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WEED CONTROL STRATEGIES AND VARIETAL RESPONSE EFFECTS ON SOYBEAN GROWTH, YIELD, AND WEED SUPPRESSION IN THE SUDAN SAVANNAH OF NIGERIA

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ABSTRACT
A field experiment was conducted during the 2022 rainy season at Bayero University Kano (BUK) and Bunkure to evaluate the effects of weed control methods and soybean varieties on growth, yield, and weed suppression efficiency in the Sudan Savannah. Treatments consisted of three soybean varieties (TGX 1448-2E, TGX 1835-10E, and TGX 1951-3F) combined with six weed control practices: hoe weeding (HW) at 3 and 6 weeks after sowing (WAS), Pendimethalin (1.0 kg a.i. ha^{-1}), Imazethapyr (100 g a.i. ha^{-1}), Pendimethalin + Supplementary how weeding (SHW) at 6 WAS, Pendimethalin + Imazethapyr, and a weedy check, replicated thrice in a Randomized complete block design. Results showed that weed control significantly ($p < 0.001$) improved plant height, leaf area index, pod number, and yield compared with the weedy check. HW at 3 and 6 weeks after sowing (WAS) recorded the highest pod yield (2,904 kg ha^{-1} at BUK; 4,715 kg ha^{-1} at Bunkure) and the greatest weed control efficiency (70.6% & 84.0%) at BUK and Bunkure, while the weedy check consistently had the lowest yields (1,403 and 1,323 kg ha^{-1}) and zero efficiency. Similarly, Pendimethalin at 1.0 kg a.i. ha^{-1}) + Imazethapyr (100 g a.i. ha^{-1}) achieved competitive yields (2,675 kg ha^{-1} at BUK; 4,587 kg ha^{-1} at Bunkure) and high weed control efficiency (65.8% and 79.7%). Among varieties, TGX 1951-3F was most productive, yielding 2,456 kg ha^{-1} at BUK and 2,899 kg ha^{-1} at Bunkure, due to superior competitiveness and reduced weed dry matter. The significant ($p < 0.001$) interaction between weed control methods and varieties showed that HW at 3 and 6 WAS combined with TGX 1951-3F produced maximum yields (3,283 kg ha^{-1} at BUK; 4,715 kg ha^{-1} at Bunkure). These findings suggest that integrating effective weed management with high-yielding varieties like TGX 1951-3F offers a sustainable pathway to improve soybean productivity and food security in the Sudan Savannah.

Key words: Crop-weed competition, Herbicide integration, Hoe weeding, Weed management, Soybean, Sudan savanna

INTRODUCTION

Soybean (*Glycine max* L.), a key leguminous crop in the Fabaceae family, is globally valued for its nutritional and economic importance, with seeds containing about 20% oil, 40% protein, and 34% carbohydrates, making it vital for food, feed, and industrial uses (Degola et al., 2018; Dong et al., 2020). In Nigeria's Sudan Savannah, soybean not only supports household income diversification but also improves soil fertility through biological nitrogen fixation (Abubakar et al., 2025). However, sustainable production is severely constrained by weed competition, especially during the first four to six weeks after planting, the critical period of crop–weed interference (Costa et al., 2020). Uncontrolled weed infestation can reduce soybean yield by 52–58% in Nigeria and similar agroecologies, while increasing harvesting difficulty and production costs (Daramola et al., 2019; Merga & Alemu, 2019). Although manual weeding is widely practiced, it is labor-intensive and increasingly unsustainable, prompting greater reliance on herbicides (Jadhav & Kashid, 2019; Otieno, 2023). Pre-emergence herbicides such as Pendimethalin and S-Metolachlor have proven effective in suppressing early-season weeds and improving soybean yield in the Sudan and Northern Guinea Savannas (Ezebuiro et al., 2021; Shittu & Lamarana, 2024). Planting method and varietal response further influence weed–crop dynamics, with drilling and improved varieties like TGX 1955-4F enhancing weed suppression and grain yield (Abubakar et al., 2025).

However, limited information exists on the interaction between weed control strategies and soybean varieties under Sudan savannah conditions. This study therefore evaluates the effects of weed management practices, varieties, and their interactions on weed suppression, growth, and yield.

MATERIALS AND METHODS

Experimental sites

A field experiment was conducted during the 2022 rainy season at two sites within the Sudan Savannah of Nigeria: The Teaching and Research Farm, Faculty of Agriculture, Bayero University Kano (11.097° N, 8.041° E, 481 m asl) and the Bunkure Research Farm, Kano State (11.681° N, 8.548° E, 488 m asl). The Sudan Savannah is characterized by a semi-arid climate with a unimodal rainfall pattern ranging from 500-800 mm annually, a growing season of about 100-120 days, and mean daily temperatures of 27-32°C. Soils in the zone are typically sandy loam, inherently low in organic matter and essential nutrients such as nitrogen and phosphorus.

Treatments and experimental design

The experiment comprised seven weed control treatments—pendimethalin at 1.0 kg a.i. ha^{-1}, pendimethalin at 1.5 kg a.i. ha^{-1}, imazethapyr at 100 g a.i. ha^{-1} applied post-emergence (PoE), pendimethalin at 1.0 kg a.i. ha^{-1} combined with imazethapyr at 100 g a.i. ha^{-1} (PoE), pendimethalin at 1.0 kg a.i. ha^{-1} followed by supplementary hoe weeding (SHW) at 6 weeks after sowing (WAS), hoe weeding at 3 and 6 WAS, and a weedy check, together with three soybean varieties (TGX 1448-2E, TGX 1835-10E, and TGX 1951-1D).The trial was laid out in a split-plot design with weed control treatments assigned to main plots and varieties to subplots, replicated three times.

Varietal characteristics and source

The soybean varieties used were sourced from the International Institute of Tropical Agriculture (IITA), Kano station. TGX 1448-2E is medium maturing, high-yielding (1,700-2300 kg ha^{-1}), with low pod shattering, high oil content, and excellent grain color. TGX 1835-10E is early maturing, resistant to rust and bacterial pustule. TGX 1951-1D is medium maturing, with tolerance to rust and bacterial pustule, and resistance to pod shattering.

Cultural practices

At each site, the land was ploughed and harrowed, then ridged 0.75 m apart. Each gross plot measured 2.0 × 4.5 m (9 m^2), while the net plot size was 2.0 × 1.5 m (3 m^2). A 0.5 m lee way was left between plots and 1.5 m between replications. Seeds were manually planted at three seeds per hole, later thinned to two seedlings per stand at 2 WAS, with spacing of 0.75 m between rows and 0.10 m within rows.

Pre-emergence herbicides were applied one day after sowing, while post-emergence imazethapyr was applied at 3 WAS according to treatment. Applications were carried out in the morning using a CP_3 knapsack sprayer fitted with a flat-fan nozzle, calibrated at 2.1 kg m^{-2} to deliver 250 L ha^{-1}, minimizing spray drift. Fertilizer was applied at the rate of 20 kg N, 40 kg P_2O_5, and 20 kg K_2O ha^{-1}, supplied as NPK (15:15:15) and SSP. The SSP was basally applied at sowing while NPK was applied at 2 WAS. Hoe weeding was carried out manually on treatment basis (either at 3 and 6 WAS, or as supplementary weeding at 6 WAS. Harvesting was done when pods turned pale yellow, indicating physiological maturity, and before full dryness to minimize shattering losses.

Data collection

Growth parameters recorded were plant height (cm), number of leaves per plant, leaf area index (LAI), and days to 50% flowering. Plant height and leaf number were measured at 9 weeks after sowing (WAS) from five randomly tagged plants per plot. LAI was also measured at 9 WAS using an AccuPAR LP-80 ceptometer, with readings taken above and below the canopy. Days to 50% flowering were determined as the interval from sowing until half of the plants in each plot had flowered. Yield parameters included number of pods per plant and pod yield (kg). Pods per plant were counted from five tagged plants at 12 WAS, while pod yield was obtained from net plot harvests, weighed using a Mettler Toledo SB 8001 monobloc balance, and expressed in kilograms per hectare. Similarly, data on weed parameters were collected, including weed dry weight, weed index, and weed control efficiency. Weed dry weight was determined by oven-drying sampled weeds at 70 ºC for 48 hours to a constant weight. Weed index was calculated using the formula: WI (%) $= \frac{X - Y}{X} \times 100$….Equa 1

where X = yield in the weed-free plot and Y = yield in the treated plot.

Weed control efficiency was calculated as: WCE (%) = $\frac{Wc - Wt}{Wc} \times 100.$ …….Equa 2

where Wc = weed dry weight in the control plot and Wt = weed dry weight in the treated plot. These parameters were used to assess the effectiveness of the weed management treatments.

Statistical analysis

All data generated were subjected to analysis of variance (ANOVA) using GenStat statistical package (17th Edition). Means showing significant differences were separated using the Student–Newman–Keuls (SNK) test at the 5% probability level.

RESULTS AND DISCUSSION

The results of the soil analysis for the experimental sites at BUK and Bunkure are presented in Table 1. At BUK, the soil was classified as sandy loam, with a particle size distribution of 665 g kg^{-1} sand, 230 g kg^{-1} silt, and 105 g kg^{-1} clay. The soil was slightly acidic with a pH of 6.10 and had low organic carbon (0.65%), total nitrogen (0.06%), and phosphorus (4.89 mg g^{-1}). The electrical conductivity (EC) was 108.2 µS cm^{-1}, while the exchangeable bases were 0.20, 2.90, and 0.84 cmol kg^{-1} for K^+, Ca^{2+}, and Mg^{2+}, respectively. At Bunkure, the soil was also sandy loam but more acidic than BUK, with a pH of 5.62. The particle size distribution was 720 g kg^{-1} sand, 180 g kg^{-1} silt, and 100 g kg^{-1} clay. Organic carbon content (0.47%) was lower than at BUK, but total nitrogen (0.24%) and phosphorus (9.52 mg g^{-1}) were higher. The EC was 246 µS cm^{-1}, and exchangeable K^+, Ca^{2+}, and Mg^{2+} were 0.18, 1.93, and 0.35 cmol kg^{-1}, respectively.

Overall, both soils were sandy loam with inherently low fertility, a common feature of semi-arid savanna soils that often limits water-holding capacity and nutrient retention (Brady & Weil, 2019; FAO, 2021). While Bunkure contained more nitrogen and phosphorus, its lower organic carbon may restrict microbial activity and long-term nutrient cycling, whereas BUK soils, despite slightly higher organic carbon, remained limited in nitrogen and phosphorus. These constraints highlight the importance of soil amendments and fertilizer application to enhance soybean growth and productivity under the Sudan savanna environment (Havlin et al., 2016; Lal, 2020; Shittu et al, 2025).

Table 1: Physical and Chemical Properties of the Soils of the Experimental Sites during 2022 rainy season

Properties	BUK	Bunkure
Physical (g kg^{-1})		
Sand	665	720
Silt	230	180
Clay	105	100
Textural class	Sandy Loam	Sandy Loam
Chemical Composition		
pH in H_2O	6.10	5.62
Organic carbon (%)	0.65	0.47
Total nitrogen (%)	0.06	0.24
Available Phosphorus (mg g^{-1})	4.89	9.52
Exchangeable bases (cmol kg^{-1})		
Mg^{++}	0.84	0.35
Ca^{++}	2.90	1.93
K^{+}	0.20	0.18
EC(Us/cm)	108.2	246

Analysed at the Department of Soil Science, Bayero University Kano

Effect of weed control treatment and variety on Plant height, Number of leaves per plant and Leaf area index

Table 2 shows the effects of weed control treatments and soybean varieties on plant height, number of leaves per plant, and leaf area index at BUK and Bunkure during the 2022 rainy season. At both locations, weed control treatments significantly ($p < 0.001$) influenced plant height. At BUK, the application of pendimethalin at 1.0 kg a.i. ha^{-1} + imazethapyr at 100 g PoE produced the tallest plants, which were statistically similar to two hoe weedings (HW) at 3 and 6 WAS and to pendimethalin at 1.0 kg a.i. ha^{-1} + HW at 6 WAS. In contrast, the weedy check consistently resulted in the shortest plants. A similar trend was observed at Bunkure. Variety also had a significant ($p < 0.001$) effect on plant height at both sites. TGX 1951-3F produced the tallest plants, while TGX 1448-2E had the shortest. However, no significant interaction between weed control treatments and variety was observed for plant height at either location.

Weed control treatments also significantly ($p < 0.001$) affected the number of leaves per plant at BUK and Bunkure. At BUK, pendimethalin at 1.0 kg a.i. ha^{-1} + imazethapyr at 100 g ha^{-1} and two HW at 3 and 6 WAS produced the highest number of leaves, followed closely by pendimethalin at 1.0 kg a.i. ha^{-1} + HW at 6 WAS and imazethapyr at 100 g ha^{-1}. The weedy check consistently produced the fewest leaves. A comparable pattern was observed at Bunkure. Varietal effects on leaf number were significant at BUK, where TGX 1448-2E and TGX 1835-10E were statistically similar and produced more leaves ($p < 0.001$) than the other variety. At Bunkure, however, variety had no significant ($p > 0.05$) effect.

Table 2. Effect of Weed Control Treatments and Variety on Plant Height, Number of Leaves and Leaf Area Index of Soybean at BUK and Bunkure during the 2022 Rainy Season

	BUK			Bunkure		
Treatment	Plant height (cm)	Number of leaves plant^{-1}	Leaf Area index	Plant height (cm)	Number of leaves plant^{-1}	Leaf Area index
Weed Control (WC)						
Pendimethalin (PE) at 1.5 kg a.i. ha^{-1}	43.56c	22.24cd	3.33c	44.16c	23.11c	3.72c
Pendimethalin (PE) 1.0 kg a.i. ha^{-1}	51.70b	21.05d	2.77d	50.88bc	21.00d	2.74d
Imazethapyr at 100 g PoE	50.15b	22.89bc	3.61bc	49.02bc	23.77c	4.05c
Pendimethalin at 1.0 kg a.i. ha^{-1} + Imazethapyr 100 g ha^{-1}	57.70a	26.87a	5.49a	67.36a	30.53a	6.10a
Pendimethalin at 1.0 kg a.i. ha^{-1} + HW at 6 WAS	53.78ab	23.80b	4.04b	55.83b	26.17b	5.13b
Hoe Weeding at 3 and 6 WAS	60.30a	27.46a	5.71a	62.89ab	30.69a	6.65a
Weedy check	40.30d	19.75e	2.19e	40.02d	19.18e	1.93d
p-value	0.003	<.001	<.001	<.001	<.001	<.001
SE±	2.74	0.55	0.25	3.20	0.66	0.40
Variety (V)						
TGX 1448-2E	46.76b	23.80a	3.70b	50.02b	25.27	4.47
TGX 1835-10E	47.25b	23.78a	4.03a	51.10b	25.14	4.65
TGX 1951-3F	50.62a	22.73b	3.90ab	57.94a	24.35	4.72
p-value	0.022	<.001	0.047	0.002	0.090	0.504
SE±	1.41	0.28	0.12	2.10	0.43	0.11
Interaction						
WC × V	0.358	0.028	0.200	0.333	0.009	0.290

Means in a column sharing the same letter are not significantly different at 5 % level of probability using SNK

A significant interaction between weed control treatments and variety was observed for the number of leaves per plant at both locations (Figure 1). At BUK, the combination of two HW at 3 and 6 WAS with TGX 1951-3F produced the highest number of leaves, which was statistically similar to application of pendimethalin at 1.0 kg a.i. ha⁻¹ + imazethapyr at 100 g ha⁻¹ combined with TGX 1835-10E and TGX 1951-3F. In contrast, the weedy check combined with TGX 1448-2E recorded the lowest number of leaves. At Bunkure, the combination of pendimethalin at 1.0 kg a.i. ha⁻¹ + imazethapyr at 100 g ha⁻¹ with TGX 1448-2E and TGX 1835-10E resulted in the highest number of leaves per plant, though statistically at par with other treatment–variety combinations. Across both sites, all varieties under the weedy check consistently produced the fewest leaves.

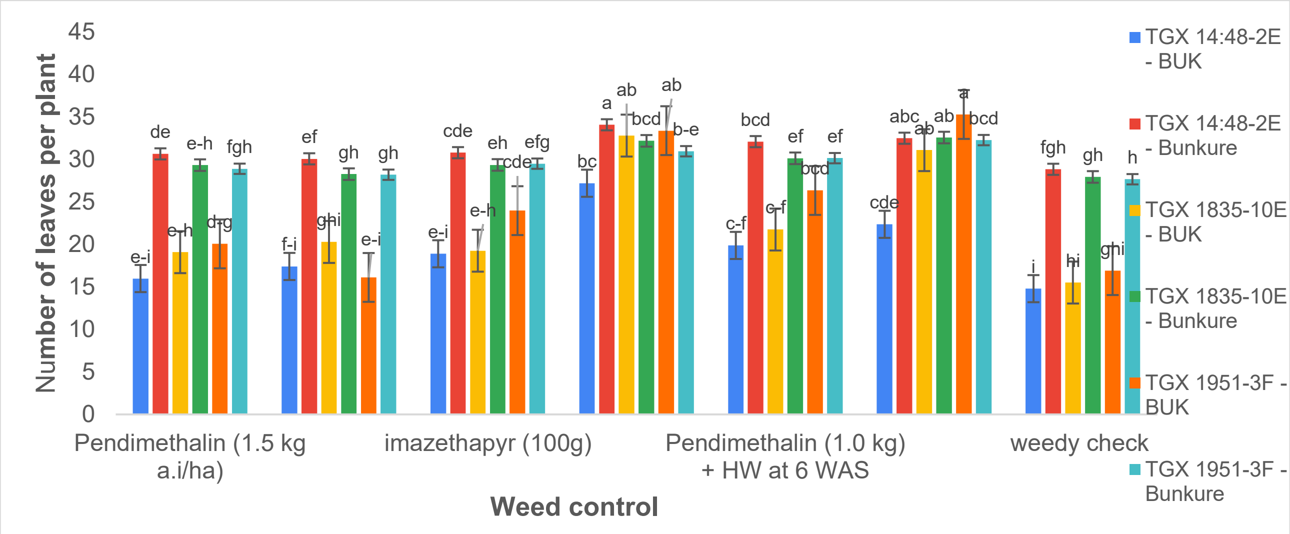

Figure 1: Interaction of weed control with variety on number of leaves per plant at BUK and Bunkure during the 2022 Rainy season.

The results also showed a significant effect of weed control treatments on leaf area index (LAI) at both locations (Table 2). At BUK, the application of pendimethalin at 1.0 kg a.i. ha⁻¹ + imazethapyr at 100 g produced the highest LAI ($p < 0.001$), which was statistically similar to two HW at 3 and 6 WAS. This was followed by application of pendimethalin at 1.0 kg a.i. ha⁻¹ + HW at 6 WAS, while the weedy check consistently recorded the lowest LAI. A similar trend was observed at Bunkure.

Variety also had a significant effect on LAI at BUK, where TGX 1951-3F produced the highest ($p < 0.05$) values. TGX 1448-2E recorded the lowest LAI, which was statistically similar to TGX 1835-10E. However, at both locations, the interaction between weed control treatments and variety was not significant ($p > 0.05$).

Effect of Weed Control Treatment and Variety on Phenological and Yield Traits

The effects of weed control treatments and soybean varieties on days to 50% flowering, number of pods per plant, and pod yield per hectare at BUK and Bunkure during the 2022 rainy season are presented in Table 4. At both locations, weed control treatments significantly $p < 0.001$) affected days to 50% flowering. At BUK, the weedy check delayed flowering the most (58.11 days), while all other treatments were statistically similar, resulting in earlier flowering (52.33–53.11 days). A comparable trend was observed at Bunkure, where the weedy check took the longest to flower (60.67 days) compared with all other treatments (54.89–56.00 days). Variety also had a significant effect at both locations: TGX 1448-2E flowered latest (55.86 days at BUK), while TGX 1951-3F flowered earliest (49.19 days), with the same trend observed at Bunkure. No significant ($p > 0.05$) interaction between weed control treatments and variety was observed for days to 50% flowering at either site.

Weed control treatments also significantly influenced the number of pods per plant at both locations. At BUK, hoe weeding (HW) at 3 and 6 WAS produced the highest number of pods (117.9), followed by pendimethalin at 1.0 kg a.i. ha⁻¹ + imazethapyr at 100 g ha⁻¹ (106.4). The weedy check recorded the fewest pods (43.0). Similarly, at Bunkure, HW at 3 and 6 WAS produced the highest number of pods (151.1), which was statistically similar to pendimethalin + imazethapyr (133.2), while the weedy check produced the lowest (38.7).

Variety had a significant effect on pod production at both sites. TGX 1951-3F consistently produced the highest number of pods (94.0 at BUK and 112.2 at Bunkure), while TGX 1448-2E recorded the lowest (63.3 and 70.6, respectively).

A significant ($p < 0.05$) interaction between weed control treatments and variety was observed for pod number at both BUK and Bunkure (Figure 2). At BUK, HW at 3 and 6 WAS combined with TGX 1951-3F and TGX 1835-10E resulted in the highest pod counts (135.48 and 121.51, respectively). At Bunkure, HW at 3 and 6 WAS combined with TGX 1951-3F produced the greatest number of pods (194.9), while all varieties under the weedy check recorded the lowest pod counts.

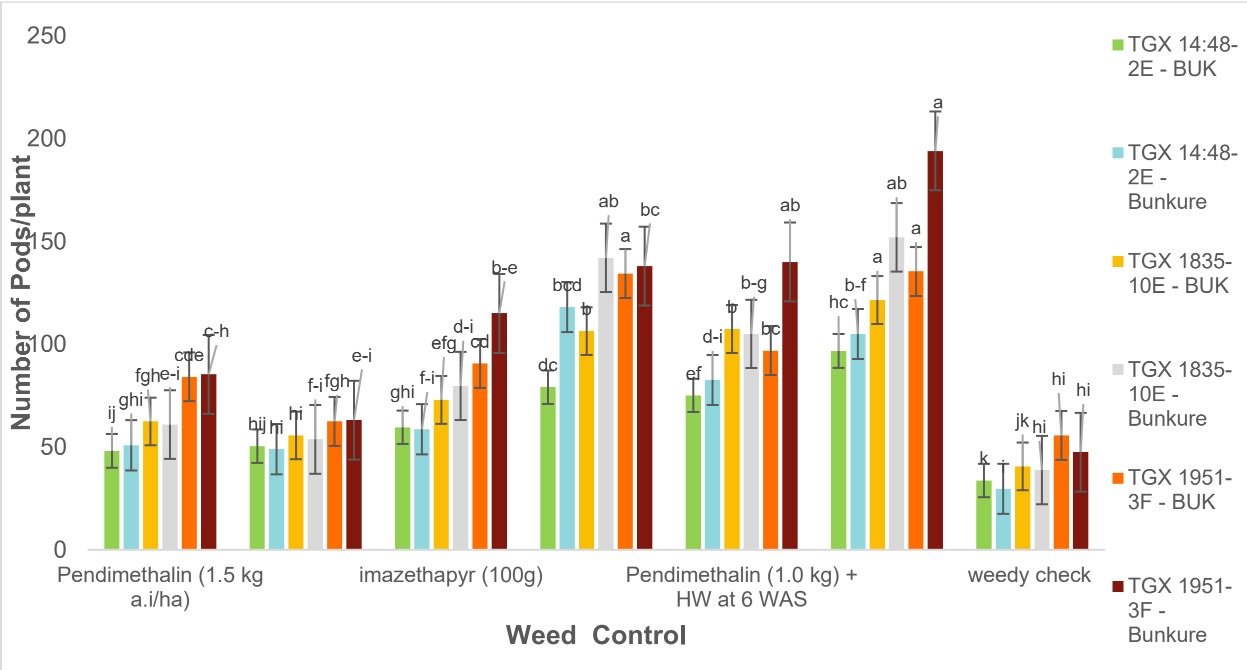

Figure 2: Interaction of weed control with variety on number of pods per plant at BUK and Bunkure during the 2022 Rainy season.

Table 3. Effect of Weed Control Treatments and Variety on Days to 50% flowering, Number of Pods per plant and Pod yield of Soybean at BUK and Bunkure during the 2022 Rainy Season

Treatment	BUK			Bunkure		
	Days to 50% flowering	Number of Pods plant^{-1}	Pod Yield (kg ha^{-1})	Days to 50% flowering	Number of Pods plant^{-1}	Pod Yield (kg ha^{-1})
Weed control (WC)						
Pendimethalin (PE) at 1.5 kg a.i. ha^{-1}	53.11b	64.6e	1,987d	56.00b	65.7cd	2,152d
Pendimethalin (PE) 1.0 kg a.i. ha^{-1}	52.33b	56.2f	1,829e	54.89b	55.2de	1,931d
Imazethapyr at 100 g PoE	52.56b	74.5d	2,112d	55.22b	84.5c	2,531c
Pendimethalin at 1.0 kg + Imazethapyr 100 g a.i. ha^{-1}	53.00b	106.4b	2,675b	55.67b	133.2a	3,557a
Pendimethalin at 1.0 kg a.i. ha^{-1} + HW at 6 WAS	52.67b	93.1c	2,309c	54.89b	109.5b	3,008b
Hoe weeding at 3 and 6 WAS	52.33b	117.9a	2,904a	55.22b	151.1a	3,707a
Weedy check	58.11a	43.0g	1,403f	60.67a	38.7e	1,363e
p-value	<.001	<.001	<.001	<.001	<.001	<.001
SE±	0.90	3.00	61.6	0.80	6.36	141.6
Variety (V)						
TGX 1448-2E	55.86a	63.3c	1,856c	56.95a	70.7c	2,075c
TGX 1835-10E	52.29b	80.9b	2,213b	53.67b	90.4b	2,448b
TGX 1951-3F	49.19c	94.0a	2,456a	50.62c	112.2a	2,899a
p-value	<.001	<.001	<.001	0.012	<.001	<.001
SE±	0.46	2.80	34.7	0.46	3.21	68.3
Interaction						
WC × V	0.198	0.012	<0.001	0.212	0.009	<0.001

Means in a column sharing the same letter are not significantly different at 5 % level of probability using SNK

Results further revealed that weed control treatments significantly influenced pod yield at both locations. At BUK, the highest yield was obtained with HW at 3 and 6 WAS (2,904 kg ha^{-1}), followed by pendimethalin at 1.0 kg a.i. ha^{-1} + imazethapyr at 100 g ha^{-1} (2,675 kg ha^{-1}), while the weedy check produced the lowest yield (1,403 kg ha^{-1}). At Bunkure, HW at 3 and 6 WAS also gave the highest yield (4,715 kg ha^{-1}), which was statistically similar to pendimethalin + imazethapyr (4,587 kg ha^{-1}). The weedy check consistently recorded the lowest yield (1,323 kg ha^{-1}). Varietal effects on pod yield were also significant. At BUK, TGX 1951-3F produced the highest yield (2,456 kg ha^{-1}), whereas TGX 1448-2E had the lowest (1,854 kg ha^{-1}). A similar trend was observed at Bunkure, where TGX 1951-3F recorded the highest yield (2,899 kg ha^{-1}).

A significant interaction between weed control treatments and variety was detected at both sites (Figure 3). At BUK, HW at 3 and 6 WAS combined with TGX 1951-3F resulted in the highest yield (3,283 kg ha^{-1}). At Bunkure, pendimethalin at 1.0 kg a.i. ha^{-1} + imazethapyr at 100 g ha^{-1} combined with TGX 1951-3F produced the highest pod yield (4,587 kg ha^{-1}), which was statistically similar to HW at 3 and 6 WAS combined with TGX 1951-3F (4,715 kg ha^{-1}). Across both locations, all varieties under the weedy check consistently produced the lowest pod yields.

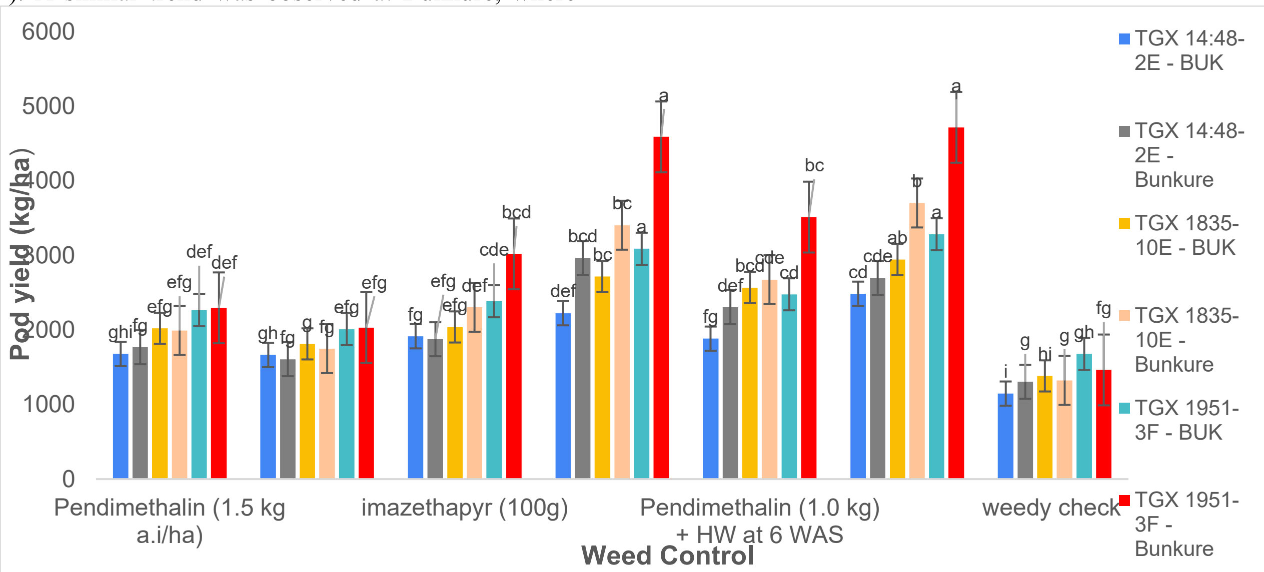

Figure 3: Interaction of weed control and variety on Pod yield of soybean at BUK and Bunkure during the 2022 Rainy season.

Effect of Weed Control Treatment and Variety on Weed Dry Weight, Weed Control Efficiency, and Weed Index

Table 4 summarizes the effects of weed control methods and soybean varieties on weed dry weight, weed control efficiency, and weed index at BUK and Bunkure during the 2022 rainy season.

Weed control treatments significantly influenced weed dry weight at both locations. At BUK, the lowest weed dry weight was recorded in plots treated with hoe weeding (HW) at 3 and 6 WAS (40.9 g), followed by pendimethalin at 1.0 kg a.i. ha^{-1} + imazethapyr at 100 g ha^{-1} (70.0 g), and pendimethalin at 1.0 kg a.i. ha^{-1} + HW at 6 WAS (95.8 g). In contrast, the weedy check produced the highest weed dry weight (139.7 g). A similar pattern was observed at Bunkure, where HW at 3 and 6 WAS recorded the lowest weed dry weight (31.9 g), while the weedy check resulted in the highest (159.8 g).

Variety also had a significant ($p < 0.001$) effect on weed dry weight at both locations. At BUK, TGX 1951-3F recorded the lowest weed dry weight (86.7 g), while TGX 1448-2E had the highest (113.3 g). Similarly, at Bunkure, TGX 1951-3F produced the lowest value (88.7 g), whereas TGX 1448-2E recorded the highest (105.3 g).

A significant interaction of weed control treatments and variety was observed at BUK but not at Bunkure. As shown in Figure 4, the weedy check combined with TGX 1448-2E produced the highest weed dry weight (157.3 g), while all varieties under hoe weeding at 3 and 6 WAS were statistically similar and consistently recorded the lowest values.

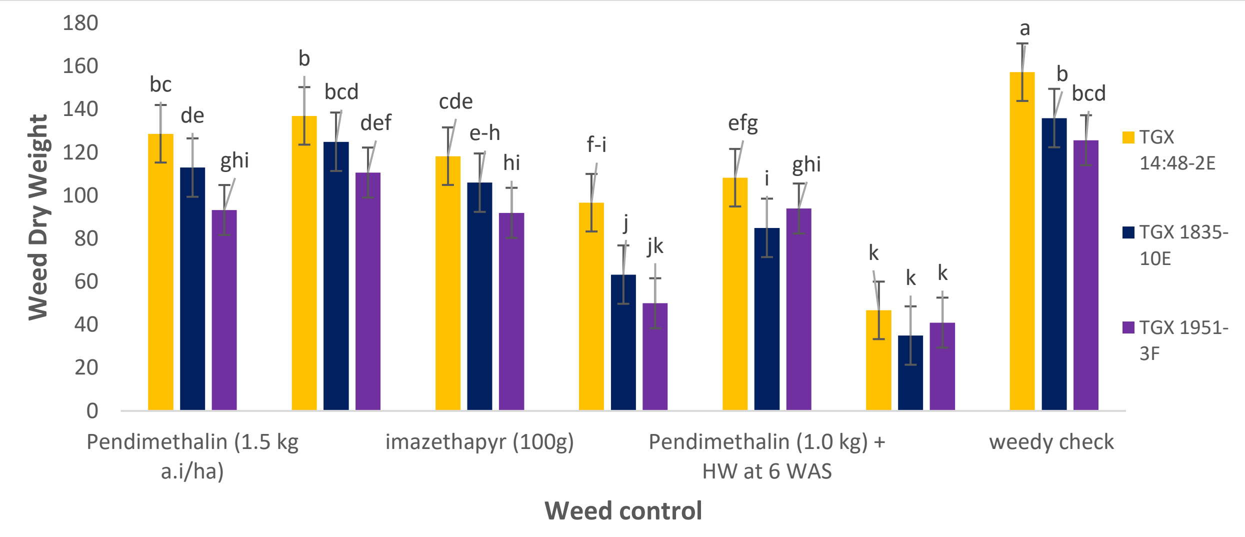

Figure 4: Interaction of Weed control and Variety on Weed dry weight at BUK during the 2022 Rainy season.

Similarly, weed control treatments significantly influenced weed control efficiency at both locations. At BUK, hoe weeding (HW) at 3 and 6 WAS (70.61%) and the combination of pendimethalin (1.0 kg a.i. ha^{-1}) + imazethapyr (100 g ha^{-1}) (65.79%) were statistically similar and recorded the highest efficiency, while the weedy check had the lowest (0.00%). A comparable pattern was observed at Bunkure, where HW at 3 and 6 WAS (84.01%) and the pendimethalin + imazethapyr combination (79.72%) were most effective. Neither variety nor the interaction between weed control and variety had a significant effect on weed control efficiency at either location.

Weed control treatments also had a significant effect on the weed index at both sites. The weedy check recorded the highest values at BUK (62.12%) and Bunkure (74.30%), whereas HW at 3 and 6 WAS resulted in the lowest (0.00%), statistically similar to plots treated with pendimethalin (1.0 kg a.i. ha^{-1}) + imazethapyr (100 g ha^{-1}). Variety significantly ($p < 0.001$) affected the weed index at both locations. At BUK, TGX 1951-3F and TGX 1448-2E recorded the lowest values, while TGX 1835-10E had the highest. At Bunkure, TGX 1448-2E produced the lowest weed index, whereas TGX 1835-10E and TGX 1951-3F recorded the highest.

A significant interaction between weed control treatments and variety was observed at both locations (Figure 5). The weedy check consistently produced the highest weed index across all varieties, while HW at 3 and 6 WAS combined with any variety resulted in the lowest values. At BUK, the pendimethalin (1.0 kg a.i. ha^{-1}) + imazethapyr (100 g ha^{-1}) treatment combined with TGX 1835-10E and TGX 1951-3F achieved similarly low indices. At Bunkure, the combination of pendimethalin (1.0 kg a.i. ha^{-1}) + HW at 6 WAS with all varieties produced comparable effects.

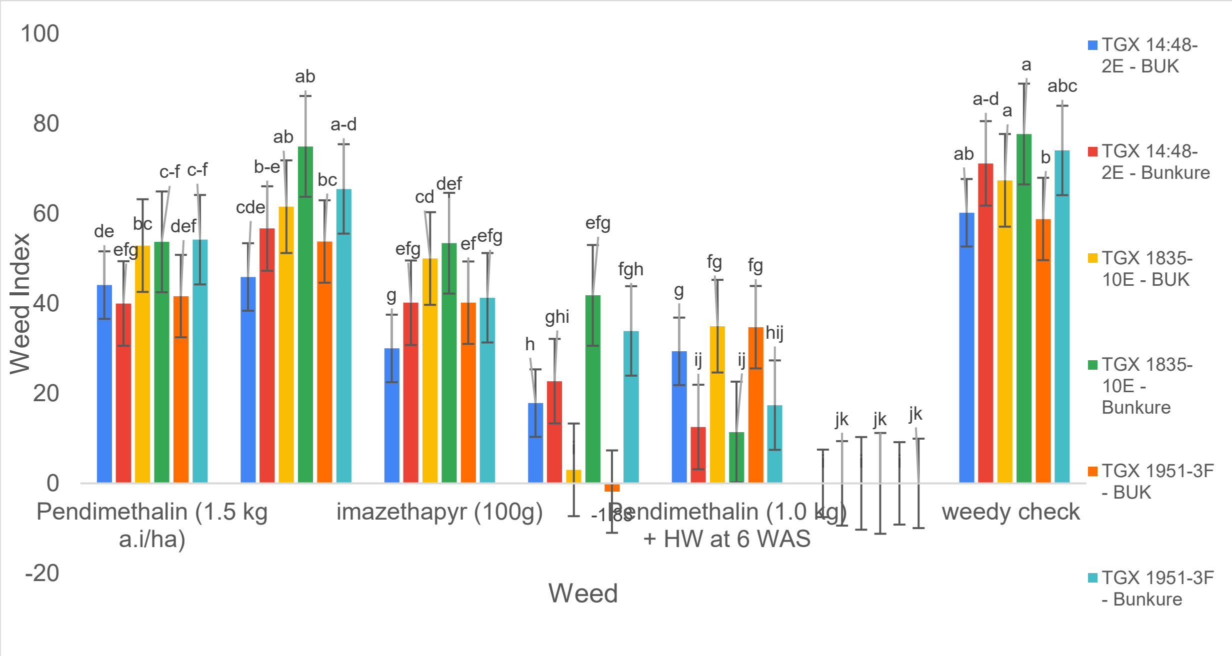

Figure 5: Interaction of Weed control and Variety on Weed index at BUK and Bunkure during the 2022 Rainy season.

Table 4. Effect of Weed Control Treatments on Weed Dry Weight, Weed Control Efficiency and Weed Index on Soybean Varieties at BUK and Bunkure during the 2022 Rainy Season

	BUK			Bunkure		
Treatment	Weed dry weight (g)	Weed control efficiency (%)	Weed Index (%)	Weed dry weight (g)	Weed control efficiency (%)	Weed Index (%)
Weed control (WC)						
Pendimethalin (PE) at 1.5 kg a.i. ha^{-1}	111.7c	40.07c	46.21c	121.8b	44.60d	49.30c
Pendimethalin (PE) 1.0 kg a.i. ha^{-1}	124.2b	30.95d	53.74b	130.4b	39.36d	65.69b
Imazethapyr at 100 g PoE	105.4c	44.31c	40.07c	100.0c	49.70c	44.95c
Pendimethalin at 1.0 kg + Imazethapyr 100 g a.i. ha^{-1}	70.0e	65.79a	6.34e	54.3e	79.72a	5.43e
Pendimethalin at 1.0 kg a.i. ha^{-1} + HW at 6 WAS	95. 8d	51.32b	33.02d	76.1d	65.28b	32.81d
Hoe weeding at 3 and 6 WAS	40. 9f	70.61a	0.00e	31.9f	84.01a	0.00e
Weedy check	139.7a	0.00e	62.12a	159.8a	0.00e	74.30a
p-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
SE±	5.10	3.92	2.75	5.16	3.70	2.46
Variety (V)						
TGX 1448-2E	113.3a	27.83	32.48b	105.3a	38.90	31.17b
TGX 1835-10E	94.8b	30.27	38.54a	95.0b	40.00	44.71a
TGX 1951-3F	86.7c	31.07	32.47b	88.7b	46.40	40.90a
p-value	<.001	0.290	<.001	0.003	0.207	<.001
SE±	2.80	2.09	1.54	4.35	4.44	2.02
Interaction						
WC × V	0.039	0.060	<0.001	0.776	0.984	0.023

Means in a column sharing the same letter are not significantly different at 5 % level of probability using SNK

DISCUSSION

Effect of Weed Control Methods on Soybean Productivity

The significant yield advantage observed in treated plots compared to the weedy control underscores the vital importance of early-season weed interference mitigation for maximizing the genetic potential of soybean in semi-arid environments. Improved growth, higher LAI, and greater yield attributes in treated plots are likely due to reduced competition for light, nutrients, and water, which enhanced photosynthesis and assimilate partitioning. Similar benefits of weed management on crop performance have been reported in soybean (Otto et al., 2024; Pokhrel et al., 2025) and groundnut (Shittu et al., 2022; 2023). The comparable effectiveness of hoe weeding at 3 and 6 WAS and the combination of pendimethalin with imazethapyr reflects the ability of these methods to control both broadleaf and grassy weeds, in line with recommendations by Walia et al. (2021) and Jatto & Yakub (2022). Integrating pendimethalin with hoe weeding further supports earlier reports that combined chemical and manual approaches offer superior and more sustainable weed control Avidimel & Manasseh (2022) and Choudhary et al., 2025).

Varietal Performance of Soybean

Genotypic differences also influenced soybean productivity, as TGX 1951-3F consistently exhibited stronger growth and yield performance. Its taller canopy and higher LAI likely improved resource capture and suppressed weed growth, consistent with findings that vigorous, early-closing canopies reduce weed competition (Sadiq et al., 2022; Apon & Nongmaithem, 2022; Abubakar et al., 2025). In contrast, TGX 1448-2E and TGX 1835-10E showed less competitive ability, reinforcing the role of genetic traits in determining varietal adaptability under weedy conditions (Kipshakbayeva et al., 2024; Shittu, 2025).

Interaction of Weed Control and Variety

The significant weed control × variety interactions observed in this study demonstrate that soybean response to weed management is strongly mediated by varietal traits governing early vigor, canopy architecture, and competitive ability. Varieties exhibiting rapid emergence, greater leaf area expansion, and improved branching can more effectively utilize reduced weed pressure to enhance radiation interception, resource capture, and biomass accumulation during critical growth stages. In contrast, less competitive genotypes experience greater yield penalties under prolonged weed interference due to reduced assimilate production and partitioning efficiency. The superior performance of TGX 1951-3F under effective weed suppression reflects its capacity to translate improved resource availability into reproductive output, consistent with established genotype × management interaction principles in soybean production systems (Ezin et al., 2025). Comparable synergistic responses between varietal competitiveness and weed control efficiency have also been documented in groundnut and other legumes under savanna conditions (Shittu et al., 2022; 2025).

Conclusion and Recommendations

Effective weed control significantly enhanced soybean growth and productivity in the Sudan savannah of Nigeria. The best performance was recorded with weeding at 3 and 6 WAS. Pendimethalin at 1.0 kg a.i. ha^{-1} + imazethapyr at 100 g ha^{-1} gave a comparable result with less labour. The productivity further enhanced by pendimethalin at 1.0 kg a.i. ha^{-1} + Imazethapyr at 100 g + HW at 6 WAS, proves the advantage of integrated weed management. TGX 1951-3F consistently out yielded the varieties TGX 1835-10E and TGX 1448-2E as a result of its better growth and competitive ability against weeds. Thus, the use of competitive soybean varieties particularly TGX 1951-3F and integrated weed management strategies are recommended for sustainable weed suppression and improved soybean productivity in the Sudan Savannah of Nigeria

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