International Journal of Plant & Soil Science

Volume 37, Issue 6, Page 643-654, 2025; Article no.IJPSS.138026
ISSN: 2320-7035

Response of Cotton (*Gossypium hirsutum* L) Yield to Fertilization in Titanium-Mined Reconstituted Soils, Kenya

Consolata Mueni Muindi [a*], James Biriah Ndiso [a], Jackson Muema Mulinge [a], Lenard Gichana Mounde [a] and Nick Okello [b]

[a] Department of Crop Sciences, Pwani University, P.O. Box 195, 80108, Kilifi, Kenya.
[b] Department of Environment, Base Titanium Limited, P.O. Box 1214, 80400, Kwale, Kenya.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.9734/ijpss/2025/v37i65542

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://pr.sdiarticle5.com/review-history/138026

Original Research Article

Received: 15/04/2025
Accepted: 17/06/2025
Published: 23/06/2025

ABSTRACT

Cotton has historically played a vital role in Kenya's agricultural economy, supporting smallholder farmers and supplying raw material for the textile industry. However, recent years have seen a troubling decline in cotton yields, threatening rural incomes and the sustainability of the cotton value chain. A field experiment was conducted in Kwale County's at base titanium mining company during May–August 2022 and September–December 2023 to assess how combinations of sunnhemp (a green manure), farmyard manure (FYM), and inorganic fertilizers affect cotton yield in

**Corresponding author: E-mail: consamuindi60@gmail.com;*

Cite as: *Muindi, Consolata Mueni, James Biriah Ndiso, Jackson Muema Mulinge, Lenard Gichana Mounde, and Nick Okello. 2025. "Response of Cotton (Gossypium Hirsutum L) Yield to Fertilization in Titanium-Mined Reconstituted Soils, Kenya". International Journal of Plant & Soil Science 37 (6):643-54. https://doi.org/10.9734/ijpss/2025/v37i65542.*

different soil conditions. Using a Randomized Complete Block Design with 10 treatment combinations replicated three times across four soil conditions (undisturbed, mined with topsoil, reconstituted without topsoil, and reconstituted with topsoil), the study involved 120 plots. Treatments included various rates of FYM, sunnhemp, and NPK fertilizer. Key data collected included initial soil properties and cotton yield traits such as boll weight, lint weight, and seed characteristics. Results showed that the combination of 200 kg NPK fertilizer and sunnhemp significantly increased the number of bolls (by 77.3%), lint weight (by 86.6%), and overall yield (by 72%) compared to control. The study recommends integrated nutrient management using sunnhemp, FYM, and inorganic fertilizers for rehabilitating mined lands and boosting cotton productivity, emphasizing the need for long-term, site-specific research.

Keywords: Cotton; yield; green manure; sunn hemp; organic amendments; site-specific.

1. INTRODUCTION

Cotton (*Gossypium hirsutum* L.) remains one of the most important fiber crops globally, supporting the livelihoods of millions of smallholder farmers and sustaining textile industries in numerous developing countries. It also serves as a vital source of agricultural employment, particularly in low-income regions (Food and Agricultural Organisation, 2021), and continues to dominate the natural fiber sector, making a substantial contribution to the global textile economy (Marquardt & Savage, 2023). In Kenya, cotton cultivation is central to the socio-economic development of arid and semi-arid regions, notably in Kwale County, where it provides a crucial source of income for rural farmers (Traub & Jayne, 2008). The government's emphasis on revitalizing the cotton sector under the Big Four Agenda highlights its strategic role in national development (Republic of Kenya, 2018).

Despite its potential, cotton production in Kenya faces numerous challenges, with soil fertility decline especially in mining-impacted areas emerging as a significant constraint. While titanium mining is economically beneficial, it has caused notable ecological degradation, particularly in Kwale County. Mining operations typically involve extensive topsoil removal, resulting in habitat destruction, diminished soil structure, and loss of biodiversity. Conventional reclamation techniques, such as topsoil replacement, have shown limited success in restoring the chemical and biological functions of the soil. Consequently, post-mining soils often remain unproductive due to depleted organic matter and disrupted nutrient cycles, necessitating targeted interventions to restore agricultural viability (Iqbal *et al*., 2023).

Sustainable rehabilitation of such degraded lands requires a systems-based approach to soil fertility management (Sampson, 2025).). Integrated Nutrient Management (INM) which combines organic amendments like farmyard manure (FYM) and green manure such as sunn hemp (*Crotalaria juncea*) with inorganic fertilizers (e.g., NPK) offers a promising solution for restoring mined lands. These integrated inputs can improve soil structure, stimulate microbial activity, soil aeration, water holding capacity and boost nutrient retention. FYM and sunn hemp serve as slow-release nutrient sources and help enrich soil organic matter, while inorganic fertilizers ensure immediate nutrient availability for optimal crop uptake (Marahatta *et al*., 2023). The combined use of these inputs ensures a balanced nutrient supply throughout the growing season, promoting healthy plant development and greater productivity.

In addition, INM has been shown to improve cotton's physiological and reproductive traits, including enhanced root growth and photosynthetic efficiency, thereby increasing plant vigor and stress tolerance. These benefits support improved boll initiation, retention, and development key factors that determine overall cotton yield. The nutrients provided through INM also play critical roles in osmotic regulation, energy metabolism, and enzymatic functions (Reddy & Reddy, 2023). Evidence from diverse agro-ecological regions consistently shows that integrated nutrient strategies enhance boll formation and seed cotton yield while synchronizing nutrient release with plant demand, thus improving nutrient use efficiency and reducing stress. INM has shown provide adequate nutrients to so many field, arable and plantation crops (Ikeh *et al*, 2023a, Ikeh *et al*, 2023b).

In mining-degraded areas like Kwale County, the combined application of sunn hemp, FYM, and inorganic fertilizers presents an ecologically and economically viable method of soil revitalization and cotton yield enhancement (Yadav *et al*., 2021). The use of organic amendments, such as

FYM, also promotes microbial health and long-term soil fertility, which are essential for sustained agricultural productivity. However, the effectiveness of such strategies depends on their proper implementation, contextual adaptation, and continuous assessment. Furthermore, post-mining land restoration must align with broader ecological objectives and community livelihood needs (Singh *et al*., 2023). Within this framework, Integrated Nutrient Management serves a dual purpose: enhancing crop productivity while contributing to environmental restoration and rural economic development (Singh *et al*., 2023).

Accordingly, this study aims to assess the effects of integrating sunn hemp, FYM, and inorganic fertilizers on cotton growth and productivity in titanium-mined soils of Kwale County, Kenya. The objective is to identify the most effective nutrient management approach for rehabilitating soil fertility and enhancing agricultural output in post-mining environments (Singh et al.,, 2023).

2. MATERIALS AND METHODS

2.1 Experimental Site

The study was carried out at Base Titanium Limited (BTL) mine, located in Kwale County, 50 km south of Mombasa, from May 2022 and December 2023. The Base Titanium farm lies between latitudes 3°S–4°S and longitudes 39°E–40°E. Kwale County generally experiences warm temperatures throughout the year, ranging between 24.2°C during the coldest months (June and July) and 27°C during the hottest months (January and February). Rainfall patterns show a distinct bimodal distribution. The long rains (L.R.) occur from March to May, while the short rains (S.R.) fall between October and December. The area receives an average seasonal rainfall of between 900–1350 mm. Inter-seasonal rainfall variation is high, with a coefficient of variation between 45% and 58%, and temperature variation from 17°C to 24°C. Evapotranspiration rates are typically high and exceed rainfall amounts for most of the year, except in November.

Originally, the soils in this region were well-drained, red to dusky red in color, very friable, with a texture ranging from sandy clay loam to clay, and a topsoil of loamy sand to sandy—classified as Rhodic Ferralsols. Soil sampling and analysis of chemical properties were performed using the procedures described by Okalebo *et al*. (2002). The results are presented in Table 1.

2.2 Experimental Materials and Their Sources

The experimental materials used in this study are cotton seeds, sunn hemp (*Crotalaria juncea* L.) seeds, farmyard manure (FYM), and NPK fertilizer. The cotton seeds were sourced locally and uniformly planted across all plots to ensure consistency in varietal response to the applied treatments. Sunn hemp seeds, used as a green manure, were also obtained from a certified supplier and sown two months prior to cotton planting in the relevant plots. All these major agricultural inputs cotton seeds, sunn hemp seeds, and NPK fertilizer were purchased from Coast Farmcare Agrovet Ltd, a licensed agro-dealer.

Farmyard manure was collected from nearby livestock farms and applied at two rates: 7.5 tons/ha and 15 tons/ha, depending on the treatment group. The NPK fertilizer (formulated as 17:17:17) was applied at rates of 100 kg/ha and 200 kg/ha. Application of all treatments was conducted manually according to experimental requirements.

2.3 Experimental Layout and Crop Management

The experiment was carried out in a Randomized Complete Block Design (RCBD) replicated three times. The treatments were: 1. Cotton with no amendment (control), designated as T1; 2. Cotton with sunnhemp (SH) only, designated as T2; 3. Cotton with 7.5 tons farm yard manure only, designated as T3; 4. Cotton with 7.5 tons farmyard manure and sunnhemp only, designated as T4; 5. Cotton with 15 tons farmyard manure only, designated as T5; 6. Cotton with 15 tons farm yard manure and sunnhemp only, designated as T6; 7. Cotton with 100 kg NPK fertilizer only, designated as T7; 8. Cotton with 100 kg NPK fertilizer and sunnhemp only, designated as T8; 9. Cotton with 200 kg NPK fertilizer only, designated as T9; 10. Cotton with 200kg NPK fertilizer and sunnhemp only, designated as T10. Each plot size was 4m x 4m. The trial was carried out on four sites: the first site was unmined or undisturbed soils; the second site was a mined area covered with topsoil; the third site was a mined area covered with reconstituted mix and no topsoil; and the fourth site was a mined area with reconstituted mix covered with topsoil. Each trial had 30 plots, making a total of 120 plots for the entire experiment.

Table 1. Initial soil chemical characteristics

Parameters	**pH**	**EC**	**P**	**K**	**Ca**	**Mg**	**S**	**NA**	**Fe**	**Mn**	**Bo**	**Cu**	**Zn**	**CEC**	**TN (%)**	**OM (%)**	**C/N**
Value	6.44	116	11.6	509	100	15.4	15.5	13.3	159	196	0.43	0.87	2.29	4.29	0.079	1.65	3.05
Class	Optimal	Optimal	Low	Optimal	Optimal	Low	Optimal	Optimal	Optimal	Optimal	Low	Low	Optimal	Low	Low	Low	Low

Land preparation was done in early May 2022 using a tractor. The plots with Sunnhemp (SH) were planted 2 months before planting cotton. The seeding rate was 34 to 56 kg/ha in 6-inch rows drilled. The sunnhemp was ploughed back and incorporated in the soil 45 days after sowing. The crop was ploughed down at early flowering stage, normally about 45 days after planting, after attaining an average height of 1.80 m. The SH was ploughed back after 6 weeks as green manure because if it was allowed to grow beyond this stage, the plants would become fibrous and difficult to plough under.

After ploughing back, the SH, all the plots were planted with cotton at the same time and given the treatments accordingly. The cotton seeds were planted in rows of 1m by 0.5m at a depth of 2 cm. Weeding was done every 4 weeks after planting. Harvesting cotton was done by hand after 4 months when it reached physiological maturity.

2.4 Data Collection

Fifteen (15) plants from each net plot were randomly marked and used for all subsequent data collection on yield parameters. The collected data on yield components included yield per plant, boll traits such as boll weight, number of seeds per boll, seed weight, percent seed weight, lint weight, percent lint weight, and lint-seed ratio. Thirty-three bolls were picked from the sample plant and placed into paper envelopes per plant. The bolls were hand-ginned, and seeds and lint were placed in separate envelopes per boll. Data on plant yield was collected by weighing all the cotton seeds per plant. All cotton seeds per plant were picked and weighed using a Precisa XT Series 210A electronic balance. Mean weight in grams was obtained by dividing the total cotton seed yield per plant by the total number of plants (Yang et al., 2001).

Data on boll weight was collected by weighing at least two bolls picked from the sample plant at random. Each boll was weighed using a Precisa XT Series 210A electronic balance. Mean boll weight was obtained by dividing the total cotton seed weight by the total number of bolls picked. Seed weight per boll was determined by ginning the bolls. Seeds were placed into separately labelled Kirk envelopes on a boll basis. The seeds from each boll were weighed using an electronic balance, and each result was recorded in grams. The average seed weights were calculated by dividing the total seed weight by the number of seeds.

After ginning, seeds obtained from the entire boll were pooled, counted, and divided by the total number of bolls to obtain the number of seeds per boll. Clean and dry samples of cotton seed were weighed and then ginned separately by hand. The lint obtained from each sample was weighed using an electronic balance and the average lint yield per boll was calculated by dividing the total lint weight by the number of bolls (Liu et al., 2024). The lint obtained from each boll was weighed, and the lint percentage was calculated using the formula: Lint percent = (weight of lint in a boll / weight of cotton seed in a boll) × 100 (Liu *et al*., 2024).

The seeds obtained from each boll were weighed, and the percent seed weight was calculated using the formula: Seed percentage = (weight of seeds in a boll / weight of seed cotton in a boll) × 100 (Dollete,2024). The data on seed-lint ratio was calculated by dividing the weight of seed by the weight of lint per boll.

2.5 Data Analysis

All the obtained data were subjected to analysis of variance (ANOVA) using the SAS statistical package (SAS, Version 10). Significant means at the F-test were ranked using Turkey's test at a 5% significance level.

3. RESULTS

3.1 Effects of Different Levels of Sunn Hemp, FYM and Inorganic Fertilizer on Number of Bolls and Lint Weight in Cotton Grown in Titanium Mined and Reconstituted Soils

Sunn hemp, FYM and inorganic fertilizer levels had a significant ($P \leq 0.05$) effect on the number of bolls and lint weight (Table 2). Specifically, crops supplied with Cotton with 200 kg NPK and SH produced a significantly higher number of bolls (25) and lint weight (5.6g), followed closely by treatments with Cotton with 200 kg NPK only (19) and lint weight (4.6g). Cotton with 15 tons FYM only (18) and lint weight (4.1g) also performed well. In contrast, the Cotton with SH only treatment produced only 12 bolls and a lint weight of 2.2g, which, was better than the Cotton with no amendment (11 bolls) and a lint weight of 2.1g, still falls short of the performance of other treatments.

Table 2. Number of bolls and lint weight of cotton as influenced by sunn hemp with different levels of FYM and inorganic fertilizer in titanium mined and reconstituted soils

Treatments	Number of bolls	Lint weight(g)
Cotton with no amendment (control)	11.30g	1.58f
Cotton with Sunnhemp only	12.67g	2.11e
Cotton with 7.5 tons farm yard manure only	13.68fg	2.19e
Cotton with 7.5 tons farmyard manure and sunnhemp only	17.17cd	3.33c
Cotton with 15 tons farmyard manure only	17.60cd	3.46c
Cotton with 15 tons farm yard manure and sunnhemp only	18.43bcd	4.16b
Cotton with 100 kg NPK fertilizer only	15.82def	2.68d
Cotton with 100 kg NPK fertilizer and sunnhemp only	16.95cde	4.15b
Cotton with 200 kg NPK fertilizer only	19.00bc	4.61a
Cotton with 200 kg NPK fertilizer and sunnhemp	25.18a	5.58a
Mean	16.55	2.85
CV (%)	9.5	27.53991
P≤0.05	0.0014	<.0001

Means bearing distinct alphabet letters vary significantly at p ≤ 0.05 by LSD test

**Values followed by the same letter on the same column are not significantly different according to Tukey's test at p≤0.05*

Table 3. Boll weight and seed weight of cotton grown in titanium mined and reconstituted soils amended with sunn hemp, FYM and inorganic fertilizer

Treatment	Boll weight	Seed weight
Cotton with no amendment (control)	3.95f	2.66e
Cotton with Sunnhemp only	4.97e	3.34de
Cotton with 7.5 tons farmyard manure only	4.95e	2.76e
Cotton with 7.5 tons farmyard manure and sunnhemp only	4.91e	3.66d
Cotton with 15 tons farmyard manure only	4.94e	3.72d
Cotton with 15 tons farm yard manure and sunnhemp only	5.21de	3.90d
Cotton with 100 kg NPK fertilizer only	5.46de	4.10cd
Cotton with 100 kg NPK fertilizer and sunnhemp only	5.70cd	4.37c
Cotton with 200 kg NPK fertilizer only	7.63ab	4.93b
Cotton with 200 kg NPK fertilizer and sunnhemp	7.97a	5.86a
Mean	5.59	4.12
CV (%)	16.32296	19.98848
P≤0.05	<.0001	<.0001

Means bearing distinct alphabet letters vary significantly at p ≤ 0.05 by LSD test

**Values followed by the same letter on the same column are not significantly different according to Tukey's test at p≤0.05*

3.2 Effects of Sunn Hemp with Different Levels of FYM and Inorganic Fertilizer on Boll Weight and Seed Weight in Cotton Grown in Titanium Mined and Reconstituted Soils

Similar to other parameters, the single boll weight did not vary significantly (P ≤ 0.05) among the different treatments. However, it was observed that the addition of fertilizers generally increased the boll weight. The boll weight was significantly influenced (p ≤ 0.05) by the fertilizer levels applied, as shown in Table 3 The highest boll weight recorded was 7.97g, obtained from crops fertilized with Cotton with 200 kg NPK and SH. This result was not significantly different (p ≤ 0.05) from the Cotton with 200 kg NPK only with ball weight of 7.63g. The lowest boll weight of 3.95g was obtained from the control plots.

The different fertilizer levels also had a significant effect (P ≤ 0.05) on cotton seed weight, as shown in Table 3 The treatment of Cotton with 200 kg NPK and SH produced the highest cotton seed weight of 5.86g. This was followed by treatments with Cotton with 200 kg NPK only (4.9g) and Cotton with 100 kg NPK and SH (4.4g), indicating that the inclusion of sunn hemp further enhances the benefits of both inorganic and organic fertilizers.

Table 4. Number of seeds and yield of cotton grown in titanium mined and reconstituted soils amended with sunn hemp, FYM and inorganic fertilizer

Treatment	Number of seeds	Yield
Cotton with no amendment (control)	30.28c	79.33d
Cotton with Sunnhemp only	31.27c	102.98d
Cotton with 7.5 tons farmyard manure only	31.10c	144.08c
Cotton with 7.5 tons farmyard manure and sunnhemp only	31.42bc	141.28c
Cotton with 15 tons farmyard manure only	32.47bc	190.23b
Cotton with 15 tons farm yard manure and sunnhemp only	32.53bc	230.81a
Cotton with 100 kg NPK fertilizer only	32.63bc	164.64bc
Cotton with 100 kg NPK fertilizer and sunnhemp only	32.83bc	170.82bc
Cotton with 200 kg NPK fertilizer only	34.25ab	233.18a
Cotton with 200 kg NPK fertilizer and sunnhemp	35.97a	260.17a
Mean	**33.00**	**171.75**
CV (%)	12.09	26.74
P≤0.05	<.0001	<.0001

Means bearing distinct alphabet letters vary significantly at p ≤ 0.05 by LSD test
**Values followed by the same letter on the same column are not significantly different according to Tukey's test at p≤0.05*

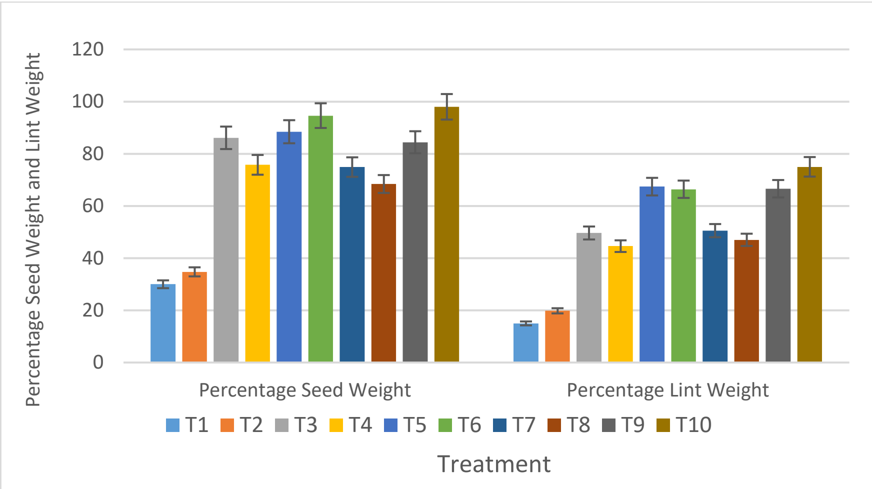

Fig. 1. Effects of varying levels of fertilizer on percentage seed weight and lint weight

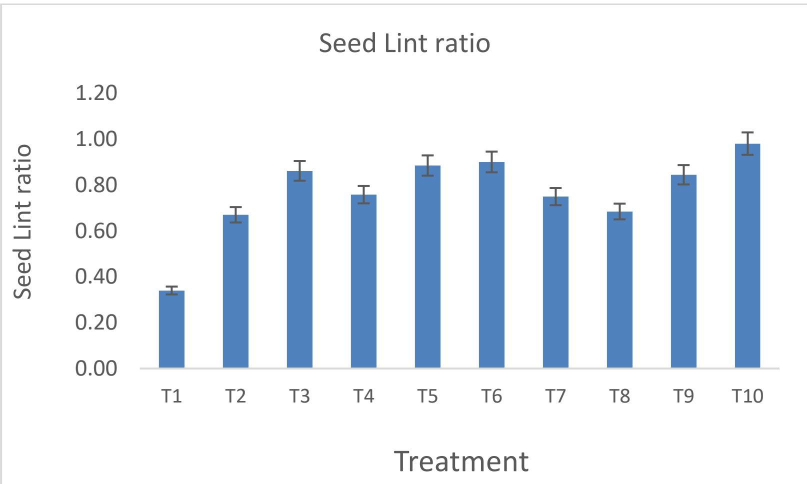

Fig. 2. Effects of different levels of fertilizer on seed lint ratio

3.3 Effects of Sunn Hemp with Different Levels of FYM and Inorganic Fertilizer on Number of Seeds per Boll and Yield in Cotton Grown in Titanium Mined and Reconstituted Soils

Sunn hemp, FYM and inorganic fertilizer levels had a significant effect (P ≤ 0.05) on the number of seeds per boll in cotton (Table 4). Among the treatments, plots that received Cotton with 200 kg NPK and SH significantly recorded a higher number of seeds per boll, with an impressive yield of 36 seeds. This treatment was on par with Cotton with 200 kg NPK only with 34 seeds. Applying different levels of fertilizers was observed to significantly (P ≤ 0.05) influence cotton yield, as illustrated in Table 4 The highest number of cotton yield (260.17g and 233.18g, respectively) was obtained from plots fertilized with Cotton with 200 kg NPK and SH and Cotton with 200 kg NPK only.

3.4 Effects of Sunn Hemp with Different Levels of FYM, and Inorganic Fertilizer on Percent Seed Weight, Lint Weight and Seed Lint Ratio in Cotton Grown in Titanium-Mined and Reconstituted Soils

The study revealed that varying levels of fertilizer had a significant (P ≤ 0.05) impact on the percent seed weight, lint weight and seed lint ratio in cotton. (Figs. 1 and 2) Specifically, the highest percent seed weight, lint weight and seed lint ratio were observed in cotton supplied with 200 kg NPK and SH which increased percent seed weight, lint weight and seed lint ratio by 68%,60% and 64%, respectively compared to control during the cropping season.

4. DISCUSSION

4.1 Effects of Sunn Hemp with Different Levels of FYM and Inorganic Fertilizer on Number of Bolls in Cotton Grown in Titanium Mined and Reconstituted Soils

Sunnhemp application with different levels of FYM and inorganic fertilizer in this experiment significantly increased cotton number of bolls. The results reflected that sunn hemp combined with inorganic fertilizer (Cotton with 200 kg NPK and SH) tended to have higher numbers of cotton bolls compared to inorganic fertilizer alone. This synergy between organic and inorganic inputs has been reported in several studies (Deshmukh *et al*., 2021). The addition of sunn hemp likely contributed to improved nutrient cycling and soil health, while inorganic fertilizers provided an immediate nutrient boost that further stimulated growth. The results observed in this study align with findings showing that combined organic and inorganic treatments outperformed individual treatments, enhancing both yield and soil health.

Similarly, the application of organic amendments like FYM combined with sunn hemp has shown to increase number of cotton bolls. The study results are in line with findings that incorporating sunn hemp with FYM increased cotton yield due to nitrogen fixation and additional nutrient supply (Singh *et al*., 2015).

4.2 Comparison Effects of Sunn Hemp with Different Levels of Sunn Hemp, FYM and Inorganic Fertilizer on Boll Weight and Seed Weight in Cotton Grown in Titanium Mined and Reconstituted Soils

Application of sunn hemp combined with different levels of FYM and inorganic fertilizer significantly affected cotton boll weight and seed weight. The interaction between sunn hemp and inorganic fertilizers led to an increase in boll and seed weight compared to treatments without sunn hemp. This might be due to the synergistic effect of combining organic amendments with inorganic fertilizers, where organic inputs like sunn hemp contribute to improving soil health, nutrient cycling, and water retention, while inorganic fertilizers provide the necessary macronutrients for cotton development (Dhaliwal *et al*., 2013). These results are consistent with findings that organic amendments, particularly leguminous crops, enhance nutrient availability and soil organic matter, while inorganic fertilizers support boll and seed development (Mahmoud *et al*., 2018; Sharma *et al*., 2018). Nitrogen-rich fertilizers were also found to significantly impact cotton boll and seed weight, likely by promoting protein synthesis and energy metabolism (Hussain *et al*., 2020).

Similarly, the combinations of sunn hemp with FYM (such as in Cotton with 15 tons FYM and SH) also led to increased boll and seed weight. This could be due to the synergistic effects of FYM supplying slow-release nutrients while sunn hemp fixes nitrogen and improves phosphorus and potassium availability. These findings are in agreement with studies showing that the integration of organic matter like sunn hemp and FYM enhances soil structure and nutrient availability for improved crop performance. Integrated nutrient management systems have been found to improve soil health, reduce environmental footprint, and maintain long-term soil fertility.

4.3 Effects of Sunn Hemp with Different Levels of Sunn Hemp, FYM and Inorganic Fertilizer on Number of Seeds Per Boll and Yield in Cotton Grown in Titanium Mined and Reconstituted Soils

Application of sunn hemp combined with different levels of FYM and inorganic fertilizer positively affected the number of seeds per boll and yield. Consistently high values were recorded where inorganic fertilizers were combined with sunn hemp (e.g., Cotton with 200 kg NPK and SH), which is in agreement with findings that this combination increases seed numbers and yields by enhancing soil structure, nutrient availability, and microbial activity .The beneficial role of nitrogen in promoting vigorous plant growth and flower development also supports higher seed production (Ikeh *et al*, 2023a; Esang & Ikeh, 2021).

The study results also demonstrated high cotton number of seeds per boll and yield on sunn hemp combined with FYM. This might be due to the beneficial role of both sunn hemp and FYM in enhancing seed production. Similar findings were found by Singh *et al*. (2021) ; Ikeh *et al*. (2023d) who posited that the combination of organic and inorganic fertilizers works synergistically to provide both short-term and long-term nutrient availability to the plants. Bhattacharyya *et al*. (2016) also found that the interaction between organic amendments like sunn hemp and FYM resulted in increased nutrient availability, moisture retention, and microbial activity in soils, which may account for the improved cotton yield.

4.4 Effects of Sunn Hemp with Different Levels of Sunn Hemp, FYM, and Inorganic Fertilizer on Percent Seed Weight, Lint Weight and Seed Lint Ratio in Cotton Grown in Titanium-Mined and Reconstituted Soils

Application of sunn hemp combined with different levels of FYM and inorganic fertilizer significantly affected percent seed weight, lint weight, and seed lint ratio. The interaction of sunn hemp, organic, and inorganic fertilizers led to an increase in percent seed weight, lint weight, and seed lint ratio compared to treatments without sunn hemp. This might be due to the synergistic effect of combining organic amendments with inorganic fertilizers, where organic inputs like sunn hemp contribute to improving soil health, nutrient cycling, and water retention, while inorganic fertilizers provide the necessary macronutrients for plant development. Reports of Ikeh *et al* (2023a) indicated that application of organic and inorganic fertilizers enhances crop growth and yield. Studies are in agreement with Ndaeyo *et al* (2013) who also reported that organic amendments, particularly leguminous crops such as sunn hemp, improve cotton boll weight by enhancing nutrient availability and soil organic matter. Inorganic fertilizers, when applied in balanced quantities, further boost this effect by supplying essential nutrients that support cotton lint and seed development. Singh *et al*. (2023) also found that nitrogen-rich fertilizers had a significant impact on lint and seed weight in cotton, a finding that is consistent with the study results, where cotton with 200 kg NPK and SH produced the heaviest cotton lint and seeds. The nitrogen likely promotes protein synthesis and energy metabolism within the plant, directly influencing seed and lint development.

5. CONCLUSIONS AND RECOMMENDATIONS

This study has explored the pressing challenges facing cotton yield in titanium-mined regions such as Kwale County, where severe soil degradation marked by topsoil loss, compaction, and nutrient depletion significantly hinders cotton productivity. The findings underscore the critical role of soil fertility restoration in improving cotton yield. Conventional mining rehabilitation methods have proven insufficient, as they often fail to restore the biological and chemical functions of soil necessary for sustainable cotton production.

Integrated Nutrient Management (INM), incorporating sunn hemp (Crotalaria juncea), with farmyard manure (FYM), and inorganic fertilizers, offers a practical and sustainable solution to enhance soil health in degraded lands hence improved cotton yield. Combined use of sun hemp with different levels of FYM and inorganic fertilizer significantly improved cotton yield parameter such as boll weight, number of seeds per boll, seed weight, percent seed weight, lint weight, percent lint weight, and lint-seed ratio. Cotton with 200 kg NPK and SH significantly produced the highest cotton yield at the end of the cropping seasons, and there was a clear trend that various treatments (especially those including sunnhemp) significantly promoted cotton yield compared to the control. Ultimately, the integration of these practices contributes to higher cotton yields essential for revitalizing Kenya's cotton value chain, improving farmer income, and reducing reliance on imported textiles. This study therefore demonstrates that INM is an essential pathway for ecological restoration and sustainable intensification of cotton yield in post-mining landscapes.

Farmers in titanium-mined regions should adopt integrated nutrient strategies combining sunn hemp with FYM and inorganic fertilizers. This approach will help rehabilitate soil health and increase cotton yields. Due to the fact that this study was carried out for a short term period, further research is needed to optimize the ratio, timing, and compatibility of INM inputs in different agro-ecological and soil conditions, particularly for reconstituted soils after mining activities. Restoration programs in mining-affected areas should include long-term monitoring of soil health indicators and cotton yield to ensure that reclamation efforts are effective and adaptable to site-specific challenges.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that they have no known competing financial interests or non-financial interests or personal relationships that could have appeared to influence the work reported in this paper.

REFERENCES

Bhattacharyya, P. N., Goswami, M. P., & Bhattacharyya, L. H. (2016). Perspective of beneficial microbes in agriculture under changing climatic scenario: A review. *Journal of Phytology, 8*, 26–41.

Deshmukh, D. P., Konde, N. M., Kadu, P. R., Katkar, R. N., Mali, D. V., Jadhao, S. D., ... & Goramnagar, H. B. (2021). Sustaining soil health and cotton productivity with tillage and integrated nutrient management in Vertisols of Central India. *Indian Journal of Soil Conservation, 49*(1), 1–11. https://ijsc.iaswc.com/index.php/ijsc/article/view/137

Dhaliwal, S. S., Walia, S. S., Walia, M. K., & Manchanda, J. S. (2013). Build up of macro, micro and secondary plant nutrients in site specific nutrient management experiment under rice-wheat system. *International Journal of Science, Environment and Technology*, *2*(2), 236-244.

Dollete, D. L. (2024). Effect of drought and defoliation on plant growth, symbiotic nitrogen fixation, soil nitrogen availability and soil microbial dynamics in forage legumes. https://era.library.ualberta.ca/items/2625d17b-eb31-4cac-87ed-017d9703d576

Esang, D. M., & Ikeh, A. O. (2021). Response of some improved upland rice varieties to different sources and rates of nitrogen fertilizer in Humid Rain Forest Region of Nigeria. *American Journal of Agricultural Science, Engineering and Technology, 5*(2), 69–91. https://doi.org/10.5281/zenodo.5456153

Food and Agricultural Organisation. (2021). *Global agricultural employment statistics*. FAO Reports. https://openknowledge.fao.org/handle/20.500.14283/cc3376en

Hussain, A., Ahmad, M., Mumtaz, M. Z., Ali, S., Sarfraz, R., Naveed, M., ... & Damalas, C. A. (2020). Integrated application of organic amendments with Alcaligenes sp. AZ9 improves nutrient uptake and yield of maize (Zea mays). *Journal of Plant Growth Regulation*, *39*, 1277-1292.

Ikeh, A. O., Essien, B. A., Orji, J. O., Okocha, I. O., Amanze, A. N., & Nwokorie, U. M. (2023c). Effects nursery media on *Irvingia gabonensis* and *Dacryodes edulis* seedlings and weed dynamics of the media. *Applied Research in Science and Technology, 3*(1), 27–35. https://areste.org/index.php/oai/article/view/41, https://doi.org/10.33292/areste.v3i1.41

Ikeh, A. O., Ndaeyo, N. U., & Ikeh, C. E. (2023a). Effects of integrated fertilization on soil sustainability and cassava (*Manihot esculenta* Crantz) yield in an ultisol. *Journal of Current Opinion in Crop Science, 4*(2), 89–102.

https://www.jcocs.com/index.php/ej/article/view/203/185, https://doi.org/10.62773/jcocs.v4i2.197

Ikeh, A. O., Okocha, I. O., Umekwe, P. N., Amanze, A. N., & Ikeh, C. E. (2023d). Effect of foliar application of cow dung extract on growth and yield of waterleaf (*Talinum triangulare* Jacq.) in an ultisol. *Journal of Current Opinion in Crop Science, 4*(3), 103–111. https://doi.org/10.62773/jcocs.v4i3.203

Ikeh, A. O., Orji, J. O., Sampson, H. U., & Akata, O. R. (2023b). Effect of oil palm bunch refuse ash in sustainable production of egusi-melon (*Colocynthis citrullus*) in an ultisol. *Asian Journal Agricultural and Horticultural Research, 10*(3), 138–148. https://doi.org/10.9734/AJAHR/2023/v10i324

Ikeh, A. O., Sampson, H. U., Ukabiala, M. E., Anonaba, N. K., Okamigbo, J. N., & Akuwueze, C. G. (2025). Effect of soil ameliorations on cucumber (*Cucumis sativus* L.) yield and soil physico-chemical properties in an ultisol of Southeastern Nigeria. *Open Soil Science and Environment, 5*(1), 1–9. https://doi.org/10.33292/ost.vol5no1.2025.146

Iqbal, A., Shafi, M. I., Rafique, M., Zaman, M., Ali, I., Jabeen, A., ... & Jiang, L. (2023). Approaches for using bio-fertilizers as a substitute for chemical fertilizers to improve soil health and crop yields in Pakistan. In *Biofertilizers for Sustainable Soil Management* (pp. 89–118). CRC Press. https://www.taylorfrancis.com/chapters/edit/10.1201/9781003286233-5

Liu, S., Li, J., Xiao, W., Chen, R., Sun, Z., Zhang, Y., ... & Chen, W. (2024). Buried interface molecular hybrid for inverted perovskite solar cells. *Nature, 632*(8025), 536–542.

Mahmoud, b. A., omar, S. A., Shaker, S. A., & Darwesh, A. E. I. (2018). MARKERS ASSISTED SELECTION FOR SALT TOLERANCE AMONG SOME COTTON (Gossypium barbadense L.) GENOTYPES. *Egyptian Journal of Genetics And Cytology*, *47*(2). https://journal.esg.net.eg/index.php/EJGC/article/view/291

Marahatta, S., Sah, S. K., McDonald, A. J., Timsina, J., Karn, R., & Devkota, K. (n.d.). Site-specific nutrient management: A robust approach to estimating indigenous nutrient supply, recommending fertilizer, and increasing rice yield in Nepal. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=5205910

Marquardt, S., & Savage, L. (2023). *Growing hemp for the future: A global fiber guide*. Textile Exchange: Lamesa, TX, USA. https://textileexchange.org/app/uploads/2023/04/Growing-Hemp-for-the-Future-1.pdf

Ndaeyo, N. U., Ikeh, A. O., Nkeme, K. K., Akpan, E. A., & Udoh, E. I. (2013). Growth and foliar yield responses of waterleaf (*Talinum triangulare* Jacq) to complementary application of organic and inorganic fertilizer in an ultisol. *American Journal of Experimental Agriculture, 3*(2), 324–335. https://journaljeai.com/index.php/JEAI/article/view/985, https://doi.org/10.9734/AJEA/2013/2599

Okalebo, J. R., Gathua, K. W., & Woomer, P. L. (2002). *Laboratory methods of soil and plant analysis: A working manual* (2nd ed.). TSBF-CIAT and SACRED Africa. https://erepository.uonbi.ac.ke/handle/11295/85257

Reddy, Y. N., & Reddy, Y. P. (2023). Morpho-physiological basis of finger millet to withstand climatic extremes: A special reference to drought. In *Translating physiological tools to augment crop breeding* (pp. 391-410). Singapore: Springer Nature Singapore. https://link.springer.com/chapter/10.1007/978-981-19-7498-4_18

Republic of Kenya. (2018). *The Big Four Agenda: Manufacturing pillar*. Government Press. https://pub.h-brs.de/frontdoor/index/index/docId/4426

Sampson, H. U., Ikeh, A. O., Orji, J. O., Uko, U. I., Okparaiheoma, D. A., Akuwueze, C. G., Anonaba, N. K., & Okamigbo, J. N. (2025). Effects of soil amendment on productivity of okra (*Abelmoschus esculentus* (L.) Moench) in an ultisol of Southeastern Nigeria. *Open Soil Science and Environment, 3*(1). https://doi.org/10.70110/osse.v3i1.33

Sharma, P., Singh, A., Kahlon, C. S., Brar, A. S., Grover, K. K., Dia, M., & Steiner, R. L. (2018). The role of cover crops towards sustainable soil health and agriculture—A review paper. *American Journal of Plant Sciences*, *9*(9), 1935-1951.

Singh, F., Kang, J. S., Singh, A., & Singh, T. (2015). Nutrient uptake, nutrient availability and quality parameters of mechanically transplanted rice (Oryza sativa L.) under split doses of nitrogen.*Agricultural*

Science Digest-A Research Journal, *35*(2), 95-100.

Singh, R., Sharma, P., & Kumar, A. (2023). Ecological land rehabilitation and rural livelihoods. In *Sustainable Agriculture Reviews, 39*, 201–215. https://books.google.com/books?hl=en&lr=&id=bgrgEAAAQBAJ&oi=fnd&pg=PR5

Traub, L. N., & Jayne, T. S. (2008). The effects of price deregulation on maize marketing margins in South Africa. *Food Policy, 33*(3), 224–236. https://www.sciencedirect.com/science/article/pii/S0306919207000589

Yadav, A., Bhuj, B. D., Ram, S., Singh, C. P., Dhar, S., Yadav, R. K., ... & Ashok, K. (2021). Organic farming for sustainable agriculture: A review. *Annals of the Romanian Society for Cell Biology, 25*(6), 8088–8123. https://search.proquest.com/openview/83f29248b4807e90119ed284b2469efd/1?pq-origsite=gscholar&cbl=2031963

Yang, J., Zhang, J., Wang, Z., Zhu, Q., & Wang, W. (2001). Hormonal changes in the grains of rice subjected to water stress during grain filling. *Plant Physiology, 127*(1), 315–323.

Peer-review history:
The peer review history for this paper can be accessed here:
https://pr.sdiarticle5.com/review-history/138026