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Evaluation of Sowing Methods and Herbicide Mixtures for Weed Management and Productivity in Sesame (*Sesamum indicum* L.)

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ABSTRACT

Sesame is an oil seed crop with great economic value. However, the production of this crop has been limited by weed competition, which prompted a field experiment during the 2021 cropping season in two locations: Teaching and Research Farm, Kwara State University, Malete, and National Centre for Agricultural Mechanization (NCAM), Idofian, Ilorin, Kwara, Nigeria. The aim was to determine the treatment combinations of sowing methods and herbicide mixtures for the effective management of weeds and for increasing sesame productivity in the southern Guinea savanna of Nigeria. The experiment consisted of twenty treatments comprising two sowing methods (dibbling and drilling) and ten weed control methods. Results showed that all the weed control methods reduced weed dry matter (67.15–186.20 and 42.00–92.45 g/m^2) than the weedy check (291.55 and 155.55 g/m^2) at Malete and NCAM, respectively. They also reduced the weed density (48.40–68.45 and 34.00–50.00/m^2) compared to the weedy check (103.60 and 73.15 g/m^2) at Malete and NCAM, respectively, from 6 to 12 weeks after planting (WAP). Dibbling (85.15 and 48.81 m^2) proved superior to the drilling method (172.42 and 51.58/m^2) for the management of weeds from 6–12 WAP and for promoting higher crop yield (dibbling: 78.90 and 422.70 kg/ha; drilling: 37.50 and 326.80 kg/ha) in Malete and NCAM, respectively. The treatment combinations with the highest gross margin were hoeing twice at 3 and 6 WAP × dibbling ($ -191.15 and $ 318.57), pendimethalin (P) + diuron (D) at 0.5 + 0.5 kg a.i./ha ($ -199.88 and $ 182.43), 2.0 + 1.5 × dibbling ($ -273.59 and $ 156.65) and butachlor (B) + diuron (D) at 1.5 + 1.0 kg a.i./ha × drilling ($ -269.59 and $ 177.38) at Malete and NCAM, respectively. Therefore, it is recommended that the dibbling sowing method at a spacing of 30 cm × 30 cm and thinned to 3 plants/stand integrated

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with herbicide mixtures of pendimethalin at 0.5 + 0.5 kg a.i./ha is recommended as an alternative to hoe weeding for effective weed control, higher yield of sesame, and economic returns.

Keywords: Agro-chemical, dibbling method, drilling sowing method, economic returns, weed control

INTRODUCTION

Sesame (*Sesamum indicum* L.) is cultivated in almost all tropical and sub-tropical countries of Asia and Africa for its highly nutritious and edible seeds. It is an oil crop grown in 26 states of Nigeria, including areas in the northeast, north-central, middle belt, and Federal Capital Territory (Ibirogba, 2021). Sesame seeds are very nutritious and, therefore, confer health benefits. Sudan is Africa's largest producer of sesame, with an output of 11.2 million tons in 2019. Sudan alone accounts for 45.8% of the total output of the top six African countries. Nigeria is the second largest producer in Africa, as her production output constitutes 18.2% (Muktar, 2021). The crop is a very important cash crop, which Nigeria is exporting. The sesame seeds exported to Japan account for 40% of sesame consumed in Japan, which netted $ 143,650,800 for Nigeria in 2021 (Odunewu, 2022). The average grain yield of sesame per hectare in Africa is still low, between 150-250 kg/ha (Adefeko, 2017), while the global sesame grain yield is around 500 kg/ha (Myint et al., 2020). The low productivity has discouraged growers, reducing the total area under sesame cultivation. Among the factors responsible for low yield in Nigeria are poor agronomic practices by Nigerian farmers, inappropriate sowing methods, and weed control problems (Take-tsaba et al., 2011).

Most peasant smallholder sesame farmers use a broadcast method of sowing for sesame production. However, this method has been reported to be inferior to the drilling method as it lacked the ability to suppress weeds and increase sesame yield compared to the drilling method in the Sudan savanna zone of Nigeria (Imoloame et al., 2007). Furthermore, in the same agroecological zone of Nigeria, the drilling method was reported to promote sesame yield rather than dibbling and broadcasting (Katanga et al., 2017). In contrast to this, Ngala et al. (2013) reported that the dibbling method, with crop spacing of 50 cm x 25 cm, and 4–6 plants per stand (320,000–480,000 plant/ha) was the best combination for optimizing the agronomic performance of sesame. Also, Take-tsaba et al. (2011) reported that dibbling of sesame seeds at a spacing of 30 cm × 30 cm with 3 plants per stand resulted in maximum sesame yield. Aside from the method of sowing, weed competition is another factor that reduces the yield of sesame (Mane et al., 2017). When weed control is not adopted, especially during the initial periods, sesame yield may be reduced by up to 75% (Bhadauria et al., 2012). It is similar to the findings of Ijlal et al. (2011), who reported reduced sesame yield by 35–70% due to uncontrolled weeds. Using a single herbicide for a prolonged period may not provide effective weed control due to the diverse nature of the weed community and the fact that it can result in the development of herbicide-resistant weeds or weed flora shift (Das, 2011). Therefore, to ensure more effective weed control and an eco-friendly environment, several researchers have advocated integrated weed management or herbicide mixtures (Imoloame, 2021; Lawal et al., 2019; Young et al., 2017).

Dibbling and drilling have been identified as more promising methods of sowing than broadcast methods for optimizing sesame yield in the Sudan savanna zone of Nigeria. However, there is a dearth of information comparing the effectiveness of these sowing methods for the management of weeds and for promoting sesame yield in the Southern Guinea savanna of Nigeria. Therefore, any research that seeks to find out the best combination of sowing method and herbicide mixture for effective weed management and increasing sesame yield would constitute an important production package that could be recommended to farmers for boosting sesame production and economic returns in the southern Guinea savanna of Nigeria. The objectives of this study were to determine the appropriate sowing, weed control method, and the best treatment combination that will provide effective weed management and higher productivity of sesame.

MATERIALS AND METHODS

Site

Field trials were established during the wet season of 2021 at the Teaching and Research (T&R) Farm of the Kwara State University, Malete, (8˚23'N, 4˚43'E) and National Centre for Agricultural Mechanization (NCAM), Idofian, Ilorin, Kwara (8^{o}71'N, 4^{o}41'E) both locations are in the southern Guinea savanna zone of Nigeria. The soil in both locations was sandy loam. However, the soil at NCAM was richer than Malete's in terms of total nitrogen, available phosphorus, and organic carbon (Table 1). Furthermore, the soil in Malete has been subjected to more years of cultivation than NCAM.

Treatment and Experimental Design

The experiment was a 2 × 10 factorial in a randomized complete block design (RCBD) with three replications. The main plot was assigned sowing methods (drilling and dibbling), while the sub-plots contained the herbicides mixtures, namely tank mixture of butachlor (B, SunRice, China) + diuron (D, Arrow, China) at 1.0 + 0.5, 1.5 + 1.0, 2.0 + 1.5, 1.0 + 0.5 kg a.i./ha + one supplementary hoe weeding (1 SHW) at 6 WAP; pendimethalin (P, Force Up, China) + diuron (D, Arrow, China) at 0.5 + 0.5, 1.0 + 1.0, 2.0 + 1.5, 0.5 + 0.5 kg a.i./ha + 1 SHW at 6 WAP, hand weeding at 3 and 6 WAP and a weedy check. The herbicides were applied pre-emergence a day after sowing.

Field Establishment and Management Practices

After the experimental fields were prepared and demarcated into subplots of 3 m × 3 m, sesame seeds (variety E8, National Cereals Research Institute, Nigeria) at 8 kg/ha were dibbled and spaced at 30 cm × 30 cm in one of the main plots, while the other plots were drilled with the same sesame seed rate per hectare at a spacing of 60 cm × 60 cm. The emerged seedlings from the dibbled plots were thinned to 3 plants/stand at 4 WAP to maintain a plant population of 333,333 plants/ha, while the drilled seedlings were not thinned. Sowing was done at the T&R Farm on August 3 and 10, 2021, at NCAM. All the herbicide mixtures were tank-mixed and applied pre-emergence a day after sowing sesame seeds using a knapsack sprayer and a green nozzle calibrated to deliver herbicide solution at 250 L/ha. Spraying was done on August 4, 2021, at the T&R Farm and August 11, 2021, at NCAM. Two hoeing was done at 3 and 6 WAP for one of the treatments (weeded control), while the other control (weedy control) was left weedy throughout the season, and two other treatments received 1 SHW at 6 WAP. Fertilizer (NPK:15:15:15) was applied to provide nutrients at the rate of 92 kg nitrogen (N_2), 22 kg phosphorus pentoxide (P_2O_5), and 22 kg potassium oxide (K_2O) to sesame. It was applied in two split doses at planting and 6 WAP. Harvesting was done at the T&R Farm on October 14, while that of NCAM was on November 8, 2021. The inner rows were harvested, while the last rows on either side of the plots were jettisoned**.** The dried pods from the net plots were threshed manually to separate the seeds from the pods, followed by winnowing to separate the grains from the chaff.

Parameters Measured

Weed Sampling

Weed density (no./m^2) and weed biomass (g/m^2) were measured at 6 and 12 WAP. Weed density was measured by counting the number of weed species in a 1 m² quadrat, randomly thrown in three locations in each plot, and the weed dry matter was determined by uprooting and gathering weed species within a 1 m^2 quadrat thrown randomly in three locations within each plot, oven-dried at 80^{o}C for two days and weighed to determine total dry matter per treatment.

Growth Assessment

Plant height was taken using a measuring tape to measure the height of five tagged plants in each plot (net plot) from the soil surface to the apex at 9 and 12 WAP.

Yield Component and Grain Yield Measurement

Pods from each of the five tagged plants in each plot (net plot) were counted at 8 and 10 WAP, and the average was calculated and recorded. Seeds harvested from the net plot in each plot were weighed and converted to kilogram per hectare for analysis.

Economic Evaluation

The economic performance of different treatment combinations of weed control treatments and sowing methods was obtained by calculating the total cost of production, total revenue, and gross income. Production cost (PC) was determined by adding the cost of inputs and farm operations used. These included seeds, herbicides, fertilizers, land preparation, labor for planting, herbicide and application, weeding, fertilizer application, harvest, and processing operations.

$$PC = PC_1 + PC_2 + PC_{3\ +}\text{-------------}PCn \quad (1)$$

Gross revenue (GR) = Crop yield (Y) × Open market price (P) (2)

Gross margin/Net revenue (NR) = Gross Revenue (GR) - Production cost (PC) (3)

Eni et al. (2013)

Data Analysis

Data collected were subjected to analysis of variance (ANOVA) using the GENSTART (version 5.32) package, and means were separated using Turkey's honestly significant difference (HSD) test at a 5% level of probability.

RESULTS

Soil Physico-chemical Characteristics

The soil of the experimental sites at Malete and NCAM was loamy sand. However, the soil at NCAM was richer than the one at Malete in terms of total nitrogen, available phosphorus, and organic carbon (Table 1).

Rainfall

The total rainfall recorded in 2021 at NCAM was 1,881.10 mm, while that of Malete was 1,233.90 mm (Table 2).

Weeds

Among the weed control methods, herbicide mixtures, P + D and B + D at 2.0 +1.5 kg a.i./ha (67.15 and 109.75 g/m^2, respectively), and hoeing twice (88.90 g/m^2) resulted in the least weed dry biomass compared to the weedy check (291.55 g/m^2) in Malete, while at NCAM, hoeing twice (42.00 g/m^2), B + D at 1.5 + 1.0 kg a.i./ha (53.25 g/m^2), P + D 0.5 + 0.5 kg a.i./ha (58.70 g/m^2) and at 0.5 + 0.5 kg a.i./ha + I SHW (63.10 g/m^2) resulted in the least weed biomass compared to the other treatments and weedy check (155.55 g/m^2) at 6 WAP (Table 3). Dibbling (85.15 g/m^2) significantly ($P < 0.05$) reduced weed biomass than the drilling method (172.42 g/

Table 1
Physical and chemical properties of the soil at the experimental site

Soil parameters	T&R Farm Malete	NCAM
Sand (%)	80.0	79.0
Silt (%)	9.0	13.0
Clay (%)	11.0	8.0
Textural class	Sandy loam	Sandy loam
Organic carbon (%)	0.72	1.21
Total nitrogen (%)	0.10	0.14
Available phosphorus (mg/kg)	6.56	6.68
pH	6.80	6.9
Exchangeable Mg (cmol/kg)	1.19	1.38
Exchangeable K (cmol/kg)	0.37	0.24
Exchangeable Ca (cmol/kg)	4.25	1.98
Exchangeable Na (cmol/kg)	0.79	0.70
Exchangeable acidity (cmol/kg)	0.40	0.30
Mn (mg/kg)	140.0	110.0
Fe (mg/kg)	130.0	98.0
Cu (mg/kg)	1.23	1.04
Zn (mg/kg)	0.90	0.92

Note. T&R Farm Malete = Teaching and Research (T&R) Farm of the Kwara State University, Malete; NCAM = National Centre for Agricultural Mechanization (NCAM), Idofian, Ilorin, Kwara, Nigeria

Table 2
Monthly rainfall (mm) at the experimental sites

Month	T&R Farm Malete	NCAM
January	0.00	0.00
February	0.00	0.00
March	10.00	29.60
April	100.50	123.80
May	120.80	131.80
June	200.60	335.30
July	150.00	121.90
August	276.00	234.70
September	366.00	508.70
October	40.00	229.30
November	0.00	166.00
December	0.00	0.00
Total	1,233.90	1,881.10

Note. T&R Farm Malete = Teaching and Research (T&R) Farm of the Kwara State University, Malete; NCAM = National Centre for Agricultural Mechanization (NCAM), Idofian, Ilorin, Kwara, Nigeria; Source for NCAM = Kwara State Agricultural Development Project (Hydrology section), Ilorin, 2021; Source for Malete = Faculty of Agriculture, Kwara State University, Malete (Meteorological Station), 2021

m^2) at Malete between 6 and 12 WAP. The same trend occurred at NCAM as dibbling (48.81 g/m^2) significantly controlled weed better than the drilling (51.58 g/m^2). At both locations at 6 and 12 WAP, Malete had significantly (P < 0.05) higher amounts of weeds (149.06 and 128.79 g/m^2) than NCAM (77.17 and 50.20 g/m^2) (Tables 3 and 4). Also, the interaction effect of location and sowing methods was significant (P < 0.05) on weed biomass at 12 WAP, as dibbling provided more effective weed control than the drilling method in both locations (Table 4). Similarly, in both locations, all the weed control methods significantly reduced weed density compared to the weedy check at 6 and 12 WAP (Tables 5 and 6). However, twice hoeing (48.40/m^2) and P + D at 0.5 + 0.5 kg a.i./ha had the least weed density (54.45/m^2) in Malete, while at NCAM, P + D at 0.5 + 0.5 kg a.i./ha resulted in the least weed dry matter (34.00/m^2) at 6 WAP (Table 5). Also, B + D at 1.0 + 0.5 and 1.5 + 1.0 kg a.i./ha resulted in the least weed density (38.55 and 8.65/m^2) in Malete and NCAM at 12 WAP, respectively (Table 6). Malete had significantly (P < 0.05) higher weed density (62.66 and 46.27/m^2) than NCAM (45.53 and 12.60/m^2) at 6 and 12 WAP, respectively (Tables 5 and 6). At 12 WAP, the interaction effect of location and sowing method on weed density was significant (P < 0.05) as plots treated with the dibbling method of sowing had significantly lower weed density than the drilling methods in Malete, while drilling was better in reducing weed density at NCAM (Table 6).

Crop Growth

In Malete, all the weed control treatments produced sesame plants of comparable height but were significantly taller than those in the weedy check. A similar trend was observed at NCAM as the weedy check resulted in significantly shorter plants than all the weed control treatments (P < 0.05). Comparing the two locations, sesame plants in Malete were significantly shorter (88.77 cm) than those at NCAM (105.09 cm) at 9 WAP ($P \leq 0.05$) (Table 7). The interaction effects of the sowing method and weed control were significant as the hoe weeding and drilling method resulted in the tallest

Table 3
Effects of weed control and sowing methods on weed biomass (g/m²) at 6 weeks after planting (WAP)

Weed control (WC)	Location (L)	T&R Farm Malete			NCAM		
	Sowing method (SM)	DB	DL	WC Mean	DB	DL	WC mean
B + D 1.0 + 0.5 kg a.i./ha		181.30	96.90	139.10	95.00	64.90	79.95
B + D 1.0 + 0.5 kg a.i./ha + 1 SHW (6 WAP)		226.70	112.90	169.80	105.80	30.20	68.00
B + D 1.5 + 1.0 kg a.i./ha		88.00	136.00	112.00	45.30	61.20	53.25
B + D 2.0 + 1.5 kg a.i./ha		149.30	70.20	109.75	61.40	71.10	66.25
Hoe weeding (3 and 6 WAP)		48.00	129.80	88.90	48.90	35.10	42.00
P + D 0.5 + 0.5 kg a.i./ha		90.70	218.50	154.60	65.80	51.60	58.70
P + D 1.0 + 1.0 kg a.i./ha		174.20	168.90	171.55	98.70	86.20	92.45
P + D 2.0 + 1.5 kg a.i./ha		43.60	90.70	67.15	117.30	67.50	92.40
P + D 0.5 + 0.5 kg a.i./ha + 1 SHW (6 WAP)		189.30	183.10	186.20	90.60	35.60	63.10
Weedy check		331.50	251.60	291.55	163.50	147.60	155.55
SM mean		152.26	145.86	149.06	89.23	65.10	77.17
Tukey ($P < 5\%$)	Standard error						
L	13.46*						
SM	13.66						
WC	30.56*						
L × SM	19.33						
L × WC	43.21						
SM × WC	43.21						
L × SM × WC	61.11						

Note. T&R Farm Malete = Teaching and Research (T&R) Farm of the Kwara State University, Malete; NCAM = National Centre for Agricultural Mechanization (NCAM), Idofian, Ilorin, Kwara, Nigeria; Standard error = Standard error of the difference between treatment mean; * = Significant at $P < 0.05$; DB = Dibbling sowing method; DL = Drilling sowing method; B = Butachlor; D = Diuron; P = Pendimerhalin; 1 SHW = One supplementary hoe weeding

Table 4
Effects of weed control and sowing methods on weed biomass (g/m²) at 12 weeks after planting (WAP)

Weed control (WC)	Location (L)	T&R Farm Malete			NCAM		
	Sowing method (SM)	DB	DL	WC mean	DB	DL	WC mean
B + D 1.0 + 0.5 kg a.i./ha		88.90	166.70	127.80	40.10	49.40	44.75
B + D 1.0 + 0.5 kg a.i./ha + 1 SHW (6 WAP)		98.10	244.40	171.25	28.20	30.40	29.30
B + D 1.5 + 1.0 kg a.i./ha		105.60	209.30	157.45	68.90	52.80	60.85
B + D 2.0 + 1.5 kg a.i./ha		109.30	192.60	150.95	39.10	49.50	44.30
Hoe weeding (3 and 6 WAP)		41.70	161.10	101.40	29.90	23.80	26.85
P + D 0.5 + 0.5 kg a.i./ha		81.50	225.90	153.70	38.00	39.80	38.90
P + D 1.0 + 1.0 kg a.i./ha		65.30	113.00	89.15	34.50	49.20	41.85

Table 4 *(continue)*

Weed control (WC)	Location (L)	T&R Farm Malete			NCAM		
	Sowing method (SM)	DB	DL	WC mean	DB	DL	WC mean
P + D 2.0 + 1.5 kg a.i./ha		113.90	174.00	143.95	63.80	54.70	59.25
P + D 0.5 + 0.5 kg a.i./ha + 1 SHW (6 WAP)		88.00	105.70	96.85	46.70	51.70	49.20
Weedy check		59.20	131.50	95.35	98.90	114.50	106.70
SM mean		85.15	172.42	128.79	48.81	51.58	50.20
Tukey (P < 5%)	Standard error						
L	12.51*						
SM	12.51*						
WC	27.97						
L × SM	17.69*						
L × WC	39.51						
SM × WC	39.55						
L × SM × WC	55.94						

Note. T&R Farm Malete = Teaching and Research (T&R) Farm of the Kwara State University, Malete; NCAM = National Centre for Agricultural Mechanization (NCAM), Idofian, Ilorin, Kwara, Nigeria; Standard error = Standard error of the difference between treatment mean; * = Significant at $P < 0.05$; DB = Dibbling sowing method; DL = Drilling sowing method; B = Butachlor; D = Diuron; P = Pendimerhalin; 1 SHW = One supplementary hoe weeding

Table 5
Effect of weed control and sowing method on weed density (no./m^2) at 6 weeks after planting (WAP)

Weed control (WC)	Location (L)	T&R Farm Malete			NCAM		
	Sowing method (SM)	DB	DL	WC mean	DB	DL	WC Mean
B + D 1.0 + 0.5 kg a.i./ha		58.70	49.80	54.25	38.20	34.20	36.20
B + D 1.0 + 0.5 kg a.i./ha + 1 SHW (6 WAP)		43.60	64.40	54.00	40.50	59.50	50.00
B + D 1.5 + 1.0 kg a.i./ha		40.90	79.10	60.00	49.80	46.20	48.00
B + D 2.0 + 1.5 kg a.i./ha		52.30	54.20	53.25	31.80	43.10	37.45
Hoe weeding (3 and 6 WAP)		55.10	41.70	48.40	32.40	43.10	37.75
P + D 0.5 + 0.5 kg a.i./ha		47.60	61.30	54.45	35.10	32.90	34.00
P + D 1.0 + 1.0 kg a.i./ha		62.20	65.80	64.00	42.20	53.40	47.80
P + D 2.0 + 1.5 kg a.i./ha		72.40	60.00	66.20	40.50	49.80	45.15
P + D 0.5 + 0.5+ 1 SHW (6 WAP)		77.80	59.10	68.45	48.00	43.60	45.80
Weedy check		84.50	122.70	103.60	76.50	69.80	73.15
SM mean		59.51	65.81	62.66	43.50	47.56	45.53
Tukey (P < 5%)	Standard error						
L	3.64*						
SM	3.82						
WC	8.14*						

Table 5 *(continue)*

	Standard error
L × SM	5.15
L × WC	11.51
SM × WC	11.51
L × SM × WC	16.28

Note. T&R Farm Malete = Teaching and Research (T&R) Farm of the Kwara State University, Malete; NCAM = National Centre for Agricultural Mechanization (NCAM), Idofian, Ilorin, Kwara, Nigeria; Standard error = Standard error of the difference between treatment mean; * = Significant at $P < 0.05$; DB = Dibbling sowing method; DL = Drilling sowing method; B = Butachlor; D = Diuron; P = Pendimerhalin; 1 SHW = One supplementary hoe weeding

Table 6
Effect weed control and sowing method on weed density (no./m²) at 12 weeks after planting (WAP)

Weed control (WC)	Location (L)	T&R Farm Malete			NCAM		
	Sowing method (SM)	DB	DL	WC mean	DB	DL	WC Mean
B + D 1.0 + 0.5 kg a.i./ha		36.43	40.67	38.55	9.77	13.37	11.57
B + D 1.0 + 0.5 kg a.i./ha + 1 SHW (6 WAP)		44.00	45.77	44.89	9.77	11.10	10.44
B + D 1.5 + 1.0 kg a.i./ha		41.33	48.43	44.88	6.20	11.10	8.65
B + D 2.0 + 1.5 kg a.i./ha		41.33	47.57	44.45	12.87	5.33	9.10
Hoe weeding (3 and 6 WAP)		35.57	48.90	42.24	13.77	11.10	12.44
P + D 0.5 + 0.5 kg a.i./ha		41.77	44.90	43.34	12.00	8.87	10.44
P + D 1.0 + 1.0 kg a.i./ha		41.33	51.57	46.45	9.33	12.90	11.12
P + D 2.0 + 1.5 kg a.i./ha		44.43	49.50	46.97	12.00	12.43	12.22
P + D 0.5 + 0.5 kg a.i./ha + 1 SHW (6 WAP)		42.67	44.03	43.35	14.23	10.23	12.23
Weedy check		60.87	74.23	67.55	34.23	21.33	27.78
SM mean		42.97	49.56	46.27	13.42	11.78	12.60
Tukey (*P* < 5%)	Standard error						
L	1.286*						
SM	1.346						
WC	2.876*						
L × SM	1.819*						
L × WC	4.068						
SM × WC	4.068						
L × SM × WC	5.753						

Note. T&R Farm Malete = Teaching and Research (T&R) Farm of the Kwara State University, Malete; NCAM = National Centre for Agricultural Mechanization (NCAM), Idofian, Ilorin, Kwara, Nigeria; Standard error = Standard error of the difference between treatment mean; * = Significant at $P < 0.05$; DB = Dibbling sowing method; DL = Drilling sowing method; B = Butachlor; D = Diuron; P = Pendimerhalin; 1 SHW = One supplementary hoe weeding

Table 7
Effect weed control and sowing method on plant height (cm) at 9 weeks after planting (WAP)

Weed control (WC)	Location (L)	T&R Farm Malete			NCAM		
	Sowing method (SM)	DB	DL	WC mean	DB	DL	WC mean
B + D 1.0 + 0.5 kg a.i./ha		91.10	96.50	93.80	115.80	110.10	112.95
B + D 1.0 + 0.5 kg a.i./ha + 1 SHW (6 WAP)		90.00	89.10	89.55	119.00	102.10	110.55
B + D 1.5 + 1.0 kg a.i./ha		90.10	90.40	90.25	112.30	105.70	109.00
B + D 2.0 + 1.5 kg a.i./ha		81.90	96.70	89.30	106.10	112.30	109.20
Hoe weeding (3 and 6 WAP)		88.90	97.60	93.25	108.00	117.80	112.90
P + D 0.5 + 0.5 kg a.i./ha		95.50	87.50	91.50	97.00	106.50	101.75
P + D 1.0 + 1.0 kg a.i./ha		94.70	83.10	88.90	102.00	101.70	101.85
P + D 2.0 + 1.5 kg a.i./ha		90.90	87.40	89.15	103.00	106.80	104.90
P + D 0.5 + 0.5 kg a.i./ha + 1 SHW (6 WAP)		89.70	85.90	87.80	94.60	111.70	103.15
Weedy check		69.10	79.20	74.15	53.50	115.70	84.60
SM mean		88.19	89.34	88.77	101.13	109.04	105.09
Tukey (*P* < 5%)	Standard error						
L	2.64*						
SM	2.91						
WC	5.89*						
L × SM	3.73						
L × WC	8.34						
SM × WC	8.22*						
L × SM × WC	11.79						

Note. T&R Farm Malete = Teaching and Research (T&R) Farm of the Kwara State University, Malete; NCAM = National Centre for Agricultural Mechanization (NCAM), Idofian, Ilorin, Kwara, Nigeria; Standard error = Standard error of the difference between treatment mean; * = Significant at $P < 0.05$; DB = Dibbling sowing method; DL = Drilling sowing method; B = Butachlor; D = Diuron; P = Pendimerhalin; 1 SHW = One supplementary hoe weeding

plants in Malete, while the B + D 1.0 + 1.5 kg a.i./ha + 1 SHW and dibbling method produced the tallest plant at NCAM. At 12 WAP in Malete, the weedy check resulted in the tallest plants but not statistically different from the other weed control treatments except B + D 1.0 + 0.5, B + D 1.0 + 1.5 kg a.i./ha + 1 SHW, and B + D at 1.5 + 1.0 kg a.i./ha, which had significantly shorter plants. While at NCAM, B + D at 1.5 + 1.0 kg a.i./ha resulted in taller plants, comparable to other weed control methods but significantly taller than plants treated with P + D at 1.0 + 1.0 kg a.i./ha (Table 8). The interaction effect of location and weed control method on plant height was significant as the weedy check produced taller plants in Malete, while B + D at 1.5 + 1.0 kg a.i./ha produced the tallest plant at NCAM.

Table 8
Effect weed control and sowing method on plant height (cm) at 12 weeks after planting (WAP)

Weed control (WC)	Location (L)	T&R Farm Malete			NCAM		
	Sowing method (SM)	DB	DL	WC mean	DB	DL	WC mean
B + D 1.0 + 0.5 kg a.i./ha		91.30	100.40	95.85	115.70	118.70	117.20
B + D 1.0 + 0.5 kg a.i./ha + 1 SHW (6 WAP)		86.70	110.40	98.55	115.00	117.30	116.15
B + D 1.5 + 1.0 kg a.i./ha		98.10	100.80	99.45	117.40	139.80	128.60
B + D 2.0 + 1.5 kg a.i./ha		91.70	110.70	101.20	110.10	132.40	121.25
Hoe weeding (3 and 6 WAP)		102.40	105.10	103.75	106.10	119.00	112.55
P + D 0.5 + 0.5 kg a.i./ha		123.20	100.90	112.05	117.60	126.50	122.05
P + D 1.0 + 1.0 kg a.i./ha		104.20	95.60	99.90	76.20	42.20	59.20
P + D 2.0 + 1.5 kg a.i./ha		115.40	106.60	111.00	91.30	118.10	104.70
P + D 0.5 + 0.5 kg a.i./ha + 1 SHW (6 WAP)		123.80	92.80	108.30	103.70	116.50	110.10
Weedy check		117.00	110.40	113.70	103.00	117.50	110.25
SM mean		105.38	103.37	104.38	105.61	114.80	110.21
Tukey (*P* < 5%)	Standard error						
L	3.16						
SM	3.16						
WC	7.07*						
L × SM	4.47						
L × WC	10.00*						
SM × WC	10.01						
L × SM × WC	14.15						

Note. T&R Farm Malete = Teaching and Research (T&R) Farm of the Kwara State University, Malete; NCAM = National Centre for Agricultural Mechanization (NCAM), Idofian, Ilorin, Kwara, Nigeria; Standard error = Standard error of the difference between treatment mean; * = Significant at $P < 0.05$; DB = Dibbling sowing method; DL = Drilling sowing method; B = Butachlor; D = Diuron; P = Pendimerhalin; 1 SHW = One supplementary hoe weeding

Yield Component and Grain Yield

In Malete, dibbling produced significantly ($P < 0.05$) higher number of pods (8.88) than drilling (8.19). A similar observation was recorded at NCAM, where dibbling produced more pods (16.60) than drilling (11.63) at 8 WAP (Table 9). At Malete, B + D at 1.5 + 1.0 kg a.i./ha resulted in the highest number of pods (11.87), which was not different from other weed control methods, except P + D at 1.0 + 1.0 kg a.i./ha (6.25), P + D at 2.0 + 1.5 kg a.i./ha (7.50), and the weedy check (5.90), which produced significantly lesser number of pods ($P < 0.05$). At NCAM, P + D at 1.0 + 1.0 kg a.i./ha (13.94), 2.0 + 1.5 kg a.i./ha (9.03), 0.5 + 0.5 kg a.i./ha + 1 SHW (10.44), and the weedy check (11.07) resulted in significantly lesser number of pods compared to B + D at 1.0 + 0.5 kg a.i./ha (19.04) and other weed control methods, which produced significantly ($P < 0.05$) higher number of pods. Comparing the locations, sesame plants had a significantly lesser number of pods (8.53) in Malete than NCAM (14.12). Also, the location x sowing method interaction effect on the number of pods was significant at 8 WAP as dibbling produced a higher number of pods ($P < 0.05$) in the two locations (Table 9). In Table 10, hoe weeding gave the highest number of pods, which was comparable to only B + D at 1.0 + 0.5 kg a.i./ha + 1 SHW but was significantly higher than all the other weed control methods; however, weedy check produced significantly lowest amount of pods/plant in Malete. At NCAM, B + D at 1.5 + 1.0 kg a.i./ha produced the highest number of pods comparable to two hoe weeding, B + D at 2.0 + 1.5 and 1.0 + 0.5 kg a.i./ha, but significantly higher than other weed control methods. Weedy check and P + D at 1.0 + 1.0 kg a.i./ha significantly produced the lowest numbers of pods. In terms of location, Malete supported a significantly lower number of pods (17.34) compared to NCAM (23.89) (Table 10).

Table 9
Effect weed control and sowing method on the number of pods at 8 weeks after planting (WAP)

Weed control (WC)	Location (L)	T&R Farm Malete			NCAM		
	Sowing method (SM)	DB	DL	WC mean	DB	DL	WC mean
B + D 1.0 + 0.5 kg a.i./ha		10.97	6.13	8.55	22.8	15.27	19.04
B + D 1.0 + 0.5 kg a.i./ha + 1 SHW (6 WAP)		7.27	6.53	6.90	17.33	7.73	12.53
B + D 1.5 + 1.0 kg a.i./ha		12.67	11.07	11.87	18.33	12.53	15.43
B + D 2.0 + 1.5 kg a.i./ha		8.87	12.80	10.84	23.87	9.3	16.59
Hoe weeding (3 and 6 WAP)		9.60	12.00	10.80	17.73	18.5	18.12
P + D 0.5 + 0.5 kg a.i./ha		10.20	6.47	8.34	17.47	12.53	15.00
P + D 1.0 + 1.0 kg a.i./ha		6.97	5.53	6.25	15	12.87	13.94
P + D 2.0 + 1.5 kg a.i./ha		8.53	6.47	7.50	12.73	5.33	9.03
P + D 0.5 + 0.5 kg a.i./ha + 1 SHW (6 WAP)		9.20	7.60	8.40	11.07	9.8	10.44
Weedy check		4.47	7.33	5.90	9.67	12.47	11.07
SM mean		8.88	8.19	8.53	16.60	11.63	14.12
Tukey ($P < 5\%$)	Standard error						
L	0.926*						
SM	0.921*						
WC	2.070*						
L × SM	1.309*						
L × WC	2.928						
SM × WC	2.931						
L × SM × WC	4.141						

Note. T&R Farm Malete = Teaching and Research (T&R) Farm of the Kwara State University, Malete; NCAM = National Centre for Agricultural Mechanization (NCAM), Idofian, Ilorin, Kwara, Nigeria; Standard error = Standard error of the difference between treatment mean; * = Significant at $P < 0.05$; DB = Dibbling sowing method; DL = Drilling sowing method; B = Butachlor; D = Diuron; P = Pendimerhalin; 1 SHW = One supplementary hoe weeding

Dibbling (78.90 and 422.70 kg/ha) resulted in significantly higher grain yield than drilling (37.50 and 326.80 kg/ha) in Malete and NCAM, respectively (Table 11). Though there was no significant difference in grain yield between the weed control treatments in both locations, hoe weeding, P + D at 2.0 + 1.5, P + D at 0.5 + 0.5, B + D at 1.0 + 0.5, and B + D at 1.5 + 1.0 kg a.i./ha increased sesame yield by 97.20, 70.0, 58.1, 57.2, and 56.3%, respectively at NCAM, while at Malete, hoeing twice, P + D at 0.5 + 0.5, B + D at 2.0 + 1.5 kg a.i./ha increased sesame yield by 52.0, 28.0, and 22%, respectively. Between the two locations, the grain yield (58.20 kg/ha) of sesame in Malete was significantly ($P < 0.05$) lower than that at NCAM (374.75 kg/ha) (Table 11).

Economic Assessment

In Malete, a treatment combination of hoe weeding at 3 and 6 WAP × dibbling method

Table 10
Effect of location, weed control, and sowing method on the number of pods at 10 weeks after planting (WAP)

Weed control (WC)	Location (L)	T&R Farm Malete			NCAM		
	Sowing method (SM)	DB	DL	WC mean	DB	DL	WC mean
B + D 1.0 + 0.5 kg a.i./ha		15.27	17.67	16.47	26.73	25.20	25.97
B + D 1.0 + 0.5 kg a.i./ha + 1 SHW (6 WAP)		19.93	25.50	22.72	29.20	19.13	24.17
B + D 1.5 + 1.0 kg a.i./ha		16.13	16.60	16.37	36.73	26.67	31.70
B + D 2.0 + 1.5 kg a.i./ha		9.00	12.47	10.74	34.53	21.73	28.13
Hoe weeding (3 and 6 WAP)		29.33	26.13	27.73	32.40	23.40	27.90
Mean		17.29	17.40	17.34	24.49	23.30	23.89
P + D 1.0 + 1.0 kg a.i./ha		23.47	17.27	20.37	19.23	23.33	21.28
P + D 2.0 + 1.5 kg a.i./ha		16.63	12.53	14.58	20.87	22.67	21.77
P + D 0.5 + 0.5 kg a.i./ha + 1 SHW (6 WAP)		13.40	17.93	15.67	15.47	27.87	21.67
Weedy check		8.00	15.47	11.74	10.20	18.67	14.44
Mean		17.29	17.40	17.34	24.49	23.30	23.89
Tukey ($P < 5\%$)	Standard error						
L	1.604*						
SM	1.614						
WC	3.587*						
L × SM	2.268						
L × WC	5.072						
SM × WC	5.081						
L × SM × WC	7.173						

Note. T&R Farm Malete = Teaching and Research (T&R) Farm of the Kwara State University, Malete; NCAM = National Centre for Agricultural Mechanization (NCAM), Idofian, Ilorin, Kwara, Nigeria; Standard error = Standard error of the difference between treatment mean; * = Significant at $P < 0.05$; DB = Dibbling sowing method; DL = Drilling sowing method; B = Butachlor; D = Diuron; P = Pendimerhalin; 1 SHW = One supplementary hoe weeding

Table 11
Effect of location, weed control, and sowing methods on grain yield (kg/ha)

Weed control (WC)	Location (L)	T&R Farm Malete			NCAM		
	Sowing method (SM)	DB	DL	WC mean	DB	DL	WC mean
B + D 1.0 + 0.5 kg a.i./ha		91.00	22.00	56.50	442.00	388.00	415.00
B + D 1.0 + 0.5 kg a.i./ha + 1 SHW (6 WAP)		85.00	17.00	51.00	254.00	325.00	289.50
B + D 1.5 + 1.0 kg a.i./ha		52.00	35.00	43.50	256.00	569.00	412.50
B + D 2.0 + 1.5 kg a.i./ha		125.00	17.00	71.00	196.00	343.00	269.50
Hoe weeding (3 and 6 WAP)		135.00	43.00	89.00	744.00	297.00	520.50
P + D 0.5 + 0.5 kg a.i./ha		114.00	35.00	74.50	571.00	264.00	417.50
P + D 1.0 + 1.0 kg a.i./ha		36.00	24.00	30.00	527.00	227.00	377.00
P + D 2.0 + 1.5 kg a.i./ha		51.00	57.00	54.00	564.00	334.00	449.00
P + D 0.5 + 0.5 kg a.i./ha + 1 SHW (6 WAP)		66.00	42.00	54.00	421.00	245.00	333.00
Weedy check		34.00	83.00	58.50	252.00	276.00	264.00
SM mean		78.90	37.50	58.20	422.70	326.80	374.75
Tukey (P < 5%)	Standard error						
L	32.2*						
SM	32.4*						
WC	72.1						
L x SM	45.6						
L x WC	101.9						
SM x WC	99.5						
L x SM x WC	144.2						

Note. T&R Farm Malete = Teaching and Research (T&R) Farm of the Kwara State University, Malete; NCAM = National Centre for Agricultural Mechanization (NCAM), Idofian, Ilorin, Kwara, Nigeria; Standard error = Standard error of the difference between treatment mean; * = Significant at $P < 0.05$; DB = Dibbling sowing method; DL = Drilling sowing method; B = Butachlor; D = Diuron; P = Pendimerhalin; 1 SHW = One supplementary hoe weeding

of sowing resulted in the highest yield of sesame (135.71 kg/ha), followed by B + D at 2.0 + 1.5 kg a.i./ha × dibbling and P + D at 0.5 + 0.5 kg a.i./ha × dibbling method, while B + D at 1.0 + 0.5 kg a.i./ha × drilling and P + D at 1.0 + 1.0 kg a.i./ha × drilling produced the least yield (22.13 kg/ha) and (23.83 kg/ha), respectively (Table 12). The highest cost of production emanated from P + D at 2.0 +1.5 kg a.i./ha × dibbling and P + D at 0.5 + 0.5 kg a.i./ha + 1 SHW at 6 WAP × dibbling method ($ 315.97 and $ 311.49, respectively) compared to the rest of the treatments and hoeing twice, while the treatment combinations with the least cost were weedy check × dibbling method ($ 244.56). The highest income was generated by treatment combination of twice hoeing × dibbling ($ 113.66) followed by B + D at 2.0 + 1.5 kg a.i./ha × dibbling ($ 105.05) and P + D at 0.5 + 0.5 kg a.i./ha × dibbling ($ 95.76). The least income resulted from B +

D at 2.0 + 1.5 kg a.i./ha × drilling ($ 13.93) and B + D at 1.0 + 1.5 kg a.i./ha + 1 SHW at 6 WAP × drilling ($ 13.93). The treatment combinations with the least monetary losses were weedy check × drilling ($ -177.52), followed by B + D at 2.0 + 1.5 kg a.i./ha × dibbling ($ -191.02) and P + D at 0.5 + 0.5 kg a.i./ha × dibbling ($ -199.88). The treatment combination of B + D 1.0 + 0.5 kg a.i./ha + 1 SHW × drilling attracted the highest monetary loss ($ -294.31).

In comparison, at NCAM, the treatment combination which produced the highest sesame yield was hoe weedy × dibbling (744.3 kg/ha) followed by P + D at 0.5 + 0.5 kg a.i./ha × dibbling (570.8 kg/ha) and B + D at 1.5 + 1.0 kg a.i./ha × drilling (569.1 kg/ha) and P + D at 2.0 + 1.5 kg a.i./ha × dibbling (564.3 kg/ha) while P + D at 1.0 + 1.0 kg a.i./ha × drilling resulted in the lowest yield (227.5 kg/ha). The treatment combinations with the highest cost of production were P + D 2.0 + 1.5 kg a.i./ha × dibbling and P + D 0.5 + 0.5 kg a.i./ha + 1 SHW × dibbling ($ 315.97 and $ 311.49, respectively), while the least cost was incurred by weedy check × dibbling ($ 244.56). The highest income was generated by hoe weeding × dibbling ($ 623.38) followed by P + D at 0.5 + 0.5 kg a.i./ha × dibbling ($ 478.07), B + D at 1.5 + 1.0 kg a.i./ha × drilling ($ 476.64) and P + D at 2.0 + 1.5 kg a.i./ha × dibbling ($ 472.62), while the treatment combinations with the least income were B + D at 2.0 + 1.5 kg a.i./ha × dibbling ($ 163.82). The highest gross margin resulted from hoe weeding × dibbling ($ 318.57) followed by P + D at 0.5 + 0.5 kg a.i./ha × dibbling ($ 182.43), B + D at 1.5 + 1.0 kg a.i./ha × drilling ($ 177.38) and P + D at 2.0 + 1.5 kg a.i./ha × dibbling ($ 156.65), while the treatment combination with the least gross margin was B + D at 2.0 + 1.5 kg a.i./ha × dibbling ($ -129.71) (Table 12).

DISCUSSION

Sesame has been reported to be one of the cash crops in Nigeria with huge economic potential and an important foreign exchange revenue earner. Therefore, identifying a combination of herbicide mixtures and sowing methods for effectively managing weeds and increasing crop production will help boost the country's total production of this crop. This study was carried out in two locations**:** Malete, which had a total rainfall of 1,233.90 mm, while NCAM recorded a total rainfall of 1,881.10 mm. It corroborates with Paul and Oluwatimi (2011) that the total annual rainfall in Kwara State ranges from 800 to 1,200 mm in the Northwest and 1,000 to 1,500 mm in the Southeast. The soil in the two locations was sandy loam. However, NCAM was richer than Malete in terms of total nitrogen, available phosphorus, and organic carbon. It may be due to the more prolonged continuous cultivation that the Malete site has been subjected to compared to NCAM, which was recently cultivated after many years of fallow.

The earlier establishment of the experiment and higher rainfall at Malete caused higher weed infestation at this site than NCAM in the early part of the season. However, this trend was reversed in the

Table 12
Economic analysis of the use of different treatment combinations of herbicide to produce sesame in United States dollar ($)

Treatment	Malete Yield (kg/ha)	TC ($)	Income ($)	GM ($)	NCAM Yield (kg/ha)	TC ($)	Income ($)	GM ($)
B + D 1.0 + 0.5 kg a.i./ha (DB)	91.47	292.20	76.61	-215.59	441.8	292.20	370.03	77.83
B + D 1.0 + 0.5 kg a.i./ha (DL)	22.13	288.66	18.53	-270.13	388.4	288.66	325.30	36.64
B + D 1.0 + 0.5 kg a.i./ha + 1 SHW (6 WAP, DB)	85.40	308.21	71.53	-236.68	253.6	308.21	212.40	-95.81
B + D 1.0 + 0.5 kg a.i./ha + 1 SHW (6 WAP, DL)	16.63	308.24	13.93	-294.31	324.8	308.24	269.49	-38.75
B + D 1.5 + 1.0 kg a.i./ha (DB)	52.37	290.71	43.86	-246.85	255.9	290.71	214.33	-76.38
B + D 1.5 + 1.0 kg a.i./ha (DL)	35.43	299.26	29.67	-269.59	569.1	299.26	476.64	177.38
B + D 2.0 + 1.5 kg a.i./ha (DB)	125.43	296.07	105.05	-191.02	195.6	293.53	163.82	-129.71
B + D 2.0 + 1.5 kg a.i./ha (DL)	16.63	297.18	13.93	-283.25	342.9	297.18	287.19	-9.99
Hoe weeding (DB)	135.71	304.81	113.66	-191.15	744.3	304.81	623.38	318.57
Hoe weeding (DL)	42.63	289.23	35.70	-253.53	296.8	289.23	248.58	-40.65
P + D 0.5 + 0.5 kg a.i./ha (DB)	114.33	295.64	95.76	-199.88	570.8	295.64	478.07	182.43
P + D 0.5 + 0.5 kg a.i./ha (DL)	35.30	284.51	29.57	-254.94	264.3	284.51	221.36	-63.15
P + D 0.5 + 0.5 kg a.i./ha + 1 SHW (DB)	65.70	311.49	55.03	-256.46	421.3	311.49	352.86	41.37
P + D 0.5 + 0.5 kg a.i./ha + 1 SHW (DL)	41.67	305.70	34.90	-270.80	244.8	305.70	204.36	-101.34
P + D 1.0 + 1.0 kg a.i./ha (DB)	36.40	299.98	30.49	-269.49	527.1	299.98	441.47	141.49
P + D 1.0 + 1.0 kg a.i./ha (DL)	23.83	290.97	19.96	-271.01	227.5	290.97	190.54	-100.43
P + D 2.0 + 1.5 kg a.i./ha (DB)	50.60	315.97	42.38	-273.59	564.3	315.97	472.62	156.65
P + D 2.0 + 1.5 kg a.i./ha (DL)	56.53	309.49	47.35	-262.14	333.7	309.49	279.49	-30.00
Weedy check (DB)	34.23	244.56	28.67	-215.89	252.4	244.56	211.40	-33.16
Weedy check (DL)	82.53	246.64	69.12	-177.52	276.3	246.64	231.41	-15.23

Note. TC = Total cost; GM = Gross margin = = Income – TC; NCAM = National Centre for Agricultural Mechanization; Income = Selling price x Open market price of sesame; DB = Dibbling sowing method; DL = Drilling sowing method; B = Butachlor; D = Diuron; P = Pendimerhalin; 1 SHW = One supplementary hoe weeding; WAP = Weeks after planting middle and later part of the season, probably as a result of higher rainfall and better soil conditions existing at NCAM than at Malete, which created a conducive atmosphere for vigorous vegetative growth and early closure of canopy for weed suppression, hence, the lower weed infestation at NCAM. It is in line with Ramesh et al. (2017) that an increase in rainfall would lead to additional weed pressure. Furthermore, Daniya et al. (2019) reported the easy formation of sesame canopy and better weed control in the plots seeded with 2 kg/ha of sesame. Dibbling appeared to be more effective in controlling weed density and biomass than the drilling method of sowing in the two locations, probably because of its ability to maintain a higher plant population of sesame, thereby facilitating early canopy closure for the shading and smothering of weeds. All the herbicide mixtures and two hoeing effectively reduced weed density and biomass, suggesting the efficacy of all the herbicide mixtures in weed control. However, the herbicide mixtures that have proved to be most effective were P + D 2.0 + 1.5, P + D 0.5 + 0.5, B + D 1.5 + 1.0 B + D 1.0 + 0.5, and B + D 2.0 + 1.5 kg a.i./ha. Therefore, these herbicide mixtures can be used as alternatives to hoeing twice to reduce drudgery in sesame production.

The significantly taller plants at NCAM compared to Malete could be attributed to the utilization of more moisture, nutrients, and sunlight for better growth occasioned by higher rainfall, better soil conditions, and the lower weed infestation recorded at NCAM. All the herbicide mixtures and two hoe weeding resulted in taller sesame plants compared to the weedy check in both locations at 9 WAP. It is probably due to the effectiveness of the herbicide mixtures and hoe weeding to minimize weed infestation, resulting in more growth resources for better performance, thus corroborating with Khan (2016) that a weed-free plot gave rise to taller plants. However, at 12 WAP at Malete, the weedy check achieved sesame plant height not different from plants in the plots treated with herbicide mixture and hoe weeding. It could have resulted from weed competition for light in the weedy check. Daniya et al. (2019) attributed the taller plant height of sesame seeded at a density of 8 kg/ha to intra-specific competition for growth resources, which resulted in the elongation of internodes and taller plants.

NCAM location increased the number of sesame pods compared to the Malete location at 8 and 10 WAP. It could be attributed to the higher rainfall, better soil conditions, and weed control, which resulted in the uptake and utilization of higher amounts of nutrients, moisture, and sunlight to produce taller plants and the number of pods/plants. Daniya et al. (2019) attributed the production of more capsules/plants of sesame to taller plants, which translated into more nodes from where leaves are produced. Furthermore, Imoloame (2009) reported a significant positive correlation between the amount of pods/plants of sesame and plant height. The dibbled sesame could have suffered less intra-specific competition compared to the drilled ones and, coupled with the greater ability of the dibbled method to minimize weed infestation, could have freed more nutrients and moisture for the plants to produce a higher number of pods in both locations at Malete at 8 WAP.

The effectiveness of herbicide mixtures B + D 1.5 + 1.0, B + D 2.0 + 1.5, P + D 0.5 + 0.5, and P + D 0.5 + 0.5 kg a.i./ha + 1 SHW and hoeing twice to control weeds in Malete, promoted the ability of the sesame crop to produce the highest number of pods. A similar trend played out at NCAM. At both locations, the weedy check produced the least number of pods due to intense weed competition with the sesame crop, which led to poor performance. At 10 WAP, at Malete hoeing twice, B + D 1.0 + 0.5 kg a.i./ha + 1 SHW and P + D 1.0 + 1.0 kg a.i./ha produced the highest number of pods than the other weed control methods and weedy check. However, at NCAM, all the herbicide mixtures and hoeing twice, except P + D 1.0 + 1.0 kg a.i./ha, produced a significantly higher number of pods than the weedy check. The faster vegetative growth and early canopy formation of sesame enhanced the herbicide mixtures and hoe weeding ability to control weeds better and produce a higher number of pods at NCAM than Malete. It corroborates the findings of Ndarubu et al. (2003) that effective weed control in sesame occurred using a combination of herbicide mixture of metolachlor + metobromuron at 0.75 + 0.75 kg a.i./ha[1] and drilling method at an interrow spacing of 30 cm.

The grain yield of sesame was abysmally lower in Malete than NCAM because of a lower amount of rainfall, late sowing, higher weed infestation, and poorer soil conditions, resulted in the uptake and utilization of lesser growth resources, which supported shorter plants, lower number of pods and grain yield.

Dibbling resulted in higher sesame grain yield than drilling, which could be attributed to a higher plant population in the dibbled plots than in the drilled plots, where sesame crops suffered higher intense intra-plant competition and plant mortality. Furthermore, the higher plant population and close spacing in the dibbled plots encouraged early closure of the canopy and the ability of sesame to control weeds more effectively. It subsequently made more growth resources available for uptake and utilization by the dibbled sesame for better performance. This result agrees with Ndor and Nasir (2019), who reported that dibbling produced a higher grain yield of sesame than the broadcast method but differed from the findings of Katanga et al. (2017), who recommended drilling as the best sowing method dibbling and broadcast methods to produce sesame. Though there was no significant difference in the grain yields among weed control treatments in the two locations, two hoeing at 3 and 6 WAP, P + D 2.0 + 1.5 and 0.5 + 0.5 kg a.i./ha, B+ D 1.0 + 1.5 and 1.5 + 1.0 kg a.i./ha increased sesame grain yield by 97, 70, 58.1, 57.2, and 56.3%, respectively at NCAM, while at Malete, two hoe weeding, P + D 0.5 + 0.5 and B + D 2.0 + 1.5 kg a.i./ha increased sesame yield by 52.0, 28.0, and 22%, respectively. These herbicide mixtures showed synergism as they proved more effective in controlling weeds than the other treatments. They can be integrated with the dibbling method of sowing at 30 cm × 30 cm for effective weed control and higher grain yield of sesame, which is similar to Ndarubu et al. (2003) that a combination of herbicide mixture of metolachlor + metobromuron at 0.75 + 0.75 kg a.i./ha and drilling method of sowing at 30 cm inter-row spacing was effective for weed control and production of higher grain yield of sesame.

In Malete, a combination of hoeing twice × dibbling sowing method, B + D 2.0 + 1.5 kg a.i./ha × dibbling and P + D 0.5 + 0.5 kg a.i./ha × dibbling resulted in higher sesame yields, while at NCAM higher yields were produced by treatment combinations of two hoe weeding at 3 and 6 WAP × dibbing, P + D 0.5 + 0.5 kg a.i./ha × dibbling, B + D 1.5 + 1.0 × drilling method and P + D 2.0 + 1.5 kg a.i./ha. The above treatment combinations could have provided effective weed control and enabled the uptake of more growth factors for higher yield. The treatment combination of P + D and B + D at 1.0 + 1.0 kg a.i./ha × drilling resulted in the least yield as they failed to provide effective weed control. The highest cost of production in both NCAM and Malete was the treatment combinations of P + D 2.0 + 1.5 and P + D 0.5 + 0.5 kg a.i./ha + 1 SHW × dibbing method. It could be attributed to the higher cost of higher doses of herbicides and the extra cost of one supplementary hoe weeding, which increased the cost of production, which is contrary to the findings of Imoloame (2017) that hoeing twice was the most expensive weed control method than the use of herbicides. This contradiction could have been caused by Nigeria's 18.6% inflation rate, which has affected the prices of goods (herbicides) and services (Oyekanmi, n.d.). The treatment combinations of hoeing twice × dibbling, P + D 2.0 + 1.5, and 0.5 + 0.5 kg a.i./ha × dibbling gave the highest incomes at Malete, probably due to their ability to produce higher grain yields.

However, the gross margin generated from all the treatments in Malete was losses, probably due to the low sesame yields from this location due to the late planting, low rainfall, and higher weed infestation. However, at NCAM, the same treatment combinations of hoeing twice × dibbling, P + D 2.0 + 1.5 kg a.i./ha, and at 0.5 + 0.5 × dibbling and B + D 1.5 kg a.i./ha + 1.0 kg a.i./ha × drilling method resulted in the highest (gross margin/profit) compared to the other treatments. These combinations improved weed control, producing better growth and higher sesame yields. Therefore, the best treatment combinations for effective weed control, higher yields, and economic returns were hoeing twice × dibbling, P + D 0.5 + 0.5 and 2.0 + 1.5 kg a.i./ha × dibbling method, and B + D 1.5 + 0.5 × drilling method.

CONCLUSION

From the findings of this study, it can be concluded that hoeing twice at 3 and 6 WAP, P + D at 2.0 + 1.5 and 0.5 + 0.5 kg a.i./ha, B + D at 1.0 + 0.5 and at 1.5 + 1.0 kg a.i./ha increased sesame grain yield by 97, 70, 58.1, 57.2, and 56.3%, respectively, at NCAM, while at Malete, hoeing twice, P + D 0.5 + 0.5 kg a.i./ha and B + D 2.0 + 1.5 kg a.i./ha increased sesame yield by 52, 28, and 22%, respectively. Dibbling was more effective than the drilling method for the management of weeds and for promoting crop growth and yield. The best treatment combinations for effective weed control, higher yields, and economic returns are hoe weeding at 3 and 6 WAP × dibbling, P + D 0.5 + 0.5, and 2.0 + 1.5 kg a.i./ha × dibbling and B +D 1.5 +1.0 kg a.i./ha × drilling. NCAM location produced significantly higher sesame grains than Malete. Dibbling sowing method at a spacing of 30 cm × 30 cm and thinned to 3 plants/stand integrated with pendimethalin + diuron 0.5 + 0.5 kg a.i/ha is recommended for higher yield, effective weed management, economic returns, and as an eco-friendly alternative to two hoe weeding.

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