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Comparative Effect of Sunn Hemp with Farmyard Manure and Inorganic Fertilizer Levels on Growth of Cotton in Titanium-mined Reconstituted Soils in Kwale County, Kenya

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Authors' contributions

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

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ABSTRACT

Cotton growth performance in Kenya have declined over the years, with Kwale County being one of the areas that were once suitable for cotton farming experiencing serious setbacks with soil loss and reduced arable land due to enhanced mining activities. The aim of this study was to assess the

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potential of combining sunn hemp with farm yard manure and inorganic fertilizers to enhance cotton growth in titanium-mined and reconstituted soils of Kwale County. Field trials were conducted in May–August 2022 and September–December 2023 at Base Titanium Mining company, Kwale County, on a randomized complete block design with three replications. Ten treatments with variation in mixtures of sunn hemp, farmyard manure (7.5 or 15.0 tons/ha) and NPK fertilizer (100 or 200 kg/ha), were applied in four site conditions: undisturbed soil, topsoil-covered mined land, reconstituted soil without topsoil and reconstituted soil with topsoil. Data collected included: Soil analysis and cotton growth parameters such as plant height, leaf number, leaf length, leaf width, number of fruiting branches, length of the longest fruiting branches, number of nodes on the longest fruiting branch, internodal length, leaf chlorophyll content and canopy temperature. Data collected was 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. Results indicated that cotton with 200 kg NPK with sunn hemp significantly enhanced cotton chlorophyll content by (32.7%), leaf numbers (78.6%) and plant height (41.5%) compared to control. These findings indicate the possibility of utilizing organic-inorganic input mixtures in reclaiming mined land and improving cotton development, though additional long-term studies are recommended for large-scale application and validation.

Keywords: Cotton; green manure; sunn hemp; rehabilitation; mined land; farmyard manure.

1. INTRODUCTION

Cotton (*Gossypium hirsutum*) is a globally important fiber crop, widely cultivated in tropical and subtropical regions and essential to the global textile industry (Nazeer *et al*., 2023). The cotton sector is a major source of income and employment for millions worldwide. Cotton makes up approximately 35% of all natural fibers used in the global textile industry (Townsend, 2020). Despite its economic significance, cotton production faces numerous challenges, particularly in sub-Saharan Africa, where poor agronomic practices, degraded soils, and limited access to quality inputs constrain productivity (Tlatlaa *et al*.,2023) However, in recent years, the country has experienced a sharp decline in cotton production, which poses a serious threat to agricultural sustainability, rural employment, and the broader agro-industrial economy (Chidawanyika, 2014). In Kenya, cotton has been prioritized under the manufacturing pillar of the “Big Four Agenda” for economic development Cotton requires adequate nutrient availability throughout its growth cycle for optimal productivity and fiber quality (Khan *et al*., 2017). In degraded soils, such as those affected by titanium mining, nutrient limitations severely affect cotton yield and quality (Kiponda, 2022). Titanium mining in Kenya’s Kwale County has led to soil degradation, reduced productivity, and loss of biodiversity. Conventional topsoil layering alone is often inadequate for full soil function recovery (Cribari *et al*., 2024). There is a growing call for site-specific, ecologically informed reclamation approaches (Campero *et al*.,2024). Tailored fertility management is crucial for restoring productivity in mined lands (Ndiba, 2024).

Rehabilitation of such degraded lands requires a holistic and sustainable approach to soil management. Integrated soil fertility management (ISFM) practices that combine organic and inorganic amendments provide a promising strategy for reversing the damage to post-mining soils. The use of sunn hemp (Crotalaria juncea) as a green manure crop, farmyard manure (FYM) as an organic amendment, and inorganic fertilizers (e.g., NPK) has been identified as a practical and ecologically sound solution. Sunn hemp is a fast-growing legume that contributes to nitrogen fixation and acts as an effective cover crop it contributes to nutrient cycling and soil moisture conservation essential for cotton growth under the harsh conditions of reconstituted soils. Integrated Nutrient Management (INM) enhances soil structure and nutrient availability by combining organic and inorganic sources (Marimuthu *et al*,.2014). This support root development, photosynthesis, and cotton canopy temperature (Zingore *et al*., 2007). INM ensures a balanced supply of nutrients throughout the cotton growth cycle (Yadav *et al*., 2024). It leads to vigorous vegetative growth, deeper roots, and improved cotton plant health (Jayakumar & Surendran, 2017). Cotton vegetative rate and photosynthetic rates increase significantly under integrated nutrient regimes (Marimuthu *et al*., 2014). This results in higher cotton growth and improved stress resilience.

While numerous studies have examined the individual effects of chemical fertilizers, green manures, or organic amendments such as farmyard manure (FYM) on cotton productivity (Lin *et al*., 2024; Verma *et al*., 2025) limited research has assessed the synergistic effects of integrating sunn hemp, FYM and inorganic fertilizers on cotton growth, particularly in soils degraded by titanium mining. Existing literature lacks location-specific studies focused on nutrient restoration and cotton growth in reconstituted post-mining soils such as those found in Kwale County, Kenya (Ndiba, 2024; Simmons *et al*., 2022). This gap hinders the development of tailored soil fertility management strategies that could effectively rehabilitate mined lands while supporting sustainable cotton production in marginal environments (Irfan and Ahmad, 2014).

This study is vital for addressing soil degradation caused by titanium mining, which severely affects soil structure, nutrient dynamics and biological activity (Bridge, 2004). Integrated Nutrient Management through a combination of organic and inorganic inputs has proven effective in restoring soil fertility, promoting root development and enhancing cotton performance (Marimuthu *et al*, 2014). The outcomes will also guide smallholder farmers and policymakers in adopting ecologically sound land rehabilitation approaches that enhance food security and rural livelihoods (Velmourougane *et al*., 2022).

2. MATERIALS AND METHODS

2.1 Experimental Site

The study was carried out at Base Titanium Limited (BTL) mine, located in Kwale County, 50 K.M. south of Mombasa, in May 2022. Base Titanium farm lay between latitudes 3°S-4°S and longitudes 39°E–40°E. Kwale County was generally warm throughout the year, with temperatures ranging between 24.2°C during the coldest months (June and July) and 27°C during the hottest months (January and February). Rainfall patterns exhibited a distinct bimodal distribution. The first rains fell between March and May and were known as the long rains (L.R.). The second rains, the short rains (S.R.), were received between October and December. Average seasonal rainfall was between 900-1350mm. Inter-seasonal rainfall variations were large, with a coefficient of variation ranging between 45-58 percent, while temperatures ranged between 17°C-24°C. Evapotranspiration rates were high and exceeded the amount of rainfall most of the year except in November. The original soils within the area were well-drained, red to a dusky red, very friable, sandy clay loam to clay, with a topsoil of loamy sand to sandy: rhodic Ferralsols. The soils were sampled and chemical properties analysed following the procedures described by Okalebo et al., (2002) and they are as displayed in Table 1.

2.2 Experimental Design 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.

Land preparation was done in early May 2022 using a tractor. The plots with Sunn hemp (SH) were planted 2 months before planting cotton. Sunn hemp was seeded at the rate of 40 to 60 lb pure live seed per acre (45 to 67 kg/ha). The seeding rate was 34 to 56 kg/ha in 6-inch rows if drilled. The higher seeding rates were used if the crop was incorporated in less than 60 days (30 to 45 days). The crop was ploughed down either in the bud or early flowering stage, normally about 60 days or less after planting, after attaining an average height of 1.80 m. The SH was ploughed back after two months as green manure because if it was allowed to grow beyond this stage, the plants would become fibrous and difficult to plough under.

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

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 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.

2.3 Data Collection

Fifteen (15) plants from each plot were randomly marked and used for all subsequent data collection on growth parameters. The collected data for growth performance included plant height, leaf number, leaf length, leaf width, number of fruiting branches, length of the longest fruiting branches, number of nodes on the longest fruiting branch, internodal length, leaf chlorophyll content and canopy temperature as described by Irfan & Ahmad, (2014).Each week, the height of mature plants was recorded by measuring from the soil surface to the topmost part of the plant using a measuring tape or ruler, with measurements taken in centimeters. Leaves were counted manually throughout the growing period using a handheld counter or noted on paper. This process ensured accurate monitoring of leaf development and served as a useful indicator of photosynthetic potential and plant health. Observations also helped in detecting issues such as pest infestations or nutrient stress (Haworth, 2023; Pastor *et al*., 2022).

Leaf length was determined by measuring from the point where the leaf attaches to the stem up to its tip using a ruler or tape measure. These measurements were taken at different growth stages to evaluate plant vigor and light absorption efficiency (Hossain *et al*., 2021; Sun *et al*,2024). To assess leaf surface area and morphology, the width of selected leaves was measured at their broadest point using a ruler or caliper. These data helped analyze the impact of environmental factors and treatments on leaf development and plant performance (Kang *et al*., 2024). The flowering process was monitored weekly, beginning with the emergence of the first flower and continuing until flowering was complete. Flowering percentage was calculated based on the number of flowering plants per cultivar or species (Adamsen & Coffelt, 2005). Fruiting branches were counted from the base to the top of the plant at full maturity, with totals recorded for each plant (Khan et al, 2021).

At maturity, three well-developed internodes from the longest fruiting branches were selected per plant. Each internode was measured in centimeters, and the average internodal length was calculated (Khan et al, 2021). Four of the longest fruiting branches per plant were selected and measured in centimeters. The maximum length recorded among these was noted for each plant (Hamad et al., 2024). The node count was taken from the longest fruiting branch for each plant, and total nodes were recorded accordingly. Chlorophyll levels in selected leaves were estimated using a chlorometer to determine the relative chlorophyll content. Using an infrared thermometer (IRT), canopy temperature was remotely monitored during vegetative, flowering, and bolling stages. The IRT detected emitted infrared radiation and converted it to a temperature reading, reflecting the canopy's thermal status (Thorp *et al*., 2014). Just before flowering, during the vegetative phase, a chlorophyll fluorometer was used to quantify chlorophyll content in sample plants.

2.4 Data Analysis

All the obtained data were subjected to analysis of variance (ANOVA) using the SAS statistical package (Cody, 2018). Significant means at the F-test were ranked using Turkey's test at a 5% significance level.

3. RESULTS

3.1 Effect of Sunn Hemp with FYM and Inorganic Fertilizer on Cotton Plant Height and Leaf Number at 120 Days After Planting in Titanium Mined and Reconstituted Soils

Cotton plant height was significantly ($P \leq 0.05$) affected by sunn hemp (SH) combined with farmyard manure (FYM) and inorganic fertilizer (NPK) treatments at 120 days after sowing (DAS) during the planting season (Table 2). Cotton treated with combined 200 kg NPK and SH recorded the tallest cotton plants of 101.1 cm while control recorded the least height of 71.4cm. Control results were comparable with cotton with sunhemp only and cotton with 7.5 tons of FYM with average heights of 74.0 cm and 80.6 cm, respectively (Table 2). Combined SH, FYM and NPK treatment on cotton significantly ($P \leq 0.05$) influenced leaf numbers (Table 2). Cotton grown in soils treated with 200 kg NPK fertilizer and sunnhemp produced the highest number of leaves (72). These results were comparable with those obtained from cotton grown in soils amended with 200 kg NPK fertilizer (70). The lowest leaf number of 46 leaves was recorded on control plots. However, these result was comparable to those obtained from sunnhemp-only treated soils (47).

3.2 Effect of Sunn Hemp with FYM and Inorganic Fertilizer on Cotton Leaf Chlorophyll and Canopy Temperature in Titanium Mined and Reconstituted Soils

Sunn hemp, FYM and inorganic fertilizer levels significantly ($P \leq 0.05$) influenced cotton leaf chlorophyll and canopy temperature (Table 3). The highest (49.03 SPAD units) leaf chlorophyll was observed in cotton grown on soils treated with 200 kg NPK and SH. The lowest leaf chlorophyll of 36.97 SPAD units was recorded on control plots. However, these result was comparable to those obtained from sunnhemp-only treated soils (37.74 SPAD units) and 7.5 tons farm yard only treated soils (38.55 SPAD units). Cotton plots treated with 200 kg NPK with SH had the highest (24.02) canopy temperature while the lowest (21.32) was recorded in control.

Table 2. Plant height and leaf number of cotton grown in titanium mined and reconstituted soils amended with sunn hemp, FYM and inorganic fertilizer at 120 days after planting

Treatment	Plant height(cm)	Leaf number (g)
Cotton with no amendment (control)	71.4d	46.1 f
Cotton with Sunnhemp only	74.0d	47.9 ef
Cotton with 7.5 tons farm yard manure only	80.6d	51.4 d
Cotton with 7.5 tons farmyard manure and sunnhemp only	82.1c	50.2 de
Cotton with 15 tons farmyard manure only	94.3b	62.7 b
Cotton with 15 tons farm yard manure and sunnhemp only	93.7b	65.4 b
Cotton with 100 kg NPK fertilizer only	83.7c	54.5 c
Cotton with 100 kg NPK fertilizer and sunnhemp only	84.3c	57.2 c
Cotton with 200 kg NPK fertilizer only	97.1b	70.2 a
Cotton with 200 kg NPK fertilizer and sunnhemp	101.1a	72.7 a
Mean	80.2	57.8
CV (%)	7.04	6.6
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*

Table 3. Chlorophyll content and canopy temperature of cotton grown in titanium mined and reconstituted soils amended with sunn hemp, FYM and NPK fertilizer

Treatments	Chlorophyll Content	Canopy Temperature
Cotton with no amendment (control)	36.97g	21.32e
Cotton with Sunnhemp only	37.74g	21.97d
Cotton with 7.5 tons farmyard manure only	38.55fg	22.47cd
Cotton with 7.5 tons farmyard manure and sunnhemp only	40.42def	23.04bc
Cotton with 15 tons farmyard manure only	41.23cde	22.96bc
Cotton with 15 tons farmyard manure and sunnhemp only	42.23cd	23.13b
Cotton with 100 kg NPK fertilizer only	39.94ef	22.85bc
Cotton with 100 kg NPK fertilizer and sunnhemp only	42.97bc	22.70bc
Cotton with 200 kg NPK fertilizer only	44.18b	23.00bc
Cotton with 200 kg NPK fertilizer and sunnhemp	49.03a	24.02a
Mean	41.33	22.75
CV (%)	5.38	2.95
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*

Table 4. Cotton leaf width and leaf length of cotton grown in titanium mined and reconstituted soils amended with sunn hemp, FYM and inorganic fertilizer

Treatments	Leaf Width	Leaf Length
Cotton with no amendment (control)	13.31f	11.64e
Cotton with Sunnhemp only	14.19ef	12.99e
Cotton with 7.5 tons farmyard manure only	14.99de	12.21e
Cotton with 7.5 tons farmyard manure and sunnhemp only	16.14bcd	12.55de
Cotton with 15 tons farmyard manure only	15.54cd	13.54cd
Cotton with 15 tons farmyard manure and sunnhemp only	16.85abc	13.62cd
Cotton with 100 kg NPK fertilizer only	15.49cd	14.29bc
Cotton with 100 kg NPK fertilizer and sunnhemp only	16.36abc	14.34bc
Cotton with 200 kg NPK fertilizer only	17.05ab	14.46bc
Cotton with 200 kg NPK fertilizer and sunnhemp	17.86a	15.81a
Mean	15.40	13.74
CV (%)	27.53	9.63
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*

3.3 Effect of Sunn Hemp with FYM and Inorganic Fertilizer on Leaf Width and Length of Cotton Grown in Titanium Mined and Reconstituted Soil

Leaf width and length was affected significantly (P ≤ 0.05) by different levels of FYM and inorganic fertilizer (Table 4) in the two cropping seasons. Cotton fertilized with 200 kg NPK with SH (17.86 cm) had the highest leaf width of 17.86cm. This was comparable to those obtained from cotton grown in 15 tons farmyard manure and sunnhemp, in 200 kg NPK fertilizer treated soil and in 100 kg NPK fertilizer and sunnhemp amended soils. The lowest leaf width (13.31cm) was recorded in cotton grown in control plots, comparable to obtained from cotton grown in Sunnhemp only-treated plots. The highest leaf length (15.81cm) was recorded in cotton grown in 200 kg NPK fertilizer and sunnhemp-treated plots while the lowest (11.64cm) was recorded in control plots. These result was comparable to that obtained from the crop grown in Sunnhemp only, 7.5 tons farm yard manure only, and 7.5 tons farmyard manure and sunnhemp-treated plots.

3.4 Comparison Effects of Sunn Hemp with Different Levels of FYM and Inorganic Fertilizer on 50% Flowering and Longest Fruiting Branch in Cotton Grown in Titanium Mined and Reconstituted Soils

Sunn hemp, FYM and inorganic fertilizer levels significantly (P ≤ 0.05) influenced flowering rate and longest fruiting branch is given in Table 5. Among the treatments significantly highest 50% flowering were recorded in the plots that received Cotton with 200 kg NPK fertilizer and sunnhemp (49.83 DAS) and Cotton with Sunnhemp only (49.54 days) which was similar with Cotton with 200 kg NPK fertilizer only (50.00 days). Control treatment had the latest flowering time (58.46 days). Significant variations were observed on longest fruiting branch per plant as a consequence of fertilizer effect (Table 5). The shortest fruiting branch was obtained from unfertilized plots (29.88g) that significantly increased with fertilizer application with Cotton with 200 kg NPK with SH producing the longest branch (71.87g), followed closely by Cotton with 200 kg NPK fertilizer only (63.33g) and Cotton with 15 tons FYM with SH (63.08g).

3.5 Effect of Sunn Hemp with FYM and Inorganic Fertilizer on Number of Branches of Cotton Grown in Titanium Mined and Reconstituted Soil

Number of fruiting branches were significantly (P ≤ 0.05) affected by different levels of Sunn hemp, FYM and inorganic fertilizer application (Table 6). Cotton grown in 200 kg NPK with sunnhemp-treated soils recorded highest number of fruiting of (1.88) which was comparable to with the crop grown in 100 kg NPK with sunnhemp and 200 kg NPK only-treated plots. The lowest number of fruting branches of 1.43 was recorded on control plots, comparable to results obtained in Sunnhemp only (1.48) and 7.5 tons farm yard manure-treated plots (1.55).

3.6 Effects of Different Levels of Sunn Hemp, FYM and Inorganic Fertilizer on Inter Nodal Length and Number of Nodes in Cotton Grown in Titanium Mined and Reconstituted Soils

Sunn hemp, FYM and inorganic fertilizer levels significantly (P ≤ 0.05) improved inter nodal length and number of nodes (Table 7). The inter nodal length of cotton was significantly different (P ≤ 0.05) between sunnhemp. The highest inter nodal length (1.88cm) was obtained in 200 kg NPK with sunnhemp treated plots which was not significantly different with cotton grown in cotton with 200 kg NPK only and that grown in 100 kg NPK with sunnhemp treated plots. The lowest inter nodal length (1.43cm) was obtained from cotton grown in control plots, comparable to cotton grown in Sunnhemp only and Cotton with 7.5 tons farm yard manure only treated plots. The highest number of nodes (20.91) was recorded at plots ammended with 200 kg NPK with sunnhemp which was followed by treatment Cotton with 200 kg NPK only (20.08). The lowest number of nodes (14.14) was recorded in cotton grown in control plots.

Table 5. Cotton longest branch length and 50% flowering of cotton grown in titanium mined and reconstituted soils amended with sunn hemp, FYM and inorganic fertilizer

Treatments	Longest Branch	50% Flowering
Cotton with no amendment (control)	29.88g	58.46a
Cotton with Sunnhemp only	35.32f	49.54c
Cotton with 7.5 tons farm yard manure only	40.15f	57.79a
Cotton with 7.5 tons farmyard manure and sunnhemp only	48.81de	55.54b
Cotton with 15 tons farmyard manure only	54.08cd	54.00b
Cotton with 15 tons farm yard manure and sunnhemp only	63.08b	53.63b
Cotton with 100 kg NPK fertilizer only	47.39e	53.50b
Cotton with 100 kg NPK fertilizer and sunnhemp only	55.18c	51.42c
Cotton with 200 kg NPK fertilizer only	63.33b	50.00c
Cotton with 200 kg NPK fertilizer and sunnhemp	71.87a	49.83c
Mean	50.91	53.37
CV (%)	13.78	4.64
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*

Table 6. Number of branches of cotton grown in titanium mined and reconstituted soils amended with sunn hemp, FYM and inorganic fertilizer

Treatment	Number of branches
Cotton with no amendment (control)	1.43e
Cotton with Sunnhemp only	1.48de
Cotton with 7.5 tons farm yard manure only	1.55de
Cotton with 7.5 tons farmyard manure and sunnhemp only	1.69bc
Cotton with 15 tons farmyard manure only	1.69bc
Cotton with 15 tons farm yard manure and sunnhemp only	1.708bc
Cotton with 100 kg NPK fertilizer only	1.60cd
Cotton with 100 kg NPK fertilizer and sunnhemp only	1.78ab
Cotton with 200 kg NPK fertilizer only	1.76ab
Cotton with 200 kg NPK fertilizer and sunnhemp	1.88a
Mean	1.65
CV (%)	9.56
P≤0.05	<.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 7. Number of Nodes and internode length of cotton grown in titanium mined and reconstituted soils amended with sunn hemp, FYM and inorganic fertilizer

Treatment	Number of Nodes	Length of Internodes
Cotton with no amendment (control)	14.14	1.43e
Cotton with Sunnhemp only	14.86f	1.48de
Cotton with 7.5 tons farm yard manure only	17.14e	1.55de
Cotton with 7.5 tons farmyard manure and sunnhemp only	17.27e	1.69bc
Cotton with 15 tons farmyard manure only	19.32c	1.69bc
Cotton with 15 tons farm yard manure and sunnhemp only	19.34bc	1.708bc
Cotton with 100 kg NPK fertilizer only	18.07d	1.60cd
Cotton with 100 kg NPK fertilizer and sunnhemp only	18.61cd	1.78ab
Cotton with 200 kg NPK fertilizer only	20.08b	1.76ab
Cotton with 200 kg NPK fertilizer and sunnhemp	20.91a	1.88a
Mean	17.97	1.65
CV (%)	4.63	9.56
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.*

4. DISCUSSION

4.1 Effect of Sunn Hemp with FYM and Inorganic Fertilizer on Cotton Plant Height and Leaf Number at 120 Days After Planting in Titanium Mined and Reconstituted Soils

The study showed that comparison effect of sunn hemp wth different levels of FYM, and inorganic fertilizer significantly (P ≤ 0.05) influenced the height and leaf number in cotton grown in titanium mined and reconstituted soils. These findings were in line with Ali *et al*. (2014) who reported that the integration of sunn hemp with different levels of inorganic fertilizers can significantly enhance cotton height and leaf production in cotton plants grown in compromised soils. Organic legumes such as Sunn Hemp can play a key role in improving the fertility of nutrient-depleted soils. The results confirm that sunnhemp, if combined with inorganic fertilizers, can significantly boost plant growth. Ali *et al.* (2014) found that Sunn hemp provides a continuous nitrogen source to crops and enhances microbial activity, which is beneficial for nutrient cycling in the soil. Results from the current study reveal that the use of cotton with 200 kg NPK and sunnhemp significantly increased cotton height and number of leaves, a finding that agrees with Snider *et al.* (2021). Snider s *et al*. (2021) emphasized that nitrogen is crucial during the vegetative growth phase of cotton, supporting strong leaf and stem development. The results also showed that, sunhemp with different levels of FYM showed significant height and number of leaves in in cotton, which aligns with findings from Sharma *et al.* (2024). This was due to enhanced nutrient availability and soil moisture retention. FYM has the ability to improve soil structure, increase nutrient availability, and support plant growth in nutrient-poor soils.

4.2 Effect of Sunn Hemp with FYM and Inorganic Fertilizer on Cotton Leaf Chlorophyll and Canopy Temperature in in Titanium Mined and Reconstituted Soils

The study showed that comparison effect of sunn hemp wth different levels of FYM, and inorganic fertilizer significantly (P ≤ 0.05) influenced the leaf width and length in cotton grown in titanium mined and reconstituted soils. The increased leaf width and length was due could be attributed to incorporation of sunn hemp with FYM and inorganic fertilizers, particularly in nutrient-deficient environments like titanium-mined soils. This was inconjuction with a study by Esfahan *et al*. (2024) who also found that the addition of organic matter from legumes such as sunn hemp improved soil structure and increased nutrient availability, which could lead to better plant growth. This is supported by Nayem *et al*., (2025), who showed that organic amendments like sunn hemp result in larger leaves in crops grown in soils with low fertility. As seen in our study, treatments involving sunn hemp could lead to significant improvements in cotton leaf width and length, likely due to the enhanced soil fertility and improved soil structure that encourages root development and nutrient uptake.

The results from the current study confirmed that cotton with grown in 200 kg NPK with and sunnhemp fertilizer amended soil gave the highest cotton leaf width and length. The results were in line with Solaimalai *et al*. (2020), who observed that when organic amendments like sunn hemp or FYM were combined with inorganic fertilizers, cotton plants exhibited significant improvements in width and length compared to those treated with either organic or inorganic inputs alone. This synergistic effect can be attributed to the organic matter's role in improving soil structure, increasing microbial activity, and enhancing nutrient availability, while the inorganic fertilizers provide a quick nutrient boost. This integrated approach may help in overcoming the limitations of both nutrient-poor soils and the rapid nutrient release nature of inorganic fertilizers (Sharma *et al.,* 2024).

According to Solaimalai *et al*. (2020), combined use of organic amendments like sunn hemp or FYM with inorganic fertilizers could may have enhanced the phosphorus content and its uptake. Nitrogen and phosphorus are essential for vegetative growth and grain development. The higher grain weight recorded could have been influenced by the comparatively balanced supply throughout the grain filling and grain development period. These findings collaborate with those of Shah *et al.* (2024), who reported that use of organic manure and fertilizer increased soil fertility, leading to increased grain weight.

4.3 Effect of Sunn Hemp with FYM and Inorganic Fertilizer on Leaf Width and Length of Cotton Grown in Titanium Mined and Reconstituted Soil

The results showed that treatments with sunn hemp (especially those combined with inorganic fertilizers resulted in the highest chlorophyll content in cotton. This suggests that the enhanced nitrogen availability from sunn hemp played a pivotal role in improving chlorophyll production, which is crucial for photosynthesis and overall plant health. Inorganic fertilizers such as NPK improve plant growth and chlorophyll content, they may also lead to higher transpiration and, consequently, higher canopy temperatures. This results collaborated with Malinga & Laing (2022), who found that the incorporation of sunn hemp significantly enhanced soil nitrogen content and improved soil structure, leading to higher crop yields in subsequent crops. This aligns with findings from Shah *et al.* (2024), who found that while nitrogen fertilizers boosted chlorophyll levels, excessive application led to an increase in canopy temperature due to the intensified transpiration and metabolic activity of plants. Kansanga *et al.* (2023), also indicated that improved chlorophyll content in crops following the use of nitrogen-fixing plants like sunn hemp, which provided a long-lasting benefit to crop health, especially in degraded soils. The synergistic effect of sunn hemp + FYM in the present study further supports the idea that organic matter, when combined with nitrogen fixation, results in more robust plant health and higher chlorophyll levels, as seen in the higher chlorophyll content in treatments like cotton with 15 tons FYM with sunnhemp and cotton with 200 kg NPK with sunnhemp. Saliu *et al*., (2023) observed similar results, where FYM's role in improving soil structure and nutrient availability led to a decrease in soil compaction, which in turn promoted better root growth and improved nutrient uptake. Saliu *et al*., (2023) observed similar results, where FYM's role in improving soil structure and nutrient availability led to a decrease in soil compaction, which in turn promoted better root growth and improved nutrient uptake. In the present study, treatments combining sunn hemp with both FYM and inorganic fertilizers, such as cotton with 15 tons FYM with sunnhemp and Cotton with 200 kg NPK with sunnhemp, demonstrated the highest chlorophyll content. The combined use of these inputs likely created an ideal environment for cotton growth, promoting nutrient uptake while providing a constant supply of nitrogen. However, the canopy temperature in these treatments was higher, indicating that the increased growth and transpiration rates from the combination of organic and inorganic inputs contributed to a warmer canopy.

4.4 Comparison Effects of Sunn Hemp with Different Levels of FYM and Inorganic Fertilizer on 50% Flowering and Longest Fruiting Branch in Cotton Grown in Titanium Mined and Reconstituted Soils

Combining sunn hemp with FYM or inorganic fertilizers, such as Cotton with 15 tons FYM with sunnhemp and Cotton with 200 kg NPK with sunnhemp demonstrated high vegetative growth but can delay flowering. The combined use of these inputs likely created an ideal environment for cotton growth, promoting nutrient uptake while providing a constant supply of nitrogen. This results were in line with Kansanga *et al*., (2023) who posed that a delay in flowering with the use of organic amendments The findings of this study regarding the longest branch and 50% flowering are consistent with research results that suggests the synergistic effects of combining organic fertilizers (such as sunn hemp) and high inorganic fertilizers lead to enhanced vegetative growth but can delay flowering. The results showed that, treatments (like green manure) combined with inorganic fertilizers, supporting the idea that the enhanced growth triggered by these treatments can lead to later flowering as the plant takes more time to establish its vegetative structures.

The cotton grown in 200 kg NPK with sunnhemp treatment, which had the longest branches and delayed flowering, highlights the importance of balanced nutrient management in promoting strong vegetative growth before the plant transitions to reproductive growth. These results suggest that integrated nutrient management (INM) practices, combining organic and inorganic inputs, can optimize plant growth and potentially increase yield in degraded soils such as those impacted by titanium mining. The results were in agreement with Malinga and Laing (2022) who found that the combination of organic and inorganic fertilizers delayed flowering in cotton due to the increased vegetative growth from the added nutrients. Similar to the current study, the findings of Malinga and Laing (2022) indicated that enhanced nutrient availability led to delayed flowering, as plants devoted more resources to vegetative development.

4.5 Comparison Effects of Sunn Hemp with Different Levels of FYM and Inorganic Fertilizer on Inter Nodal Length, Number of Nodes and Number of Branches in Cotton Grown in Titanium Mined and Reconstituted Soils

The effect of organic and inorganic fertilizer on inter nodal length, number of nodes and number of branches of cotton showed a significance difference throughout the growing period. The increase of the cotton inter nodal length, number of nodes and number of branches could be as a result of the interaction effect of organic and inorganic fertilizer application. The result is in agreement with Kenjaev and Davronova (2023) who observed that green manure such as sunnhemp combined with chemical fertilizers resulted in improved inter nodal length, number of nodes and number of branches. Zhang *et al*. (2018) also indicated that combined organic and inorganic fertilization increased vegetative growth, including leaf size, by improving soil organic matter, nutrient availability and overall soil structure. The organic inputs (such as sunn hemp) helped restore soil health, while inorganic fertilizers ensured quick nutrient availability, resulting in optimized crop growth. The results also showed that FYM integrated with sunnhemp gave high the cotton inter nodal length, number of nodes and number of branches compared to FYM alone, this collaborates with the findings of Fujita *et al*. (2014) who suggested that the combination of FYM and sunnhemp fertilizers often results in better overall plant growth than either treatment alone. This is because the organic matter improves soil structure, microbial activity, and nutrient availability, while inorganic fertilizers provide a quick nutrient boost.

5. CONCLUSIONS AND RECOMMENDATIONS

Combined use of sun hemp with different levels of FYM and inorganic fertilizer significantly improved cotton growth and yield parameter such as plant height, number of fruiting branches, length of the longest fruiting branches, number of nodes on the longest fruiting branch, internodal length, leaf chlorophyll content and canopy temperature. Cotton with 200 kg NPK with SH significantly produced the highest cotton growth at the end of the season, and there was a clear trend that various treatments (especially those including sunnhemp) significantly promoted cotton growth compared to the control. The Base titanium post mined soils have the potential to support optimal growth performance.

Owing to the fact that the soils have sandy loam texture with compromised water and nutrient retention capacity, sustainable cotton growth calls for application of appropriate levels of quality organic amendments to improve soil carbon skeletons, aggregate stability and biotic activities. Application of balanced proportions of organic and inorganic fertilizers to supplement all deficient nutrients is also critical. To improve cotton growth performance while sustaining soil fertility, farmers should integrate green manure such as sunnhemp with FYM and inorganic fertilizers since organic fertilizers releases nutrients at a slow rate but improves soil physical properties while inorganic fertilizers provide readily available nutrients hence crop uptake. Owing to the fact that this study was carried out for a short term period, further research should be done for long term periods using other types of green manure and different rates of farm yard manure and inorganic fertilizer to determine cotton growth. Since the study was done in base titanium limited land, it can therefore be taken further and extended on other quarried areas as a form of rehabilitation. The study should also be done under rain fed situation because most farmers depend on rains for their crops and there is also lack of uniformity when it comes to irrigation.

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.

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