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Impact of Weed Management Strategies on Soil Chemical Properties, Fertility Dynamics, and Sesame (*Sesamum indicum* L.) Productivity in a Semi-Arid Environment

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Abstract
Weed competition is a major constraint to sesame production in semi-arid regions, necessitating sustainable weed management strategies. This study evaluated the efficacy of eleven weed control treatments, including hoe weeding, Pendimethalin herbicide, and *Tithonia diversifolia* extract, on weed suppression, soil fertility, and sesame yield at two locations in Northern Nigeria. The experiment was laid a randomized complete block design with three replications. Soil physicochemical properties were assessed pre-and post-treatment. Results indicated that hoe weeding at 3 and 6 significantly ($p < 0.05$) resulted in the highest yield (1.624 t ha^{-1} at BUK and 1.544 t ha^{-1} at Bagauda) with the lowest weed density and weed index. Among integrated treatments, Pendimethalin at 1.0 kg a.i ha^{-1} with *Tithonia diversifolia* extract (10% W/V) as post-emergence at 6 WAS significantly ($P < 0.001$) reduced weed density (81.0 m^2 at BUK and 141.7 m^2 at Bagauda) and increased yield (1.421 t ha^{-1} at BUK and 1.305 t ha^{-1} at Bagauda). Soil fertility analysis showed improvements in organic carbon and phosphorus levels under *Tithonia*-based treatments, suggesting its potential as a sustainable organic amendment and bioherbicide. These findings emphasize the importance of integrated weed management to enhance productivity while maintaining soil health. Future studies should explore the long-term effects of *Tithonia diversifolia* on soil ecosystems.

Keywords: Sesame, Pendimethalin, *Tithonia diversifolia*, Soil fertility, Integrated weed management

Introduction

Sesame (*Sesamum indicum* L.) is a vital oilseed crop cultivated in many semi-arid regions due to its high economic value and adaptability to low-input farming systems (Bedigian, 2021). However, weed infestation is a significant challenge in sesame production, as weeds compete for nutrients, water, and light, ultimately reducing yield (Zimdahl, 2018; Shittu et al., 2023 & 2024). Additionally, soil fertility plays a crucial role in agricultural productivity, particularly in semi-arid regions where soil degradation and nutrient depletion pose serious constraints (Lal, 2020). Effective weed management practices not only control weed competition but also influence soil physicochemical properties, including organic matter content, nutrient cycling, and microbial activity (Jabran et al., 2021). Weed control methods vary widely, including mechanical, chemical, and organic approaches. However, concerns over the environmental and soil health impacts of chemical herbicides, have necessitated the exploration of alternative weed management strategies (Damalas &Koutroubas, 2019). Organic amendments and allelopathic plant extracts, such as *Tithonia diversifolia* (Mexican sunflower), have gained attention due to their potential to suppress weeds while simultaneously enhancing soil fertility (Khan et al., 2021; Kato-Noguchi, 2020). Weed infestation remains one of the major constraints in sesame production, often leading to significant yield reductions if not properly managed. The widespread use of synthetic herbicides, though effective, raises concerns about soil degradation, disruption of microbial activity, and long-term environmental sustainability (Jabran et al., 2021; Zhou et al.,2024). While organic amendments have been widely promoted for improving soil properties, their role in weed suppression has not been fully explored. *Tithonia diversifolia*, known for its allelopathic properties, has the potential to serve as a dual-purpose soil amendment, both as a weed

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suppressor and a soil fertility enhancer (Adekiya et al., 2020; Farooq *et al*., 2020; Shittu et al., 2025). However, the extent to which *Tithonia diversifolia* influences soil chemical properties when used in weed control remains underexplored, particularly in sesame cultivation.

Understanding the impact of different weed control strategies on soil properties is essential for sustainable sesame production. Integrating allelopathic plant extracts, such as *Tithonia diversifolia,* with conventional weed management approaches may offer an eco-friendly alternative that ensures effective weed suppression while maintaining soil fertility (Brady &Weil, 2019). Additionally, the long-term effects of pendimethalin application on soil chemical properties must be evaluated to develop more sustainable weed management strategies. The findings from this study will provide valuable insights into the effects of different weed control treatments on soil fertility, particularly in sesame fields in semi-arid environments. Thus, this study was aimed at evaluating the impact of different weed management strategies, including *Tithonia diversifolia* extract, on soil chemical properties, fertility dynamics, and yield of sesame productivity in a semi-arid environment.

Materials and Methods

Experimental Location, Treatment and Experimental Design

The experiment was established during the 2019 wet cropping season at the Research and Training Farm of the Centre for Dryland Agriculture, Bayero University Kano (11°58'52.5" N and 008°24'48.6") and National Horticultural Research Institute, Bagauda (11°33'25.93" N and 008°23'11.97" E) in the Northern part of Nigeria. Eleven weed management strategies were used. These are; hoe weeding at 3 and 6 weeks after sowing (WAS), Pendimethalin at 1 kg a.i ha^{-1}, Pendimethalin at 1.5 kg a.i ha^{-1}, Pre-emergence application of *Tithonia* at 5% weight by volume (W/V), *Tithonia* extract as pre-emergence at 10% (W/V), Pre-emergence application of *Tithonia* extract at 5% (W/V) and *Tithonia* extract 5% (W/V) as post-emergence at 6 WAS, Pre-emergence application of *Tithonia* extract 5% (W/V) and *Tithonia* extract 10% (W/V) as post-emergence (POE) at 6WAS, Pendimethalin at 1.0 kg a.i ha^{-1} and *Tithonia* extract at 5% (W/V) as POE at 6WAS, Pendimethalin at 1.0 kg a.i ha^{-1} and *Tithonia* extract 10% (W/V) as post-emergence at 6WAS, Pendimethalin at 1.0 kg a.i ha^{-1} and hoe weeding at 6 WAS as well as Weedy check. The experiments were arranged in a Randomized Complete Block Design with three replications. Sesame variety ex-sudan obtained from Jigawa Research Institute was used. The size of the plot was 13.5 m^2, consisting of six ridges each 3 m long spaced at 0.75m apart. The net plot was 4.5 m^2 consisting of the two innermost ridges.

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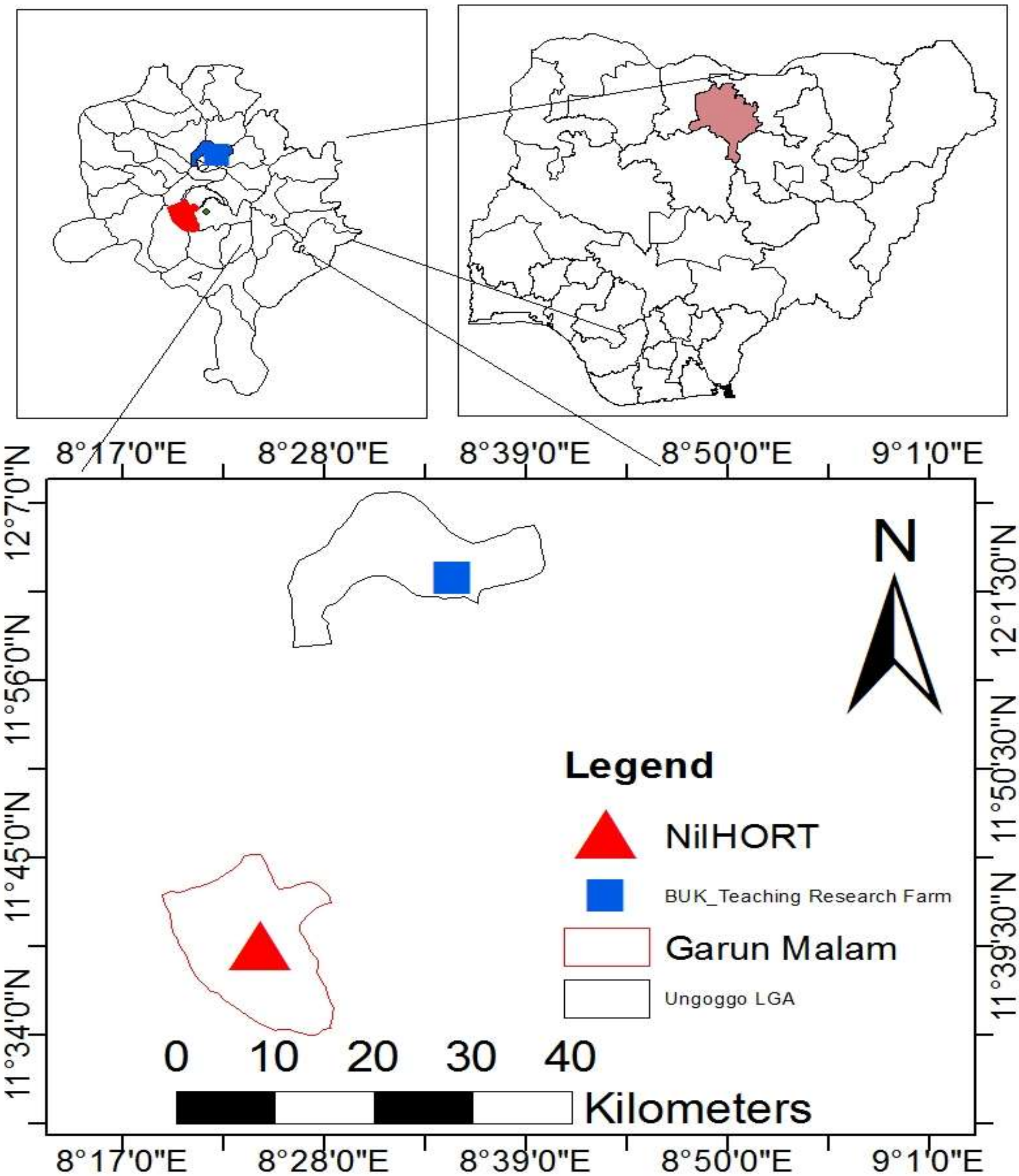

Preparation of *Tithonia diversifolia* extract

The shoots of *Tithonia diversifolia* were collected from bushes and dried under shade. The dried shoots were broken into pieces ground into a fine powder and sieved. The powder was drenched in a proportion of 1000 g to 10 L of distilled water to obtain a 10% (w/v) concentration. The mixture was filtered through four layers of Muslin cloth to obtain the water extract. 1 L of the extract was diluted to make 5% (w/v) concentrations by adding 1 L of distilled water.

Cultural practices

Pendimethalin is a pre-emergence herbicide used for the control of many categories of weeds. It acts by suppressing cell elongation and cell division. The land was cleared, ploughed, harrowed and made into ridges spaced at 75 cm apart. It was demarcated into plots of 4.5 m x 3m (13.5 m^2). Seeds were sown in moist soil at an inter-row and intra-row spacings of 75 cm and 20 cm respectively. Weeding was done as per treatments. Fertilization was done as par the requirement of the crop as described by Jakusko (2017). Insects' pest was controlled by applying Permethrin 30% at 1.0 kg a.i. ha^{-1} at weekly intervals from flowering to physiological

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maturity. Harvesting was done at maturity when the capsules turned yellow and the basal leaves started dropping. The grains were weighed using electric balance to obtain the grain yield per net plot after threshing and were extrapolated to kilogram per hectare.

Data collection

The weed count was taken from two randomly placed 1 m^2 quadrants in each plot and the mean value was recorded at physiological maturity. Weeds from two randomly placed 1 m^2 quadrants were collected and dried in an oven at 65 ^oC to a constant weight. The dried weeds were weighed using an electric balance (ADAM model, precision = 0.1 g) and extrapolated to kg ha^{-1}. The weed index was determined as the percentage yield loss caused due to weeds as compared to weed-free check. A higher weed index indicates greater loss. Hence, the weed index was calculated using the formula given by Rana & Kumar (2014).

$$\text{Weed index } (\%) = \frac{X - Y}{X} \text{ x } 100$$

Where,
X= Total seed yield from the weed free treatment
Y= Total seed yield from the treatment for which weed index is to be calculated.

Soil Sampling and Preparation

Soil samples were collected from the experimental sites at Bayero University Kano (BUK) and Bagauda before and after the application of weed control treatments. Initial soil samples were taken before treatment application to establish baseline physicochemical properties, while post-treatment samples were collected at harvest to evaluate the impact of weed management practices. Samples were collected from a depth of 0–15 cm using an auger and composited by treatment for uniformity. The collected soil was air-dried, ground, and passed through a 2 mm sieve before laboratory analysis.

Physicochemical Properties Analysis

The particle size distribution (sand, silt, and clay percentages) was determined using the hydrometer method as described by Bouyoucos (1962). The soil textural class was assigned based on the USDA soil classification system. The soil pH was measured in a 1:2.5 soil-to-water suspension using a glass electrode pH meter following the method outlined by McLean (1982). The Walkley-Black wet oxidation method (Nelson & Sommers, 1982) was used to determine soil organic carbon content. Total nitrogen content was analyzed using the Kjeldahl digestion and distillation method (Bremner & Mulvaney, 1982). Extractable phosphorus was determined using the Bray-1 extraction method, followed by colorimetric determination using a spectrophotometer (Bray & Kurtz, 1945).

The calcium (Ca^{2+}) and magnesium (Mg^{2+}) were extracted using 1N ammonium acetate (NH_4OAc) at pH 7.0 and determined via atomic absorption spectrophotometry (Thomas, 1982), while Potassium (K^+) and Sodium (Na^+) were determined using a flame photometer after ammonium acetate extraction (Knudsen *et al.*, 1982). The CEC was determined by summing the exchangeable bases and exchangeable acidity, as described by Rhoades (1982). The extractable micronutrients were determined using DTPA extraction (diethylenetriaminepentaacetic acid) and analyzed via atomic absorption spectrophotometry (AAS) as described by Lindsay & Norvell (1978).

Data Analysis

The data collected were subjected to Analysis of variance with GenStat software, 17th Edition. Where there are significant treatment means, they were separated using the Students Newman-Keuls Test (SNK) at a 5% probability level.

Results and Discussion

The results of the physical and chemical properties of the soil at the experimental sites prior to treatment application (baseline) is presented in Table 1. The findings indicate that the soil in BUK is predominantly sandy (647.0 g kg^{-1}), with smaller proportions of silt (220.4 g kg^{-1}) and clay (132.6 g kg^{-1}). This classifies it as sandy clay, a soil type often found in semi-arid regions (Brady & Weil, 2019). Sandy clay is well-draining but has a lower water-holding capacity compared to soils with a higher clay content (FAO, 2021). Similarly, the soil at Bagauda is also sandy (658.1g kg^{-1}), with slightly lower silt content (192.8 g kg^{-1}) and a higher clay proportion (149.1g kg^{-1}), classifying it as sandy clay loam. The increased clay content in Bagauda suggests a slightly better moisture retention capacity compared to BUK (Lal, 2020). The chemical analysis further reveals that the pH levels of both soils are slightly acidic to neutral, with BUK at 6.88 and Bagauda at 6.14. However, Bagauda is noticeably more acidic than BUK, which may influence nutrient availability for plants. Most crops grow optimally within a

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pH range of 6.0 to 7.0 (Brady & Weil, 2019). The low pH of Bagauda's soil may require liming to improve its suitability for certain crops as described by Havlin et al. (2016). Both soils exhibit low organic carbon content of 0.42% and 0.36% in BUK and Bagauda, respectively. According to FAO (2021), low organic carbon is a common issue in tropical and semi-arid soils, as it can limit soil fertility and water retention. Similarly, the available nitrogen levels are low (0.04% in both locations), which could impact plant productivity. The available phosphorus is also limited, with BUK having 4.97 mg kg^{-1} and Bagauda 4.86 mg kg^{-1}. According to reports by Havlin et al. (2016), phosphorus is essential for root development and energy transfer in plants, and its low levels can affect crop growth. The micronutrient analysis shows that iron (Fe) content is relatively high in both soils, with BUK at 285.56 mg kg^{-1} and Bagauda at 336.32 mg kg^{-1}. However, zinc (Zn) levels are significantly lower in Bagauda (3.28 mg kg^{-1}) compared to BUK (10.64 mg kg^{-1}), which could impact plant metabolism (Alloway, 2008). Copper (Cu) and manganese (Mn) are also present in varying amounts, with BUK having lower Cu (1.22 mg kg^{-1}) but higher Mn (17.15 mg kg^{-1}) compared to Bagauda (Cu at 2.22 mg kg^{-1}, Mn at 14.26 mg kg^{-1}). These micronutrients are crucial for plant physiological functions and should be managed accordingly (Fageria et al., 2011).

The exchangeable bases and cation exchange capacity (CEC) further provide insight into soil fertility. Calcium (Ca++) levels are identical at both sites (1.25 cmol kg^{-1}), while magnesium (Mg++) is slightly higher in BUK (0.41 cmol kg^{-1}) than in Bagauda (0.36 cmol kg^{-1}). Potassium (K++) and sodium (Na++) levels are low at both sites, indicating minimal base saturation (FAO, 2021). The CEC values are also low (1.98 cmol kg^{-1} in BUK and 2.05 cmol kg^{-1} in Bagauda), suggesting that these soils have a limited ability to retain essential nutrients, making them susceptible to nutrient leaching under heavy rainfall (Brady & Weil, 2019). Exchangeable acidity (E.A) is higher in Bagauda (0.12 cmol kg^{-1}) than in BUK (0.04 cmol/kg), indicating a slightly higher presence of acidic cations, which may necessitate soil amendments to improve crop growth conditions (Havlin et al., 2016). The micronutrient analysis shows that iron (Fe) content is relatively high in both soils, with BUK at 285.56 mg kg^{-1} and Bagauda at 336.32 mg kg^{-1}. However, zinc (Zn) levels are significantly lower in Bagauda (3.28 mg kg^{-1}) compared to BUK (10.64 mg kg^{-1}), which could impact plant metabolism. Copper (Cu) and manganese (Mn) are also present in varying amounts, with BUK having lower Cu (1.22 mg kg^{-1}) but higher Mn (17.15 mg kg^{-1}) compared to Bagauda (Cu at 2.22 mg/kg, Mn at 14.26 mg kg^{-1}). These micronutrients are crucial for plant physiological functions and should be managed accordingly (Fageria et al., 2011). Based on these findings, the soils at both experimental sites share common limitations, such as low organic carbon, nitrogen, and phosphorus content, which could restrict plant growth. However, Bagauda's slightly higher clay content and CEC suggest a marginally better nutrient-holding capacity than BUK. To enhance soil productivity, management strategies such as organic amendments, fertilization, and pH adjustments should be considered (Lal, 2020).

Table: Physical and Chemical properties of soil of the Experimental sites during the 2019 rainy season (Base/pre-treatment)

Soil properties	**Location**	
	BUK	Bagauda
Physical (g kg^{-1})		
Sand	647.0	658.1
Silt	220.4	192.8
Clay	132.6	149.1
Textural Class	Sandy Clay	Sandy Clay Loam
Chemical		
pH	6.88	6.14
OC (%)	0.42	0.36
Total Nitrogen (%)	0.04	0.04
Available P (mg/kg)	4.97	4.86
Cu	1.22	2.22
Mn	17.15	14.26
Zn	10.64	3.28
Fe	285.56	336.32
Exchangeable bases (cmol kg^{-1})		
Ca++	1.25	1.25
Mg++	0.41	0.36
K++	0.19	0.18
Na++	0.10	0.13
CEC	1.98	2.05
E.A	0.04	0.12

Source: Laboratory of Centre for Dryland Agriculture, Bayero University, Kano.

The impact of evaluated weed management strategies on soil chemical properties (End line)

Changes in Soil pH

In BUK (Table 2), pH values decreased slightly under most treatments, with the lowest pH (5.88) recorded under Tithonia at 10% (W/V), compared to the initial value of 6.88 before treatment. However, Pendimethalin at 1.0 kg a.i.ha^{-1} *fb* SHW at 6 WAS resulted in the highest pH (6.14), indicating its potential to maintain soil pH stability. This acidification could be due to the decomposition of organic matter, the release of organic acids, or the application of herbicides like Pendimethalin, which may alter soil microbial activity (Brady & Weil, 2019). In Bagauda, pH variations were minor, ranging from 5.92 to 6.14 after treatment, compared to the pre-treatment value of 6.14 (Table 3). The relative stable pH maintained suggests that soil buffering capacity may mitigate drastic changes. However, a slight acidification under some treatments indicates that long-term use of such weed control measures may necessitate liming to maintain optimal pH levels for crop growth. It is also essential to consider the potential long-term environmental effects of Pendimethalin. Studies have shown that this herbicide can persist in the soil for extended periods, potentially affecting non-target soil organisms and reducing microbial diversity (Wang et al., 2020). Repeated use in sandy soils, such as those found at the study sites, increases the risk of leaching into groundwater. Moreover, Pendimethalin may impair beneficial soil microbes, including nitrogen-fixing bacteria and mycorrhizae, which are crucial for sustainable soil health (Sharma & Singh, 2019). Therefore, integrating Pendimethalin with organic materials like Tithonia diversifolia may reduce environmental risks while maintaining weed control efficiency.

Nitrogen Availability

Nitrogen content showed a slight increase in some treatments. In BUK, higher nitrogen levels (0.24%) were recorded under treatments involving Pendimethalin at 1.0 kg a.i.ha^{-1} *fb Tithonia* at 5% (W/V) and its variants, whereas nitrogen remained relatively unchanged (0.04%) in Bagauda. This suggests that combining chemical and organic weed control methods may improve nitrogen retention enhanced by microbial activity resulting from organic amendments (Fageria et al., 2011). Findings further corroborate those of Hang et al. (2021) & Elwan et al. (2024) who separately reported that incorporating organic amendments in soil fertility improvement increases the microbial community of the soil. In Bagauda, nitrogen levels remained unchanged, indicating that the applied treatments did not significantly enhance nitrogen availability in this location. This suggests that additional nitrogen fertilization may be necessary to support crop growth.

Phosphorus Dynamics

Available phosphorus (P) showed some fluctuations across treatments. In BUK, the highest P content (6.56 mg kg^{-1}) was observed under *Tithonia* at 5% (W/V) *fb Tithonia* at 5%, compared to the initial 4.97 mg kg^{-1}, indicating a positive effect of organic amendments on phosphorus availability. This suggests that organic amendments like Tithonia can contribute to phosphorus mineralization and improve P availability for crops as disclosed by Havlin et al. (2016). Similarly, Otieno et al. (2023) & Sparta et al. (2024), reported that integrating inorganic fertilizer and manure enhanced phosphorus use efficiency. In Bagauda, P levels were relatively stable across treatments, with slight increases observed under Pendimethalin at 1.5 kg a.i.ha^{-1} and its combinations, implying that the treatments had minimal effects on phosphorus solubility in this soil type.

Organic Carbon (O.C) and Soil Fertility

Organic carbon (O.C) improved after treatment, especially in BUK, where values increased to a maximum of 0.63% under hoe weeding at 3 and 6 WAS, compared to the initial 0.42%. This increase indicates that soil organic matter accumulation was enhanced, which is beneficial for soil fertility and water retention which aligns with the findings of FAO (2021) and Omidvar et al. (2023). In Bagauda, changes in O.C were minimal, with slight increases observed under Pendimethalin at 1.5 kg a.i.ha^{-1} *fb Tithonia* at 10% (W/V) (0.45%) compared to the initial 0.36%, suggesting that organic amendments had less impact on improving soil organic matter in this location.

Potassium and Cation Exchange Capacity (CEC)

Potassium (K) content showed some variation, with BUK treatments generally maintaining or slightly increasing K levels. The highest K content (0.14 cmol kg^{-1}) was recorded under Tithonia at 5% (W/V) *fb Tithonia* at 5% and *Tithonia* at 10% (W/V), compared to the pre-treatment value of 0.19 cmol kg^{-1}. In Bagauda, potassium levels ranged between 0.16 and 0.19 cmol kg^{-1} across treatments. This suggests that organic amendments contributed to

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potassium retention and slow release (Alloway, 2008). Cation exchange capacity (CEC) exhibited a slight increase in some treatments, particularly in BUK, where the highest value (3.73 cmol kg^{-1}) was recorded under Tithonia at 5% (W/V) fb Tithonia at 10%, compared to the initial 1.98 cmol kg^{-1}. In Bagauda, the CEC values remained relatively stable, with minor increases under certain treatments. This indicates improved nutrient-holding capacity, which can enhance soil fertility in the long term as reported by Lal (2020).

Table 2: Impact of weed management on Physical and Chemical properties of soil at Harvest in BUK during the 2019 rainy season

Treatment	Soil properties					
	pH	N	P (%)	O.C	K (cmol/kg)	CEC
Hoe weeding at 3 and 6 WAS	5.89^{cd}	0.06	5.61	0.63	0.10	2.75
Pendimethalin at 1.0 kg a.i.ha^{-1}	6.03^{abc}	0.07	4.73	0.50	0.09	2.85
Pendimethalin at 1.5 kg a.i.ha^{-1}	5.95^{bcd}	0.06	4.96	0.41	0.11	2.95
Tithonia at 5% (W/V)	6.07^{ab}	0.06	5.62	0.47	0.11	2.95
Tithonia at 10% (W/V)	5.88^{d}	0.06	5.82	0.55	0.14	3.35
Tithonia at 5% (W/V) *fb* Tithonia at 5% at 6WAS	5.89^{d}	0.05	6.56	0.60	0.14	3.31
Tithonia at 5% (W/V) *fb* Tithonia at 10% at 6WAS	5.97^{bcd}	0.24	5.29	0.54	0.12	3.73
Pendimethalin at 1.0 kg a.i.ha^{-1}*fb* Tithonia at 5% (W/V)	5.93^{bcd}	0.24	6.56	0.61	0.12	3.25
Pendimethalin at 1.0 kg a.i.ha^{-1} *fb* Tithonia at 10% (W/V)	5.96^{bcd}	0.24	6.47	0.61	0.12	2.66
Pendimethalin at 1.0 kg a.i.ha^{-1} *fb* SHW at 6 WAS	6.14^{a}	0.24	5.57	0.41	0.12	3.08
Weedy check	6.05^{ab}	0.24	4.730	0.42	0.12	2.623
P of F	<0.001	0.479	0.022	0.097	0.060	0.164
SEM	0.0305	0.094	0.404	0.062	0.009	0.268

Means followed by the same letter(s) in a column are not significantly different at a 5% probability level using the SNK Test. SE$\pm$= standard error of the mean, W/V= weight by volume, HW = Hoe Weeding, WAS= Weeks After Sowing, fb= followed by. POE= post-emergence

Table 3: Impact of weed management on Physical and Chemical properties of soil at Harvest in Bagauda during the 2019 rainy season

Treatments	Soil properties					
	pH	N	P (%)	O.C	K (cmol/kg)	CEC
Hoe weeding at 3 and 6 WAS	6.00	0.04	4.90	0.36	0.17	2.01
Pendimethalin at 1.0 kg a.i.ha^{-1}	6.14	0.04	4.86	0.37	0.18	2.12
Pendimethalin at 1.5 kg a.i.ha^{-1}	6.01	0.04	5.52	0.52	0.17	2.11
Tithonia at 5% (W/V)	5.94	0.04	4.93	0.35	0.16	2.14
Tithonia at 10% (W/V)	5.92	0.04	4.90	0.35	0.16	2.09
Tithonia at 5% (W/V) *fb* Tithonia at 5% at 6WAS	6.14	0.04	4.90	0.35	0.18	1.94
Tithonia at 5% (W/V) *fb* Tithonia at 10% at 6WAS	6.00	0.04	4.90	0.37	0.18	2.13
Pendimethalin at 1.0 kg a.i.ha^{-1}fb Tithonia at 5% (W/V)	6.09	0.04	5.14	0.45	0.17	2.09
Pendimethalin at 1.0 kg a.i.ha^{-1} *fb* Tithonia at 10% (W/V)	5.92	0.03	5.41	0.45	0.19	2.06
Pendimethalin at 1.0 kg a.i.ha^{-1} *fb* SHW at 6 WAS	6.00	0.04	4.90	0.34	0.18	2.00
Weedy check	6.03	0.04	5.20	0.51	0.16	2.13
P of F	0.184	0.839	0.645	0.655	0.363	0.355
SEM	0.065	0.003	0.267	0.076	0.009	0.060

Weed density, weed index, Days to 50% flowering and seed yield of sesame

Table 4 presents the impact of various weed control methods on weed density, weed index, days to 50% flowering, and seed yield of sesame at two locations, BUK and Bagauda, during the 2019 rainy season. The results indicated that weedy check significantly ($P < 0.001$) recorded the highest weed density at both BUK (195.3 m^2) and Bagauda (346.3 m^2), resulting in the highest weed index (50.33% and 48.68%, respectively), which significantly reduced seed yield (0.806 t ha^{-1} at BUK and 0.822 t ha^{-1} at Bagauda). This confirms that uncontrolled weed competition severely limits sesame productivity, as weeds compete for essential resources such as nutrients, moisture, and light (Jabran et al., 2021; Chauhan & Mahajan, 2019). Conversely, hoe weeding at 3 and 6 WAS recorded the lowest weed density (54.7 m^2 at BUK and 99.0 m^2 at Bagauda), with a weed index of 0% at both sites, translating

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into the highest seed yield (1.624 t ha⁻¹ at BUK and 1.544 t ha⁻¹ at Bagauda). This outcome aligns with findings from Northern Nigeria and Sudan savanna regions, where hoe weeding significantly enhanced sesame yield due to effective weed suppression (Ado et al., 2018; Musa et al., 2020). However, despite its effectiveness, the labor-intensive nature of hoe weeding limits its scalability.

Among the chemical and allelopathic treatments, Pendimethalin at 1.0 kg a.i ha⁻¹ combined with *Tithonia diversifolia* (10% W/V) applied post-emergence at 6 WAS proved most effective, significantly reducing weed density (81.0 m² at BUK and 141.7 m² at Bagauda) and weed index (12.36% and 15.45%), leading to higher seed yield (1.421 t ha⁻¹ at BUK and 1.305 t ha⁻¹ at Bagauda). This supports previous studies demonstrating that integrating herbicides with allelopathic plant extracts improves weed suppression while reducing environmental risks (Khan et al., 2021; Farooq et al., 2020). Notably, unlike studies focusing solely on chemical control, this research underscores the value of integrated weed management strategies that incorporate organic inputs for enhanced sustainability and soil health. The moderate weed suppression observed with *Tithonia diversifolia* alone further highlights its potential as a complementary, eco-friendly alternative to synthetic herbicides (Farooq et al., 2020; Marimuthu et al., 2024). These findings emphasize the necessity for sustainable weed management strategies incorporating allelopathic plants like Tithonia diversifolia to maintain soil fertility and ensure long-term agricultural productivity.

Table 4: Effects of Weed Management Strategies on Weed Density, Weed Dry Biomass and Weed control efficiency of Sesame at BUK and Bagauda During the 2019 Rainy Season.

Treatments	Weed Density (m^{-2}) at harvest		Weed index (%)		Days to 50% flowering (#)		Seed yield ($t\ ha^{-1}$)	
	BUK	Bagauda	BUK	Bagauda	BUK	Bagauda	BUK	Bagauda
Hoe Weeding at 3 & 6 WAS	54.70^{f}	99.00d	0.00	0.00	47.67^{f}	46.00^{c}	1.624^{a}	1.544^{a}
Pendimethalin at 1 kg a.i ha^{-1}	115.00^{b}	173.70^{b}	42.11^{b}	35.27^{bc}	63.67^{b}	49.33^{ab}	0.939^{g}	0.999^{g}
Pendimethalin at 1.5 kg a.i ha^{-1}	103.30^{c}	158.70^{bc}	39.02^{c}	35.29^{bc}	63.00^{b}	48.33^{bc}	0.989^{gh}	0.998^{f}
Tithonia at 5 % (W/V)	124.70^{b}	147.7^{bcd}	38.34^{c}	35.56^{bc}	60.00^{c}	48.33^{bc}	1.000^{g}	0.994^{f}
Tithonia at 10 % (W/V)	120.30^{b}	164.30^{bc}	37.14c	33.01^{bc}	61.00^{c}	47.33^{bc}	1.019^{g}	1.008f
Tithonia at 5 % (W/V) and Tithonia (POE) 5 % (W/V) at 6WAS	98.70^{cd}	114.30^{cd}	33.94d	35.01^{bc}	56.67^{d}	47.33^{bc}	1.071f	1.002^{f}
Tithonia at 5% (W/V) and Tithonia (POE) 10 % (W/V) at 6WAS	93.00^{d}	146.70^{bcd}	30.96e	30.06^{c}	50.67^{e}	47.67^{bc}	1.120^{e}	1.078^{e}
Pendimethalin 1 kg a.i ha^{-1} and Tithonia (POE) 5 % (W/V) at 6WAS	81.70^{e}	140.70^{bcd}	15.61^{f}	21.95^{d}	51.00^{e}	47.00^{bc}	1.369^{d}	1.203^{d}
Pendimethalin at 1 kg a.i ha^{-1} and Tithonia (POE) 10%(W/V) at 6WAS	81.00^{e}	141.70^{bcd}	12.36^{g}	15.45^{e}	44.67^{g}	46.67^{g}	1.421^{c}	1.305^{c}
Pendimethalin at 1kg a.i ha^{-1} and HW at 6 WAS	61.00^{f}	113.30^{cd}	3.96^{h}	4.54^{f}	46.00^{fg}	46.33^{c}	1.560^{b}	1.474^{b}
Weedy Check	195.30^{a}	346.30^{a}	50.33^{a}	48.68^{a}	66.67^{a}	51.00^{a}	0.806^{i}	0.822^{g}
P of F	< 0.001	< 0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
SE±	2.842	10.89	0.690	1.264	0.595	0.611	0.0160	0.0189

Means followed by the same letter(s) in a column are not significantly different at a 5% probability level using the students-Newman-Keuls (SNK) Test. SE±= standard error of the mean, W/V= weight by volume, HW = Hoe Weeding, WAS= Weeks After Sowing, fb= followed by. POE= post-emergence

Conclusion and Recommendation

The findings from this study demonstrate that effective weed management significantly enhances soil fertility and sesame yield in semi-arid conditions. Soil analysis before and after treatment application highlighted key fertility constraints, including low organic carbon, nitrogen, and phosphorus levels, particularly in Bagauda, where slightly higher clay content suggested better nutrient-holding capacity than BUK. The application of Tithonia diversifolia contributed to improved soil organic carbon and phosphorus mineralization, indicating its potential as a natural soil amendment. The use of hoe weeding at 3 and 6 WAS proved to be the most effective weed control method, yielding the highest sesame production due to minimal weed competition. However, its labor-intensive nature poses a challenge for large-scale implementation. Among the integrated chemical and organic treatments, the combination of Pendimethalin at 1.0 kg a.i ha⁻¹ with *Tithonia diversifolia* extract at 10% (W/V) post-emergence at 6 WAS emerged as the most efficient alternative, effectively suppressing weeds while improving soil nutrient retention and crop productivity. Thus, farmers could adopt an Integrated Weed Management (IWM) approach by combining Pendimethalin at 1.0 kg a.i ha⁻¹ with Tithonia diversifolia extract at 10% (W/V) to enhance weed suppression and soil fertility, while also promoting the use of allelopathic plant extracts like Tithonia diversifolia to reduce dependence on synthetic herbicides and improve soil health, alongside implementing soil fertility

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improvement measures such as periodic liming in acidic areas like Bagauda and targeted application of nitrogen and phosphorus fertilizers based on site-specific deficiencies.

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