plant height, number of leaves, and stem girth.

The interaction of varieties and NPK fertilizer rate on Number of leaves per plant of sorghum was significant ($p < 0.05$) throughout the sampling stages at both locations, these are presented in Tables 9 -15, where local KAURA out performed all other varieties, while adopting single planting pattern gave higher number of leaves per plant than double planting at both locations (Tables 12 - 13).

The interaction of planting pattern and NPK fertilizer rate on Number of leaves per plant of sorghum was significant

($p < 0.05$) only at 4 and 8 WAS at Dutsin-Ma and at 4, 8 and 10 WAS only at Kazaure, these are presented in Tables 14 and 15, where adopting single planting pattern produced higher number of leaves than double planting pattern. However, any increase in NPK fertilizer application induced significant ($p < 0.05$) increased number of leaves where application of N90 P30 K30 produced higher number of leaves while control treatment gave least number of leaves per plant (Tables 14 - 15).

Table 9: Effect of Sorghum Varieties, Planting Pattern and Rate of NPK Fertilizer Application on Number of Leaves at Dutsin-Ma and Kazaure during 2023 Rainy Season

Treatment	Number of Leaves Per Plant							
	Dutsin-Ma				Kazaure			
	4WAS	6WAS	8WAS	10WAS	4WAS	6WAS	8WAS	10WAS
Varieties (V)								
Samsorg KSV 400	3.85 ^c	5.63 ^c	7.00 ^c	8.71 ^c	3.83 ^b	5.00 ^c	6.63 ^c	8.08 ^c
Samsorg CSR 01	3.88 ^b	6.33 ^b	8.00 ^b	9.50 ^b	3.92 ^b	5.75 ^b	6.96 ^b	8.63 ^b
Local Kaura	4.25 ^a	7.25 ^a	8.92 ^a	10.54 ^a	4.208 ^a	6.17 ^a	8.13 ^a	9.38 ^a
SE±	0.005	0.016	0.005	0.009	0.009	0.005	0.007	0.005
Planting Pattern (P)								
Single row	3.97 ^a	6.44	8.03 ^a	9.64 ^a	4.11 ^a	5.67	7.44 ^a	8.92 ^a
Double row	3.83 ^b	6.36	7.92 ^b	9.53 ^b	3.86 ^b	5.61	7.03 ^b	8.47 ^b
SE±	0.003	0.011	0.003	0.006	0.006	0.003	0.005	0.003
N.P.K rate (F)								
0	3.00 ^d	5.28 ^d	6.17 ^d	7.39 ^d	3.11 ^d	5.22 ^c	6.33 ^d	7.44 ^d
N ₃₀ P ₃₀ K ₃₀	3.33 ^c	6.00 ^c	7.06 ^c	9.89 ^c	3.33 ^c	5.67 ^b	6.89 ^c	8.50 ^c
N ₆₀ P ₃₀ K ₃₀	4.50 ^b	7.00 ^b	8.67 ^b	10.06 ^b	4.50 ^b	5.67 ^b	7.56 ^b	9.00 ^b
N ₉₀ P ₃₀ K ₃₀	4.78 ^a	7.33 ^a	10.00 ^a	11.00 ^a	5.00 ^a	6.00 ^a	8.17 ^a	9.83 ^a
SE±	0.007	0.021	0.007	0.011	0.012	0.007	0.009	0.007
Interaction								
V*P	NS	NS	**	NS	NS	NS	**	**
V*F	**	*	**	**	**	**	**	**
P*F	**	NS	**	NS	**	NS	**	**
V*P*F	NS	NS	NS	NS	NS	NS	NS	NS

Source: Field Survey Data. (Salisu, 2023)

WAS= Week after sowing; NS= Not Significant at 5% level of probability

* = Significant at 5% level of probability; ** = Significant at 1% level of probability; SE = Standard error

Table 10: Interaction between Sorghum Varieties and Planting Pattern on Number of Leaves of Sorghum at 8 WAS during 2023 Rainy Season at Dutsin-Ma

Treatment	Planting Pattern	
	Single row	Double row
Varieties		
Samsorg KSV 400	7.00 ^d	7.00 ^d
Samsorg CSR 01	8.00 ^c	8.00 ^c
Local Kaura	9.08 ^a	8.75 ^b
SE±	0.034	

Means followed by the same letters are not significant different at 5% probability level according to Duncan Multiple Range Test (DMRT) (Salisu, 2023)

Table 11: Interaction between Sorghum Varieties and Planting Pattern on Number of Leaves of Sorghum during 2023 Rainy Season at Kazaure

Treatment	Planting Pattern	
	Single row	Double row
	8WAS	
Varieties		
Samsorg KSV 400	7.00 ^d	6.25 ^f
Samsorg CSR 01	7.08 ^c	6.83 ^e
Local Kaura	8.25 ^a	8.00 ^b
SE±	0.049	
	10WAS	
Samsorg KSV 400	8.25 ^d	7.92 ^e
Samsorg CSR 01	9.00 ^c	8.25 ^d
Local Kaura	9.50 ^a	9.25 ^b
SE±	0.034	

Means followed by the same letters are not significant different at 5% probability level according to Duncan Multiple Range Test (DMRT) (Salisu, 2023)

Table 12: Interaction between Sorghum Varieties and N.P.K Fertilizer Rate on Number of Leaves of Sorghum at 4WAS during 2023 Rainy Season at Dutsin-Ma

Treatment	N.P.K Fertilizer Rate			
	Control	N30 P30 K30	N60 P30 K30	N90 P30 K30
Varieties			4WAS	
Samsorg KSV 400	3.00 ^e	3.00 ^e	4.00 ^d	4.33 ^c
Samsorg CSR 01	3.00 ^e	3.00 ^e	4.50 ^b	5.00 ^a
Local Kaura	3.00 ^e	4.00 ^d	5.00 ^a	5.00 ^a
SE±			0.048	
			6WAS	
Samsorg KSV 400	4.50 ^f	5.00 ^e	6.00 ^c	7.00 ^b
Samsorg CSR 01	5.33 ^d	6.00 ^c	7.00 ^b	7.00 ^b
Local Kaura	6.00 ^c	7.00 ^b	8.00 ^a	8.00 ^a
SE±			0.157	
			8WAS	
Samsorg KSV 400	6.00 ^g	6.00 ^g	7.00 ^e	9.00 ^c
Samsorg CSR 01	6.00 ^g	7.00 ^e	9.00 ^c	10.00 ^b
Local Kaura	6.50 ^f	8.17 ^d	10.00 ^b	11.00 ^a
SE±			0.048	
			10WAS	
Samsorg KSV 400	7.00 ^d	8.67 ^c	9.17 ^c	10.00 ^{bc}
Samsorg CSR 01	7.00 ^d	10.00 ^{bc}	10.00 ^{bc}	11.00 ^{ab}
Local Kaura	8.47 ^{cd}	11.00 ^{ab}	11.00 ^{ab}	12.00 ^a
SE±			0.083	

(Salisu, 2023)

Means followed by the same letters are not significant different at 5% probability level according to Duncan Multiple Range Test (DMRT)

Table 13: Interaction between Sorghum Varieties and N.P.K Fertilizer Rate on Number of Leaves of Sorghum during 2023 Rainy Season at Kazaure

Treatment	N.P.K Fertilizer Rate			
	Control	N30 P30 K30	N60 P30 K30	N90 P30 K30
Varieties			4WAS	
Samsorg KSV 400	3.00 ^h	3.00 ^h	4.33 ^e	5.00 ^a
Samsorg CSR 01	3.00 ^h	3.00 ^h	4.66 ^b	5.00 ^a
Local Kaura	3.33 ^g	4.00 ^f	4.50 ^c	5.00 ^a
SE±			0.085	
			6WAS	
Samsorg KSV 400	5.00 ^d	5.00 ^d	5.00 ^d	5.00 ^d
Samsorg CSR 01	5.00 ^d	6.00 ^b	6.00 ^b	5.00 ^d
Local Kaura	5.67 ^c	6.00 ^b	6.00 ^b	7.00 ^a
SE±			0.048	
			8WAS	
Samsorg KSV 400	6.00 ^h	6.50 ^g	6.50 ^g	7.50 ^c
Samsorg CSR 01	6.00 ^h	6.67 ^f	7.17 ^d	8.00 ^b
Local Kaura	7.00 ^e	7.50 ^c	9.00 ^a	9.00 ^a
SE±			0.069	
			10WAS	
Samsorg KSV 400	6.83 ^g	8.00 ^e	8.50 ^d	9.00 ^c
Samsorg CSR 01	7.50 ^f	8.50 ^d	9.00 ^c	9.50 ^b
Local Kaura	8.00 ^e	9.00 ^c	9.50 ^b	11.00 ^a
SE±			0.048	

(Salisu, 2023)

Means followed by the same letters are not significant different at 5% probability level according to Duncan Multiple Range Test (DMRT)

Table 14: Interaction between Planting Pattern and N.P.K Fertilizer Rate on Number of Leaves of Sorghum during 2023 Rainy Season at Dutsin-Ma

Treatment	N.P.K Fertilizer Rate			
	Control	N30 P30 K30	N60 P30 K30	N90 P30 K30
Planting pattern			4WAS	
Single row	3.00 ^e	3.33 ^d	4.67 ^b	4.89 ^a
Double row	3.00 ^e	3.33 ^d	4.33 ^c	4.67 ^b
SE±			0.039	
			8WAS	
Single row	6.33 ^e	7.11 ^c	8.67 ^b	10.00 ^a
Double row	6.00 ^f	7.00 ^d	8.67 ^b	10.00 ^a
SE±			0.039	

(Salisu, 2023)

Means followed by the same letters are not significant different at 5% probability level according to Duncan Multiple Range Test (DMRT)

Table 15: Interaction between Planting Pattern and N.P.K Fertilizer Rate on Number of Leaves of Sorghum at 4 WAS during 2023 Rainy Season at Kazaure

Treatment	N.P.K Fertilizer Rate			
	Control	N30 P30 K30	N60 P30 K30	N90 P30 K30
Planting pattern			4WAS	
Single row	3.22 ^e	3.33 ^d	4.89 ^b	5.00 ^a
Double row	3.00 ^f	3.33 ^d	4.11 ^c	5.00 ^a
SE±			0.069	
			8WAS	
Single row	6.33 ^f	7.33 ^d	7.78 ^c	8.33 ^a
Double row	6.33 ^f	6.44 ^e	7.33 ^d	8.00 ^b
SE±			0.056	
			10WAS	
Single row	7.67 ^f	8.67 ^d	9.33 ^c	10.00 ^a
Double row	7.22 ^g	8.33 ^e	8.67 ^d	9.67 ^b
SE±			0.039	

(Salisu, 2023)

Means followed by the same letters are not significant different at 5% probability level according to Duncan Multiple Range Test (DMRT)

Effects on Yield Components and Grain Yield

Grain yield and yield components were significantly influenced by variety, planting pattern, and fertilizer rate. SAMSORG KSV 400 consistently produced the highest grain yield across both locations. Double-row planting

significantly increased grain yield compared with single-row planting. Grain yield increased progressively with increasing NPK fertilizer rate, with N90:P30:K30 producing the highest yield (Table 16 and 17).

Table 16: Interaction between Sorghum Varieties, Planting Pattern and N.P.K Fertilizer Rate on Total Dry Matter of Sorghum during 2023 Rainy Season at Dutsin-Ma and Kazaure

Treatment	N.P.K Fertilizer Rate			
	Control	N30 P30 K30	N60 P30 K30	N90 P30 K30
Varieties				
Samsorg KSV 400	3014.0 ^d	3310.5 ^c	3325.1 ^b	3390.5 ^a
Samsorg CSR 01	2549.2 ^e	2192.2 ^h	2273.0 ^g	2414.5 ^f
Local Kaura	1509.9 ^l	1607.9 ^k	1712.6 ^j	1809.9 ⁱ
SE±			0.759	
			Kazaure	
Samsorg KSV 400	3013.0 ^d	3295.7 ^b	3302.0 ^a	3280.2 ^c
Samsorg CSR 01	2095.3 ^h	2166.7 ^g	2259.0 ^f	2393.7 ^e
Local Kaura	1495.1 ^l	1580.5 ^k	1682.2 ^j	1734.3 ⁱ
SE±			4.935	

(Salisu, 2023)

Means followed by the same letters are not significant different at 5% probability level according to Duncan Multiple Range Test (DMRT)

Table 17: Interaction between Sorghum Varieties, Planting Pattern and N.P.K Fertilizer Rate on Total Dry Matter of Sorghum during 2023 Rainy Season at Dutsin-Ma and Kazaure

Treatment	N.P.K Fertilizer rRAate			
	Control	N30 P30 K30	N60 P30 K30	N90 P30 K30
Dutsin-Ma				
Planting pattern				
Single row	2203.6 ^h	2365.3 ^g	2435.7 ^e	2534.5 ^b
Double row	2511.7 ^c	2375.0 ^f	2438.1 ^d	2542.1 ^a
SE±	0.620			
Kazaure				
Planting pattern				
Single row	2193.1 ^h	2342.3 ^f	2403.3 ^d	2443.4 ^b
Double row	2209.2 ^g	2352.9 ^e	2428.2 ^c	2495.3 ^a
SE±	4.030			

(Salisu, 2023)

Means followed by the same letters are not significant different at 5% probability level according to Duncan Multiple Range Test (DMRT)

Interaction Effects

Significant interaction effects were observed among variety, planting pattern, and NPK fertilizer rate for several yield parameters. The yield advantage of improved varieties was more pronounced under double-row planting and higher fertilizer rates.

Economic Performance

Economic analysis showed that the highest gross margin and return per naira invested were obtained from SAMSORG KSV 400 grown under double-row planting with N90:P30:K30 fertilizer. Control treatments and local variety under low fertilizer rates produced the lowest economic returns (Table 18 and 19).

The tables shows the costs and returns analysis on investment of growing sorghum varieties using varied planting pattern and NPK fertilizer rate at Dutsin-Ma and Kazaure the result revealed that, Using Variety Samsorg KSV 400 produced the highest profitability which consistently observed under single row planting couple with 90:30:30 NPK rate at both locations with a gross margin of ₦1,368,920 (Dutsinma) and ₦1,359,200

(Kazaure). Single planting provided better returns than double planting due to significantly lower input cost (TVC), even though double planting increased yield and the gross margin ratio peaked at 6.7, indicating a high return per ₦1 invested.

However, Variety Samsorg CSR 01 consistent performance with both planting patterns, although performed well second only to KSV 400. And the maximum profitability also occurred with single planting on ridge at N90: P30: K30 with gross margin of ₦1,190,720 at Dutsinma and ₦1,188,200 at Kazaure. However, double planting on ridge only became beneficial at higher NPK rates, but at lower rates the cost outweighed the yield benefit, resulting in negative or marginal returns.

Local Kaura (local variety) was the lowest performing variety economically. The yield response to fertilizer was minimal compared to improved varieties and at zero and low NPK rates, the gross margin was very low or negative, especially under double planting. Although best scenario (single planting on ridge + N90: P30: K30) still had lower profits than improved varieties.

Table 18: Economic Analysis on Sorghum Productivity as Affected by Planting Pattern and NPK Fertilizer Application Rate at Dutsin-Ma during 2023 Rainy Season

NPK Rate	Fert.	Planting Pattern	Varieties	Total Yield	Average price	Gross Revenue	Total Variable Cost	GR-TVC	Gross Margin
0		Single planting	Samsorg KSV 400	1,124	360	404640	205,000	199,640	1
N30 P30 K30		"	Samsorg KSV 400	2,536	360	912960	205,000	707,960	3.5
N60 P30 K30		"	Samsorg KSV 400	3,485	360	1254600	205,000	1,049,600	5.1
N90 P30 K30		"	Samsorg KSV 400	4,372	360	1573920	205,000	1,368,920	6.7
0		Double planting	Samsorg KSV 400	1,130	360	406800	410,000	-3,200	0
N30 P30 K30		"	Samsorg KSV 400	2,755	360	991800	410,000	581,800	1.4
N60 P30 K30		"	Samsorg KSV 400	3,798	360	1367280	410,000	957,280	2.3
N90 P30 K30		"	Samsorg KSV 400	4,532	360	1631520	410,000	1,221,520	3
0		Single planting	Samsorg CSR 01	1,015	360	365400	205,000	160,400	0.8
N30 P30 K30		"	Samsorg CSR 01	2,265	360	815400	205,000	610,400	3
N60 P30 K30		"	Samsorg CSR 01	3,118	360	1122480	205,000	917,480	4.5

NPK Rate	Fert.	Planting Pattern	Varieties	Total Yield	Average price	Gross Revenue	Total Variable Cost	GR-TVC	Gross Margin
N90 P30 K30 0		Double planting	Samsorg CSR 01	3,877	360	1395720	205,000	1,190,720	5.8
N30 P30 K30			Samsorg CSR 01	1,054	360	379440	410,000	-30,560	-0.1
N60 P30 K30			Samsorg CSR 01	2,388	360	859680	410,000	449,680	1.1
N90 P30 K30 0			Samsorg CSR 01	3,318	360	1194480	410,000	784,480	1.9
N90 P30 K30 0		Single planting	Samsorg CSR 01	4,145	360	1492200	410,000	1,082,200	2.6
N30 P30 K30			Local Kaura	724	360	260640	201,200	59,440	0.3
N60 P30 K30			Local Kaura	1,211	360	435960	201,200	234,760	1.2
N90 P30 K30 0			Local Kaura	1,883	360	677880	201,200	476,680	2.4
N30 P30 K30		Double planting	Local Kaura	2014	360	725040	201,200	523,840	2.6
N60 P30 K30			Local Kaura	771	360	277560	402,400	-124,840	-0.3
N90 P30 K30 0			Local Kaura	1257	360	452520	402,400	50,120	0.1
N30 P30 K30			Local Kaura	2016	360	725760	402,400	323,360	0.8
N60 P30 K30			Local Kaura	2052	360	738720	402,400	336,320	0.8

(Salisu, 2023)

Total Variable Cost (TVC) Gross Margin (GM) in ₦ per hectare = GR-TVC, Gross margin per ₦ invested = GM/TVC, GR = Gross revenue (₦) and TVC = Total variable cost (₦)

Table 19: Economic Analysis on Sorghum Productivity as Affected by Planting Pattern and NPK Fertilizer Application Rate at Kazaure during 2023 Rainy Season

NPK Fertilizer Rate	Planting Pattern	Varieties	Total Yield	A p	GR	TVC	GR-TVC	Gross M
0	Single planting	Samsorg KSV 400	1121	360	403560	205,000	198,560	1
N30 P30 K30	"	Samsorg KSV 400	2532	360	911520	205,000	706,520	3.4
N60 P30 K30	"	Samsorg KSV 400	3,453	360	1243080	205,000	1,038,080	5.1
N90 P30 K30 0	"	Samsorg KSV 400	4,345	360	1564200	205,000	1,359,200	6.6
0	Double planting	Samsorg KSV 400	1203	360	433080	410,000	23,080	0.1
N30 P30 K30	"	Samsorg KSV 400	2,756	360	992160	410,000	582,160	1.4
N60 P30 K30	"	Samsorg KSV 400	3,781	360	1361160	410,000	951,160	2.3
N90 P30 K30 0	"	Samsorg KSV 400	4,514	360	1625040	410,000	1,215,040	3
0	Single planting	Samsorg CSR 01	1008	360	362880	205,000	157,880	0.8
N30 P30 K30	"	Samsorg CSR 01	2102	360	756720	205,000	551,720	2.7
N60 P30 K30	"	Samsorg CSR 01	3104	360	1117440	205,000	912,440	4.5
N90 P30 K30 0	"	Samsorg CSR 01	3870	360	1393200	205,000	1,188,200	5.8
0	Double planting	Samsorg CSR 01	1088	360	391680	410,000	-18,320	0
N30 P30 K30	"	Samsorg CSR 01	2303	360	829080	410,000	419,080	1
N60 P30 K30	"	Samsorg CSR 01	3304	360	1189440	410,000	779,440	1.9
N90 P30 K30 0	"	Samsorg CSR 01	4123	360	1484280	410,000	1,074,280	2.6
0	Single planting	Local Kaura	702	360	252720	201,200	51,520	0.3
N30 P30 K30	"	Local Kaura	1111	360	399960	201,200	198,760	1
N60 P30 K30	"	Local Kaura	1872	360	673920	201,200	472,720	2.3
N90 P30 K30 0	"	Local Kaura	2008	360	722880	201,200	521,680	2.6
0	Double planting	Local Kaura	796	360	286560	402,400	-115,840	-0.3
N30 P30 K30	"	Local Kaura	1232	360	443520	402,400	41,120	0.1
N60 P30 K30	"	Local Kaura	2002	360	720720	402,400	318,320	0.8
N90 P30 K30 0	"	Local Kaura	2010	360	723600	402,400	321,200	0.8

(Salisu, 2023)

Total Variable Cost (TVC) Gross Margin (GM) in ₦ per hectare = GR-TVC, Gross margin per ₦ invested = GM/TVC, GR = Gross revenue (₦) and TVC = Total variable cost (₦)

Discussion

The results of this study demonstrate that sorghum productivity in the Sudan Savanna of Nigeria is strongly influenced by varietal choice, planting pattern, and NPK fertilizer rate. The superior grain yield of SAMSORG KSV 400 compared with the local KAURA variety confirms the

yield advantage of improved sorghum cultivars, as reported by Borrell et al. (2014) and Murray et al. (2017). Improved varieties are bred for enhanced harvest index and efficient assimilate partitioning, which explains their higher grain yield despi

Effect of Sorghum Varieties on Growth, Yield and Yield Components of Sorghum

Samsorg variety Local Kaura consistently stood out as the tallest, followed by SAMSORG CSR 01, while SAMSORG KSV 400 was the shortest among them and also Local Kaura and SAMSORG CSR 01 consistently yielded more leaves than SAMSORG KSV 400 at both locations.

This aligns with findings of Bello et al. (2018), who noted that local sorghum varieties often show better vegetative growth due to their genetic adaptation to local conditions. These variations could also stem from genetic differences that affect internode elongation and overall vigor (Ali et al., 2022). SAMSORG CSR 01 and Local Kaura produced more tillers than KSV 400, possibly due to their genetic potential for tillering. Stem girth mirrored that of plant height, with SAMSORG CSR 01 boasting the thickest stems, closely followed by Local Kaura. This observation shows that, improved varieties possess a structural strength that helps them resist lodging (Olakojo et al., 2019). Similar results were reported by Showemimo (2007) on improved sorghum varieties which showed reduction in stem girth, panicle length and plant height.

SAMSORG CSR 01 outperformed other varieties in terms of LAI, likely due to its superior photosynthetic ability (Ibrahim et al. 2017). Local Kaura consistently produced the longest and heaviest panicles, followed by SAMSORG CSR 01, while SAMSORG KSV 400 had the smallest panicles. These variations highlight the natural genetic differences in how plants allocate resources and develop their reproductive structures (Olakojo et al., 2019). The number of grains per panicle showed trends that mirrored those of panicle weight. Local Kaura had the highest grain count, indicating its excellent floral fertility and ability to move resources effectively (Bello et al., 2018).

The weight of 1000 grains was significantly influenced by both the variety and the fertilizer rate used. Local Kaura and SAMSORG CSR 01 produced the heaviest grains, while SAMSORG KSV 400 had the lightest. This difference can be linked to genetic variations in grain size and endosperm density (Singh et al., 2019). Grain yield (kg ha^{-1}), which is essentially the sum of all growth and yield factors. It turns out that variety, spacing, and NPK rates had a significant impact at both locations. Where, the local Kaura variety outperformed the improved ones, likely because of its impressive vegetative growth, larger leaf area, and bigger panicles. These traits helped it gather and redistribute nutrients more effectively during the grain-filling stage. Similar findings regarding local sorghum varieties were noted by Bello et al. (2018) and FAO (2020).

There was a significant variation in grain yield across different varieties, planting patterns, and NPK rates. SAMSORG KSV 400 achieved the highest yield at both locations, which aligns with its enhanced genetic potential for grain filling (Abdullahi et al., 2020). The low yield recorded by the local KAURA and SAMSORG CSR 01 could

be attributed to their genetic makeup. This result was in line with findings of Reset and Traore (2016) who reported that sorghum varieties like SAMSORG KSV 400 produced high grain yield. SAMSORG KSV 400 stood out with the highest harvest index, which suggests it does a better job of directing nutrients to the grain compared to other varieties. Both local Kaura and SAMSORG CSR 01 showed lesser HI values compared to SAMSORG KSV 400, this indicated that they are also more efficient at converting biomass into grain (Musa et al., 2021).

Effect of Sorghum Varieties on Planting Pattern

Planting pattern especially double row planting has significant effect on variety and produced high yield component because it has more plant density. The significantly taller plants in single row planting compared to double row planting might be attributed to less competition for light and nutrients among the plant which supports similar findings by (Ajeigbe et al. 2019, and Abdullahi et al., 2020). Single planting also result in a greater number of leaves compared to double planting, likely due to reduced shading and competition, which enhances photosynthetic efficiency (Fakir et al., 2021; Yusuf et al., 2017). The lack of effects on tillering, from variety and spacing might be due to consistent environmental conditions or the dominant influence of nutrient supply. Similar observations were made by Musa et al. (2021), who found that sorghum tillering mainly responds to nitrogen levels rather than the spacing used. However, the denser competition in double planting may have restricted nutrient availability for tiller formation, which is why no significant differences were noted between the planting patterns. Single planting combined with higher NPK rates significantly boosted stem girth, indicating that less competition and better nutrient availability promote the expansion of stem diameter. The positive response to N90 P30 K30 aligns with findings from Okonkwo et al. (2018), who noted that potassium and nitrogen enhance stem strength by increasing lignin deposition and thickening cell walls.

The single-row planting method yielded a higher LAI compared to double-row planting, indicating a more effective canopy expansion and light capture, which aligns with the research by Ibrahim et al. (2017). Single-row planting led to significantly longer panicles compared to double planting. This is likely due to less competition among plants for light, moisture, and nutrients, which allows for more resources to be directed toward the reproductive parts (Ajeigbe et al., 2019). Single-row planting yielded more grains per panicle compared to double-row planting, thanks to better light capture and nutrient access for each plant. This finding aligns with what Yusuf et al. (2017) noted: wider spacing boosts individual plant productivity by minimizing competition among plants. Single-row planting resulted in heavier grains than

double-row planting, due to better allocation of resources per panicle. These findings are consistent with Okonkwo et al. (2018), who discovered that nitrogen and potassium play a crucial role in enhancing kernel development and weight in sorghum. Single-row planting outperformed double-row planting, appreciating better light capture and reduced competition. This aligns with Akinwale et al. (2019), who found that wider spacing in sorghum led to higher yields per plant, even if the total number of plants per hectare dropped slightly.

Planting density had a significant impact on harvest index (HI), when plants were double spaced, HI decreased due to increased competition among the plants and shading. Ibrahim et al. (2017) found similar outcomes, noting that closer planting reduced the photosynthate supply available for each panicle. Furthermore, double planting resulted in a significantly higher harvest index than single planting, this indicates that a denser plant population boosts grain yield more effectively than just increasing vegetative biomass (Hassan et al., 2021).

Moreover, SAMSORG KSV 400 again taking the lead on grain yield production, while Local Kaura trailing behind. The double row planting method yielded more dry matter than single row planting, probably due to better ground coverage and enhanced canopy photosynthesis (Yakubu et al., 2022). The double planting pattern outperformed single planting in terms of yield, likely due to a greater number of plants per area compensating for the lower performance of individual plants. Similar studies conducted by Fan et al. (2019), Ullah et al. (2020) and Wei et al. (2019) showed the optimum advantages of plant population double planting and N combinations on grain yield increased in improved sorghum varieties.

Effect of N.P.K. Fertilizer Rates on Sorghum Varieties

Nitrogen (N) is commonly the most limiting nutrient factor for crop production in the majority of the world's agricultural areas, and therefore, adoption of good N management strategies often results in large economic return to farmers. Consequently, N has become the foremost input in relation to cost and energy requirement in advanced agricultural production systems. Nitrogen is a major input in sorghum production that affects both yield and quality those components which have great contribution in increasing grain yield of sorghum.

Plant height increased steadily with higher fertilizer rates, increasing the fertilizer rates especially to N₉₀ P₃₀ K₃₀ kg ha⁻¹, led to a remarkable boost in height, highlighting the crucial role of nitrogen in promoting vegetative growth and chlorophyll production (Mengel and Kirkby, 2021). This observation is also consistent with Ayuba et al. (2020), who found that nitrogen significantly boosts cell elongation and vegetative growth in sorghum. Furthermore, increasing NPK rates significantly boosted the leaf count, peaked at N₉₀ P₃₀ K₃₀. The rise in leaf count with higher NPK rates

underscores the vital importance of nitrogen and potassium in leaf growth and photosynthesis (Amanullah et al., 2019). This highlights just how crucial a balanced nutrient supply is for healthy foliage growth. Nitrogen, in particular, plays a key role in promoting leaf expansion and chlorophyll production, both of which are vital for effective photosynthesis (Fageria et al., 2010).

SAMAORG CSR 01 and Local Kaura produced more tiller than KSV 400, possibly due to their genetic potential for tillering. The highest number of tillers was achieved with N₉₀ P₃₀ K₃₀, indicating that sufficient nitrogen encourages the development of axillary buds (Singh et al., 2019). The increase in tiller numbers with higher NPK rates (especially N₉₀ P₃₀ K₃₀) indicates that a sufficient nutrient supply is essential for the initiation and growth of tiller buds (Tadesse et al., 2020). This suggests that the availability of nutrients, especially nitrogen, was the main factor driving tiller production.

At Dutsin-Ma, the control plots initially showed a higher LAI during early growth, hinting at a potential nutrient-induced delay in early leaf expansion under fertilized conditions. However, as the growth progressed, the fertilized plots eventually outperformed the control, highlighting the long-term advantages of nutrient supplementation. This observation supports the conclusions of Akinwale et al. (2019), who stressed that a balanced NPK fertilizer regimen boosts canopy development, enhances photosynthetic efficiency, and increases dry matter accumulation in cereals. Increasing the NPK fertilizer rates up to N₉₀ P₃₀ K₃₀ kg ha⁻¹ resulted in a steady increase in both panicle length and weight. This supports the findings of Ayuba et al. (2020), which suggest that a good supply of nutrients especially nitrogen and potassium boosts panicle initiation and grain-filling efficiency. The application of NPK fertilizer significantly boosted the grain number at both sites, reinforcing the idea that having enough nutrients improves pollination efficiency and grain set (Fageria et al., 2010). Applying NPK at N₉₀ P₃₀ K₃₀ led to a notable increase in grain weight compared to lower rates or the control, highlighting how balanced nutrition supports starch accumulation and grain filling (Marschner, 2012).

As grain yield consistently rose with increasing rates, with N₉₀ P₃₀ K₃₀ yielded best results. Nitrogen plays a crucial role in chlorophyll production, while phosphorus aids in energy transfer, both of which boost photosynthesis and grain formation (Havlin et al., 2014). Potassium also helps with the movement of photosynthates and improves water efficiency. On the flip side, the control plots showed the lowest yields, primarily due to a lack of nutrients.

The peak grain yield was recorded at N₉₀ P₃₀ K₃₀ kg ha⁻¹, supporting the findings of Jaliya et al. (2021) that balanced fertilizer rates can significantly boost sorghum productivity by improving nutrient uptake and photosynthetic efficiency.

Furthermore, raising the NPK rate to N90 P30 K30, led to a notable improvement in the harvest index. This is likely because balanced nutrient uptake supports better grain filling and the movement of photosynthates (Singh et al., 2020). Fertilizer application also played a crucial role also in boosting total biomass, with N90 P30 K30 kg ha⁻¹ resulting in the highest dry matter. This highlights the synergistic benefits of balanced macro-nutrients in fostering overall plant growth and the development of structural tissues (Hawkesford et al., 2019).

Interaction between Sorghum Varieties, Planting Pattern and Rates of N.P.K Fertilizer on Growth, Yield and Yield Components of Sorghum

The significant interactions between sorghum variety and planting pattern, as well as NPK fertilizer, suggest that both genetic traits and management practices play a crucial role in determining stem robustness. The significant interaction effect on grain yield indicates that grain yield was influenced by different fertilizer rates. The highest grain yield of 4429 kg ha⁻¹ was obtained from the application of 200 kg of N ha⁻¹. This existence of significant nitrogen fertilizer interaction indicates the need for nutrients to achieve a maximum grain yield.

Results showed that grain yield varied greatly in double row planting pattern and N fertilization combinations for each variety. In this study, the highest grain yield was obtained with SAMSORG KSV 400 followed by SAMSORG CSR 01. While local KAURA has less. These results indicated that the increase in grain yield of these varieties relied on an increase in plant population double planting when the N application rate increased. Similar studies conducted by Fan et al. (2019), Ullah et al. (2020) and Wei et al. (2019) showed the optimum advantages of plant population double planting and N combinations on grain yield increased in improved sorghum varieties.

Economic Analysis

Variety Performance: Across treatments, Samsorg KSV 400 outperformed other varieties, both in terms of yield and economic returns. At the highest NPK rate (90:30:30) and single planting, Samsorg KSV 400 had the highest gross margin (₦1,368,920/ha. and 1,359,200/ha) and return per ₦ invested (6.7 and 6.6) at Dutsin-Ma and Kazaure respectively. Samsorg CSR 01 came second with ₦1,190,720 and 1,188,200 gross margin and (5.8) return per ₦ invested at both locations, while local Kaura had lower figures: (₦523,840 and 521,680) gross margin and (2.6) of return per ₦ invested. This confirms the findings of Ezeaku et al., (2015), which highlighted the superior fertilizer response and adaptability of improved sorghum varieties compared to local landraces.

Fertilizer Application and Yield Response: Increasing the NPK fertilizer rate led to higher total yields and gross revenue for all varieties, Samsorg KSV 400 (Single planting)

increased yield from 1,124 and 1.121 kg/ha (no fertilizer) to 4,372 and 4,345 kg/ha at 90:30:30, resulting in a net return of ₦1,368,920 and 1.359,200 with returns per ₦ invested of 6.7 and 6.6. Similar positive responses were observed in Samsorg CSR 01, which produced ₦1,190,720 and 1,188,200 gross margins and 5.8 return per ₦ invested at 90:30:30 under single planting at both locations. These results reflect the well-established role of balanced NPK application in promoting sorghum biomass and grain formation (Aliyu, 2000; Agbaje et al., 2002). However, diminishing returns were noted under double planting patterns, particularly for local Kaura.

Effect of Planting Pattern on Profitability: The data shows a consistent trend, single planting pattern is more economically viable than double planting across all varieties and fertilizer rates where 0 kg/ha fertilizer, Samsorg KSV 400 under single planting had a gross margins of ₦199,640/198,560 and returns per ₦ invested of 1.0, while under double planting, it incurred a loss of ₦3,200 at Dutsin-Ma and a gross margin of 23,080 at Kazaure. Similarly, Local Kaura under single planting at 90:30:30 Fertilizer gave a gross margin of ₦476,680/472,720 and returns per ₦ invested of 2.4 and 2.3 at both locations respectively, whereas the same treatment under double planting gave a much lower ₦323,360/318,320 and returns per ₦ invested of 0.8 at both Dutsin-Ma and Kazaure respectively. This aligns with findings by Yusuf et al., (2009), who noted that denser plantings (double rows) in cereals often increase input costs without proportional yield gain due to intra-specific competition.

CONCLUSION

This study evaluated the effect of sorghum varieties, planting patterns, and NPK fertilizer rates on the growth, yield and yield component of sorghum (*Sorghum bicolor* L.) during the 2023 rainy season. The experiment was conducted using a factorial arrangement in a Randomized Complete Block Design (RCBD) with three replications. The treatments consisted of three sorghum varieties (Local Kaura, SAMSORG CSR 01, and SAMSORG KSV 400), two planting patterns (single and double rows on ridge), and four NPK fertilizer rates (N0: P0: K0, N30:P30:K30, N60:P30:K30, and N90:P30:K30 kg ha⁻¹).

The physical and chemical analyses of the soils revealed that Dutsin-Ma had acidic loamy sand soil while Kazaure had slightly alkaline sandy loam soil. Both locations had low total nitrogen but moderate phosphorus and organic carbon contents. The results showed that varieties, planting patterns, and N P K fertilizer rates had significant effects on most growth and yield parameters. Local Kaura consistently outperformed the improved varieties in plant height, number of leaves, stem girth, leaf area index, while SAMSORG KSV 400 outperformed other varieties in yield and yield components. Double-row on ridge planting

pattern significantly enhanced growth compared to single-row planting on ridge, likely due to highest plant population. The N90: P30: K30 fertilizer rate gave superior results, indicating the importance of balanced nutrient supply.

Overall, the combination of SAMSORG KSV 400 variety, double-row on ridge planting pattern and N90: P30: K30 fertilizer rate gave the highest grain yield and harvest index at both locations. Kazaure performed slightly better than Dutsin-Ma due to more favorable soil chemical properties. From the findings of this research, it can be concluded that varieties, planting patterns, and NPK fertilizer rates significantly influenced the growth, yield and yield of sorghum across both locations. SAMSORG KSV 400 showed superior performance, double-row on ridge planting pattern enhanced productivity, and N90: P30: K30 fertilizer application produced the best results. Interaction effects confirmed that optimal performance depends on appropriate combinations of genotype and management practices.

RECOMMENDATION

Based on the result of the experiment the following recommendation have drawn:

- i. SAMSORG KSV 400 is recommended due its higher productivity in the study area.
- ii. Double-row planting pattern on ridge significantly produced higher grain yield at both locations. It is therefore recommended.
- iii. The application of N90: P30: K30 fertilizer rate. It is recommended fertilizer rate for improved growth, yield and yield component of sorghum under rain-fed conditions at both study areas.
- iv. Economically, sowing of the SAMSORG KSV 400 variety on a double-row planting pattern with application of N90: P:30 K30 fertilizer produced the best economic returns in both locations.
- v. Soil testing should be encouraged prior to planting to guide site-specific fertilizer management, especially in acidic soils.

This study contributes valuable insights into integrated sorghum management under Sudan savanna conditions by identifying SAMSORG KSV 400 as a high-performing variety, establishing N90P30K30 as the optimal fertilizer rate, and demonstrating the importance of planting pattern in enhancing productivity. These findings provide a basis for policy and extension recommendations for sustainable sorghum production.

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