Interactive Effects of Chicken Manure, Urea Fertilizer, and Forage Crops on Soil Physical and Chemical Properties in Contrasting Terrace Systems of Semi-Arid Sudan

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Research Article

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Abstract

Soil fertility degradation is a major constraint to sustainable forage production in semi-arid regions, particularly in terrace systems where physical and chemical properties vary sharply. This study evaluated the interactive effects of treated and untreated chicken manure, urea fertilizer, and two forage crops—*Clitoria ternatea* (*C. ternatea*) and *Chloris gayana* (*C. gayana*) on soil properties in low- and high-terrace soils in Sudan. Two field experiments were conducted during the 2020/2021 and 2021/2022 seasons using a split-plot design. Soil texture, pH, electrical conductivity (EC), organic carbon (OC), and total nitrogen (N) were measured before sowing and after harvest.

Untreated chicken manure, especially when combined with C. ternatea, produced the greatest improvements in OC, N, and EC. High-terrace soils exhibited substantial increases in clay and silt fractions and a marked rise in OC (0.067% to 1.68%), whereas low-terrace soils showed reductions in salinity and modest increases in pH. These results demonstrate that integrating fresh manure with legumes can rapidly improve soil quality in contrasting terrace systems.

Long-term studies incorporating crop yield and biological indicators are recommended to validate the sustainability of these practices.

1. Introduction

Soils are dynamic ecosystems that underpin agricultural productivity and global food security. However, intensive cultivation and heavy reliance on synthetic fertilizers have accelerated soil degradation, nutrient imbalances, and environmental risks such as groundwater contamination and greenhouse gas emissions [1, 2]. These challenges are particularly acute in arid and semi-arid regions, where fragile soils require external inputs to sustain productivity.

In Sudan, terrace soils represent an important agricultural resource but are constrained by salinity, alkalinity, and low organic matter content [3]. Their properties vary markedly across landscape positions: low terraces typically contain higher proportions of clay and silt, whereas high terraces are dominated by sand, making them more susceptible to nutrient leaching and poor water retention. Effective fertility management in such systems requires an integrated approach that considers both physical and chemical soil attributes, as these influence water-holding capacity, nutrient availability, and plant growth [4, 5].

Organic amendments such as chicken manure are increasingly promoted as sustainable alternatives to mineral fertilizers. Chicken manure is nutrient-rich, decomposes rapidly, and can improve soil aggregation and reduce salinity [6, 7]. Its use in Sudanese agriculture has shown promising results in enhancing soil fertility and crop productivity [8]. Crop choice also plays a critical role in soil improvement. Legumes such as Clitoria ternatea contribute to biological nitrogen fixation and enhance soil biological activity, whereas grasses such as Chloris gayana provide soil cover and reduce erosion [9, 10].

Despite advances in integrated nutrient management, little is known about how organic manure, chemical fertilizer, and forage crops interact to influence the physical and chemical properties of terrace soils in Sudan. Moreover, the contrasting responses of low- and high-terrace systems to these inputs have not been systematically evaluated [11, 12]. Addressing this gap is essential for developing soil- and site-specific fertility management strategies suited to semi-arid environments.

This study therefore examined how treated and untreated chicken manure, urea fertilizer, and two forage crops interact to influence soil texture, salinity, organic carbon, nitrogen, and pH in contrasting terrace soils. We hypothesized that untreated chicken manure, particularly when combined with C. ternatea, would produce greater improvements in soil organic carbon, nitrogen, and salinity reduction than treated manure or urea fertilizer, and that these effects would differ between terrace types due to their contrasting physical properties. The study aimed to evaluate the effects of manure type, fertilizer input, and forage crop on soil physical and chemical properties, compare the responses of low- and high-terrace soils, and identify integrated nutrient management strategies suitable for semi-arid terrace systems.

 Next Step

I will now proceed with:

SECTION 3 — Materials and Methods (Numbered Citations)

Just say “continue” and I will deliver the next section immediately.

2. Materials and Methods

2.1 Study Site and Soil Characteristics

The study was conducted during the 2020/2021 and 2021/2022 growing seasons at the Demonstration Farm of Nile Valley University, River Nile State, Sudan (17°48'N, 34°00'E; 346.5 m a.s.l.). The region is classified as semi-arid, receiving 150–250 mm of annual rainfall, with maximum summer temperatures exceeding 40°C and mild winter temperatures averaging 18–22°C.

Two contrasting terrace soils were selected. The low-terrace soil was classified as silty clay, with an initial pH of 7.6 and electrical conductivity (EC) of 0.66 $dS \cdot m^{-1}$. The high-terrace soil was characterized as sandy clay loam, with an initial pH of 8.8 and EC of 4.0 $dS \cdot m^{-1}$. Baseline soil texture, organic matter, and nutrient concentrations were analyzed prior to treatment application to allow comparison with post-harvest values.

2.2 Experimental Design and Treatments

A split-plot design with three replications was used. The main plots were assigned to two forage crops, Clitoria ternatea (legume) and Chloris gayana (grass), while fertilizer treatments were allocated to subplots. Six fertilizer treatments were evaluated:

- • C0 = control (no inputs)
- • N = urea at 120 kg N·ha^{-1}
- • UM1 = untreated chicken manure at 5 Mg·ha^{-1}
- • UM2 = untreated chicken manure at 10 Mg·ha^{-1}
- • TM1 = treated chicken manure at 5 Mg·ha^{-1}
- • TM2 = treated chicken manure at 10 Mg·ha^{-1}

Chicken manure was sourced from local poultry farms. Treated manure was anaerobically composted under plastic sheets for 21 days, whereas untreated manure was applied fresh. Organic amendments were broadcast and incorporated into the top 15 cm of soil before sowing. Urea was applied two weeks after sowing in a single banded application at 5 cm depth to reduce volatilization losses.

2.3 Crop Establishment and Management

Seeds of C. ternatea and C. gayana were sown at rates of 12 kg·ha^{-1} and 8 kg·ha^{-1}, respectively. Standard agronomic practices were followed throughout both seasons. Irrigation was applied weekly using the furrow method, and weeds were controlled manually. No pesticides were used during the study.

2.4 Soil Sampling and Analytical Procedures

Soil samples were collected from the 0–30 cm depth before sowing (baseline) and after harvest. Three random cores were taken from each subplot, composited, air-dried, and sieved through a 2-mm mesh.

Soil texture (sand, silt, and clay fractions) was determined using the hydrometer method [13]. Soil pH was measured in a 1:2.5 soil–water suspension [14], and EC was measured in a 1:2.5 soil–water extract [15]. Organic carbon (OC) was determined using the Walkley–Black wet oxidation method, and total nitrogen (N) was analyzed using the Kjeldahl digestion procedure [16].

2.5 Statistical Analysis

Data from both seasons were analyzed using analysis of variance (ANOVA) for a split-plot design under the General Linear Model. Treatment means were separated using the least significant difference (LSD) test at $P \leq 0.05$ [17]. Statistical analyses were performed using SPSS version 25, and figures were generated using GraphPad Prism version 9.

3. Results

3.1 Physical Properties of the Soil

3.1.1 Soil Texture (Clay, Silt, Sand)

Baseline soil texture differed markedly between terrace types (Table 1). Low-terrace soil was dominated by clay (42.12%) and silt (51.00%), whereas high-terrace soil contained a much higher proportion of sand (56.19%) and correspondingly lower clay and silt contents. These inherent differences strongly influenced the magnitude and direction of treatment responses.

After two growing seasons, clear shifts in particle size distribution were observed (Fig. 1, Fig. 2, Fig. 3). In low-terrace soils, sand content increased across all treatments, accompanied by reductions in clay and silt. The largest increase in sand occurred under untreated chicken manure at 10 $Mg \cdot ha^{-1}$ (UM2), whereas treated manure at 5 $Mg \cdot ha^{-1}$ (TM1) retained the highest clay proportion among treatments.

In contrast, high-terrace soils exhibited significant increases in clay and silt fractions, with corresponding reductions in sand. The greatest improvements in fine fractions were recorded in C. ternatea plots amended with UM2.

These changes likely reflect short-term aggregation and dispersion processes rather than true mineralogical alteration. Organic inputs may have enhanced aggregation in sandy high-terrace soils, increasing the apparent proportion of fine particles, while in clay-rich low terraces, manure and root activity may have loosened dense aggregates, increasing the detectable sand fraction [13].

Table 1
Baseline soil properties in low- and high-terrace soils before treatment application. Values represent means ± standard error. EC = electrical conductivity; OC = organic carbon; N = total nitrogen.

Property	Low Terrace	High Terrace
Clay (%)	42.1 ± 1.8	26.3 ± 2.1
Silt (%)	51.0 ± 2.3	19.4 ± 1.7
Sand (%)	6.9 ± 0.5	56.2 ± 3.0
Fine Fraction (Clay+Silt) (%)	93.1 ± 2.1	45.6 ± 2.5
pH (1:2.5 H_2O)	8.8 ± 0.2	7.6 ± 0.1
EC (mS cm^{-1})	4.00 ± 0.15	0.66 ± 0.05
Organic C (g kg^{-1})	0.67 ± 0.08	2.60 ± 0.15
Total N (mg kg^{-1})	178 ± 12	344 ± 25

3.1.2 Electrical Conductivity (EC)

Electrical conductivity decreased significantly ($P \leq 0.05$) across all treatments in both terrace types. In low terraces, EC declined from 0.66 $dS \cdot m^{-1}$ at baseline to values ranging from 0.33 to 0.36 $dS \cdot m^{-1}$, with the greatest reductions observed under UM1 and UM2.

In high terraces, EC decreased from 4.00 $dS \cdot m^{-1}$ to between 1.07 and 1.51 $dS \cdot m^{-1}$, with the strongest reductions recorded in Clitoria plots receiving untreated manure. These results indicate that organic amendments, particularly when combined with legumes, enhanced salt leaching and reduced soil salinity more effectively than grass-based systems [6, 9].

3.2 Chemical Properties of the Soil

3.2.1 Organic Carbon

Chicken manure application significantly increased soil organic carbon (OC) in both terrace types (Table 2). In low terraces, the highest OC values were recorded under UM1 (2.98%) and UM2 (2.74%), slightly exceeding the control (2.96%).

In high terraces, UM2 produced the greatest increase (1.85%), followed by UM1 (1.69%), compared with the control (1.58%). Treated manure (TM1 and TM2) consistently resulted in lower OC values than untreated manure, reflecting the higher proportion of readily decomposable organic matter in fresh manure [6, 7].

Table 2
Effect of fertilizer and manure treatments on soil organic carbon (%) in low- and high-terrace soils after two growing seasons.

Treatment	Low Terrace (Mean %)	High Terrace (Mean %)
CO	2.96	1.58
N	2.88	1.74
UM1	2.98	1.69
UM2	2.74	1.85
TM1	2.90	1.41
TM2	2.73	1.64

3.2.2 Organic Nitrogen

Soil organic nitrogen (N) exhibited trends similar to OC (Table 3). In low terraces, TM1 produced the highest N concentration (542.7 $mg \cdot kg^{-1}$), followed by UM1 (505.7 $mg \cdot kg^{-1}$). In high terraces, UM2 resulted in the greatest increase (375.5 $mg \cdot kg^{-1}$), compared with the control (316.5 $mg \cdot kg^{-1}$) and urea fertilizer (319.2 $mg \cdot kg^{-1}$).

These results suggest that untreated manure mineralized more rapidly, supplying readily available nitrogen, whereas treated manure contributed more slowly to the organic N pool [16].

Table 3
Effect of fertilizer and manure treatments on soil organic nitrogen ($mg \cdot kg^{-1}$) in low- and high-terrace soils.

Treatment	Low Terrace (Mean ppm)	High Terrace (Mean ppm)
C0	504.5	316.5
N	477.5	319.2
UM1	505.7	317.5
UM2	452.3	375.5
TM1	542.7	332.0
TM2	430.3	329.7

3.2.3 Soil pH

Soil pH varied significantly across treatments. In low terraces, pH increased slightly under all treatments (7.3–8.1), with the highest values observed under UM1 and urea fertilizer. In high terraces, pH declined modestly from 8.8 to values between 7.3 and 8.5, particularly under manure-amended treatments.

Increases in low terraces may reflect $CaCO_3$ inputs from manure and rhizosphere alkalization, whereas decreases in high terraces likely resulted from organic acid production during manure decomposition and enhanced cation exchange [6, 14].

3.3 Comparative Changes Before and After Cultivation

Direct comparison of baseline and post-treatment values revealed terrace-specific responses (Table 4; Fig. 5). In low terraces, sand content increased from 11.54% to 24.84%, while clay and silt decreased. Organic nitrogen declined from 344 to 178 $mg \cdot kg^{-1}$, suggesting that crop uptake exceeded nutrient replenishment despite manure additions.

In high terraces, clay increased from 26.26% to 35.05%, and silt increased from 19.37% to 27.12%, while sand declined. Organic carbon increased markedly from 0.067% to 1.68%, indicating strong responsiveness of sandy soils to organic amendments [12].

Overall, untreated manure enhanced organic matter and nitrogen more effectively than treated manure, while C. ternatea systems were superior to C. gayana for improving EC and nutrient status.

Table 4
Comparison of soil physical and chemical properties before and after cultivation in low- and high-terrace soils.

Property	Low Terrace (Before)	Low Terrace (After)	High Terrace (Before)	High Terrace (After)
Clay (%)	42.12	34.36	26.26	35.05
Silt (%)	51.00	42.01	19.37	27.12
Sand (%)	11.54	24.84	56.19	47.02
Organic carbon (%)	0.26	0.067	0.067	1.68
Organic nitrogen (ppm)	344	178	178	331.7
EC (mS/cm)	0.66	4.0	4.0	1.34
pH	7.6	8.8	8.8	8.3

4. Discussion

4.1 Effects on Physical Properties

Organic manure and forage crop type significantly influenced soil texture and salinity in both terrace systems. In low-terrace soils, increases in sand fraction and decreases in clay and silt were observed. Although true mineral weathering is unlikely within a two-year period, these apparent shifts can be attributed to aggregation and dispersion processes induced by manure amendments and root activity. Fresh chicken manure supplies organic acids and stimulates microbial biomass, which can disrupt macro-aggregates and release smaller particles that are subsequently detected as sand [13, 18]. Similar short-term structural modifications have been documented in manure-amended soils [13].

In high-terrace soils, the opposite trend occurred: clay and silt fractions increased while sand decreased, particularly under C. ternatea combined with UM2. This suggests that organic amendments enhanced aggregation in coarse-textured soils, binding particles into more stable micro-aggregates. Such improvements are especially valuable in sandy soils that are prone to nutrient leaching and erosion [11, 19].

Electrical conductivity decreased consistently across treatments, with the largest reductions observed in low terraces and in Clitoria-based systems. Legumes likely contributed to enhanced microbial turnover and greater organic matter inputs, which in turn accelerated salt leaching. Comparable reductions in salinity following organic amendments have been reported in long-term soil improvement studies [20, 21].

4.2 Effects on Chemical Properties

Organic carbon and nitrogen increased significantly under chicken manure applications. Untreated manure consistently produced higher OC and N than treated manure, likely due to its greater content of readily decomposable organic matter. Treated manure, having undergone composting, releases nutrients more slowly and therefore contributes to more gradual improvements. These findings are consistent with previous studies in Sudan and other semi-arid regions [6, 7, 22].

Soil pH responses differed between terrace types. In low terraces, slight increases in pH may reflect $CaCO_3$ inputs from poultry feed and rhizosphere alkalization associated with legumes. In high terraces, decreases in pH suggest acidification from manure decomposition and enhanced cation exchange, a pattern commonly observed in long-term fertilization studies [23, 14].

The integration of manure with legumes was more effective than manure with grasses for improving soil organic matter and nutrient status. Legumes enhance nitrogen cycling through biological fixation, while manure supplies macro- and micronutrients, reinforcing the benefits of integrated nutrient management [4, 24].

4.3 Strengths of the Study

This study provides several notable contributions. First, it represents one of the earliest investigations in Sudan to directly compare treated and untreated chicken manure in terrace soils, offering new insights into the performance of organic amendments under contrasting soil conditions. Second, the comparative analysis of low-terrace (clay-rich) and high-terrace (sandy) soils is particularly valuable, as few studies have examined how terrace position influences soil responses to nutrient management. This dual-terrace approach highlights the importance of site-specific strategies in semi-arid environments.

Another strength lies in the integrated evaluation of organic and inorganic nutrient sources in combination with legume- and grass-based forage systems. The study demonstrates clear synergies between manure inputs and legume cultivation, offering practical guidance for improving soil fertility in resource-limited farming systems. Finally, the assessment of both physical and chemical soil properties provides a comprehensive understanding of soil quality dynamics, with broader implications for sustainable land management and climate-smart agriculture [12, 25].

4.4 Weaknesses and Limitations

Despite its contributions, the study has several limitations. The two-year duration, while sufficient to detect short-term changes, is inadequate for assessing long-term trends in soil carbon sequestration or structural stability, which typically require multi-year monitoring [26]. Additionally, the study did not include measurements of microbial or enzymatic activity, which are essential indicators of soil biological fertility and could have provided deeper insights into nutrient cycling processes [27].

Another limitation is the absence of crop yield or biomass data. Without these agronomic indicators, it is difficult to directly link soil improvements to productivity outcomes, which are critical for evaluating the practical benefits of nutrient management strategies. Minor inconsistencies in particle-size measurements may also have occurred due to the inherent limitations of sedimentation-based methods, which are known to produce small variations in texture estimates [28]. These limitations do not undermine the overall findings but highlight areas for refinement in future research.

4.5 Implications and Future Directions

The findings clearly demonstrate that untreated chicken manure, particularly when combined with legumes such as *C. ternatea*, can rapidly enhance soil fertility in both low- and high-terrace systems. Low-terrace soils benefited primarily through reductions in salinity and modest increases in pH, while high-terrace soils exhibited substantial gains in organic matter and stabilization of fine particles. These terrace-specific responses underscore the importance of tailoring nutrient management strategies to local soil conditions.

Future research should extend these findings through long-term field trials that incorporate crop yield measurements, enabling a more complete assessment of agronomic performance [26]. Incorporating microbial and enzymatic assays would provide valuable information on biological fertility and nutrient cycling processes [27]. Advanced multivariate analytical approaches could also be applied to identify soil groups or management clusters that respond most favorably to integrated nutrient inputs [21]. Emerging climate-smart technologies such as biochar, nanofertilizers, and precision nutrient management warrant investigation for their potential to further enhance soil fertility and resilience in semi-arid environments [25].

5. Conclusion

This study demonstrated that integrating organic manure, chemical fertilizer, and forage crops can significantly improve the physical and chemical properties of terrace soils in Sudan. Untreated chicken manure consistently enhanced soil organic carbon and nitrogen more effectively than treated manure, while legumes such as Clitoria ternatea promoted greater reductions in electrical conductivity compared with Chloris gayana. Low-terrace soils benefited mainly through salinity reduction and slight increases in pH, whereas high-terrace soils showed substantial improvements in organic matter accumulation and stabilization of clay and silt fractions.

These results highlight the potential of site-specific nutrient management strategies that combine organic amendments with appropriate crop choices to restore soil fertility and support sustainable agriculture in semi-arid environments. However, the short-term nature of the study emphasizes the need for long-term evaluations that incorporate crop yield responses, microbial processes, and environmental impacts to fully assess the sustainability and scalability of these practices.

Declarations

Ethics Approval:

Not Applicable

Consent to participate:

Not Applicable

Consent to publish:

Not Applicable

Competing Interests

The authors declare that they have no financial or non-financial competing interests.

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Author Contribution

A.M.E. Sulieman: Conceptualization, supervision, manuscript writing and revision.A.N.A. Abdella: Field experimentation, data collection.R.S.E. Bairum: Laboratory analysis, data curation.A. Alreshidi: Statistical analysis, manuscript editing.All authors read and approved the final manuscript.

Data Availability

Data supporting the findings of this study are available from the corresponding author upon reasonable request.

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Figures

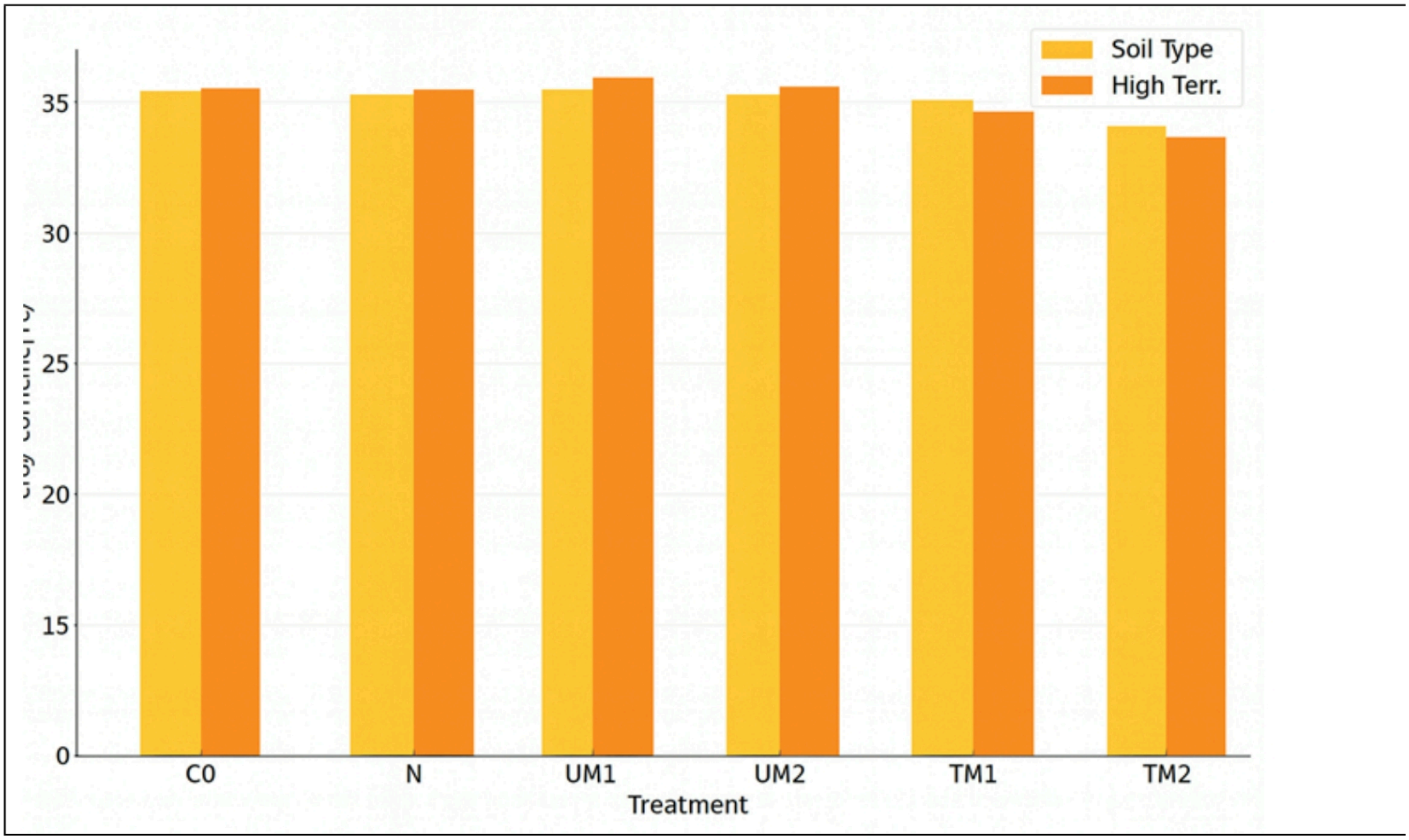

Figure 1

Effect of fertilizer and manure treatments on clay content (%) in low- and high-terrace soils after two seasons. Error bars represent standard error. Treatments: C0, N, UM1, UM2, TM1, TM2.

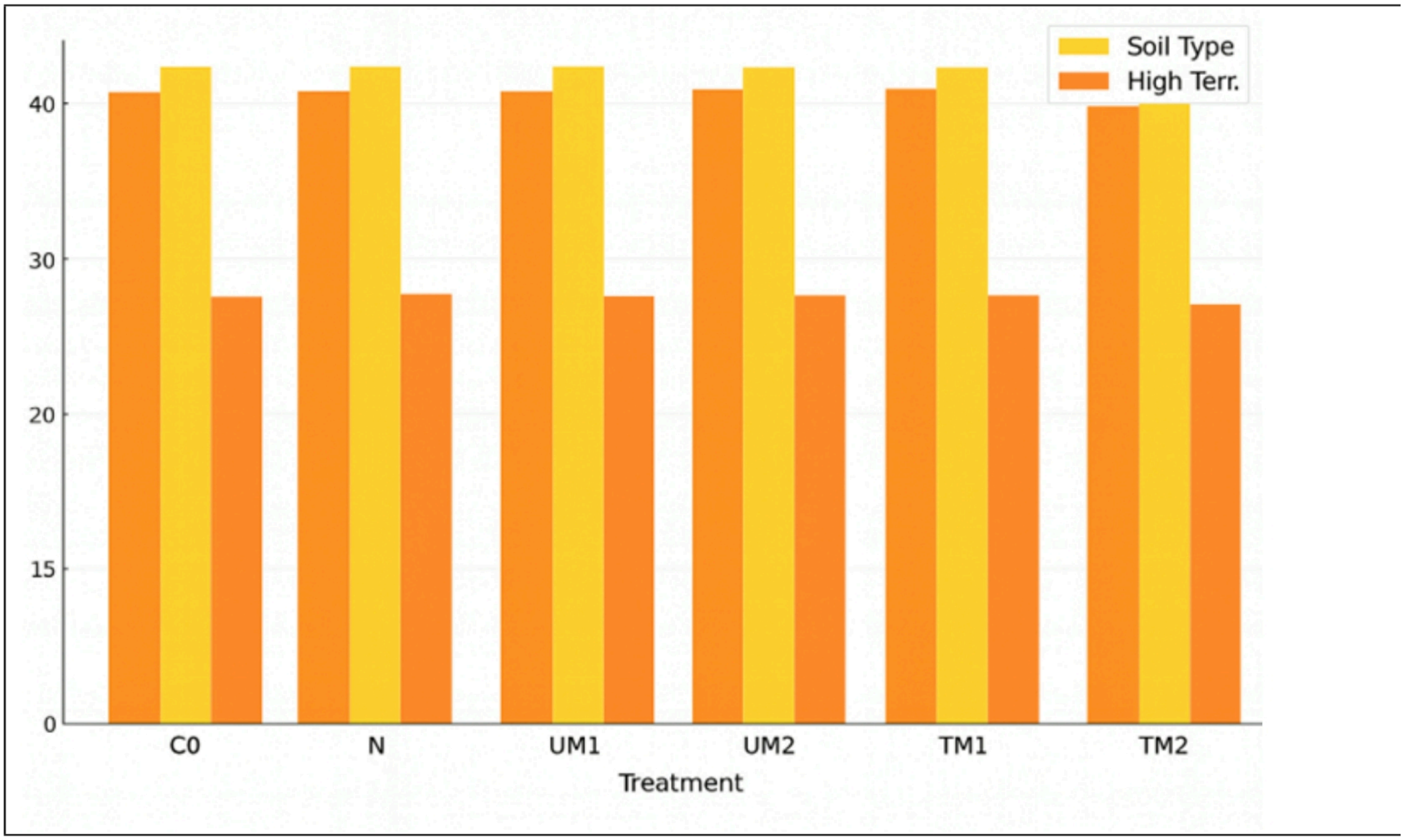

Figure 2

Effect of fertilizer and manure treatments on silt content (%) in low- and high-terrace soils. Error bars represent standard error.

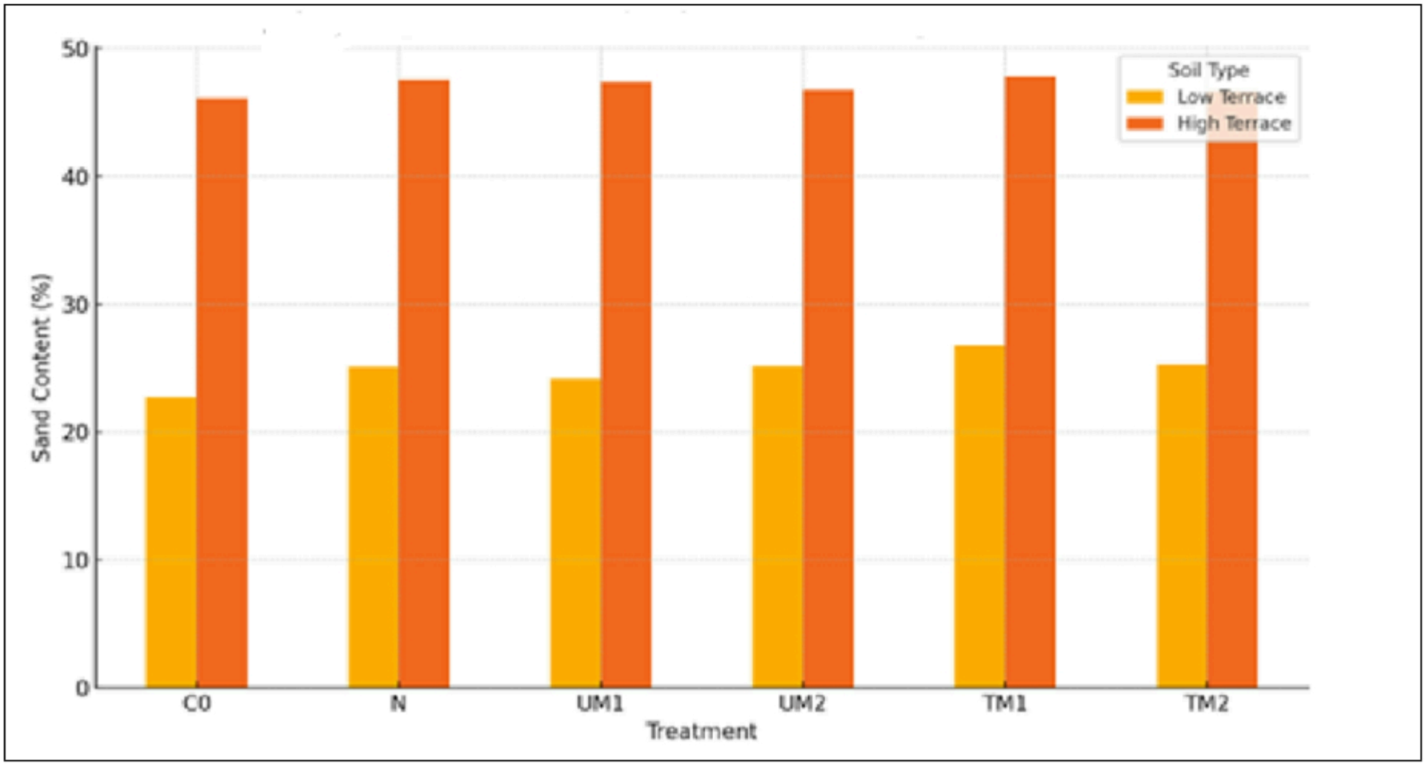

Figure 3

Effect of fertilizer and manure treatments on sand content (%) in low- and high-terrace soils. Error bars represent standard error.

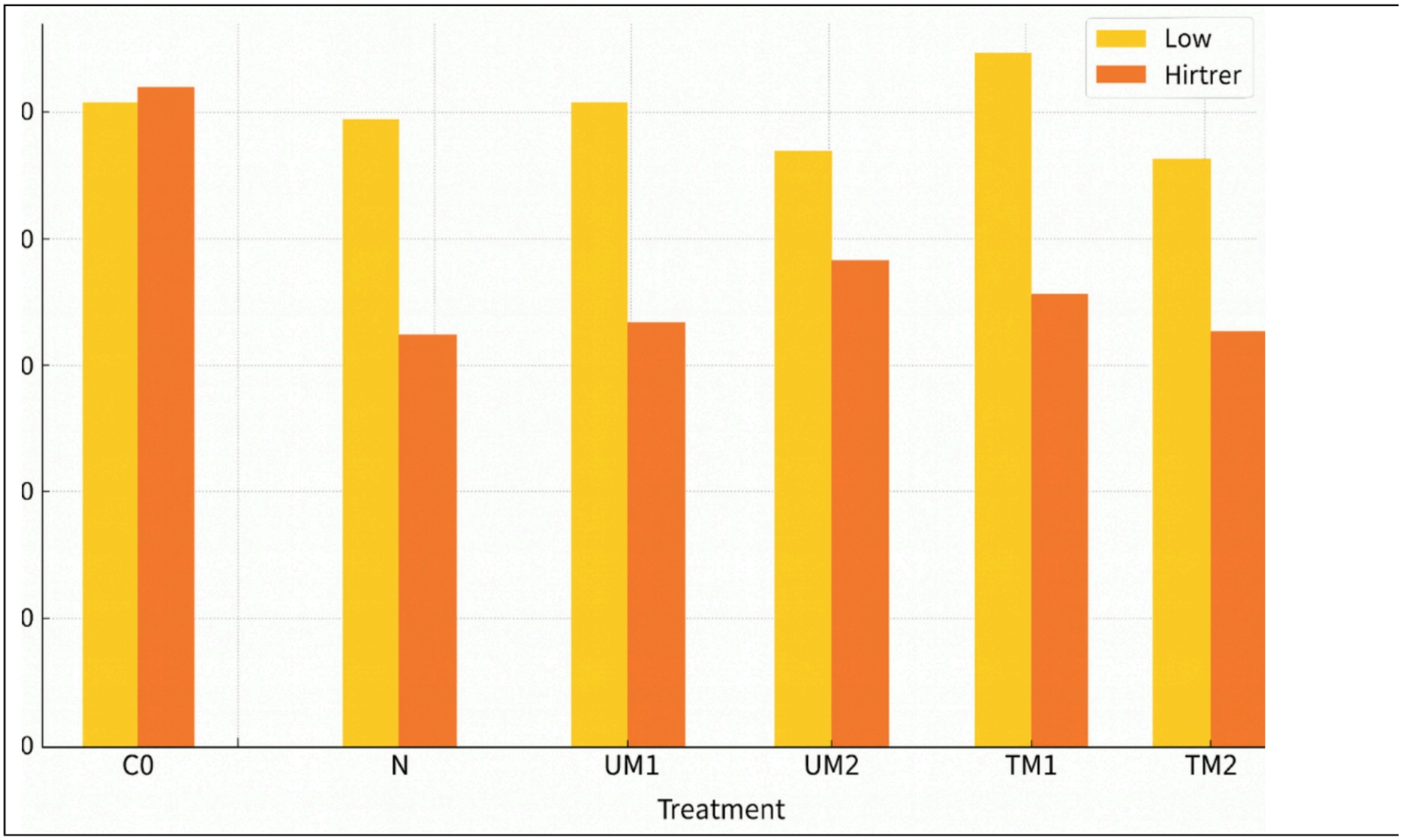

Figure 4

Soil organic nitrogen (mg·kg⁻¹) under different fertilizer and manure treatments in low- and high-terrace soils. Error bars represent standard error.

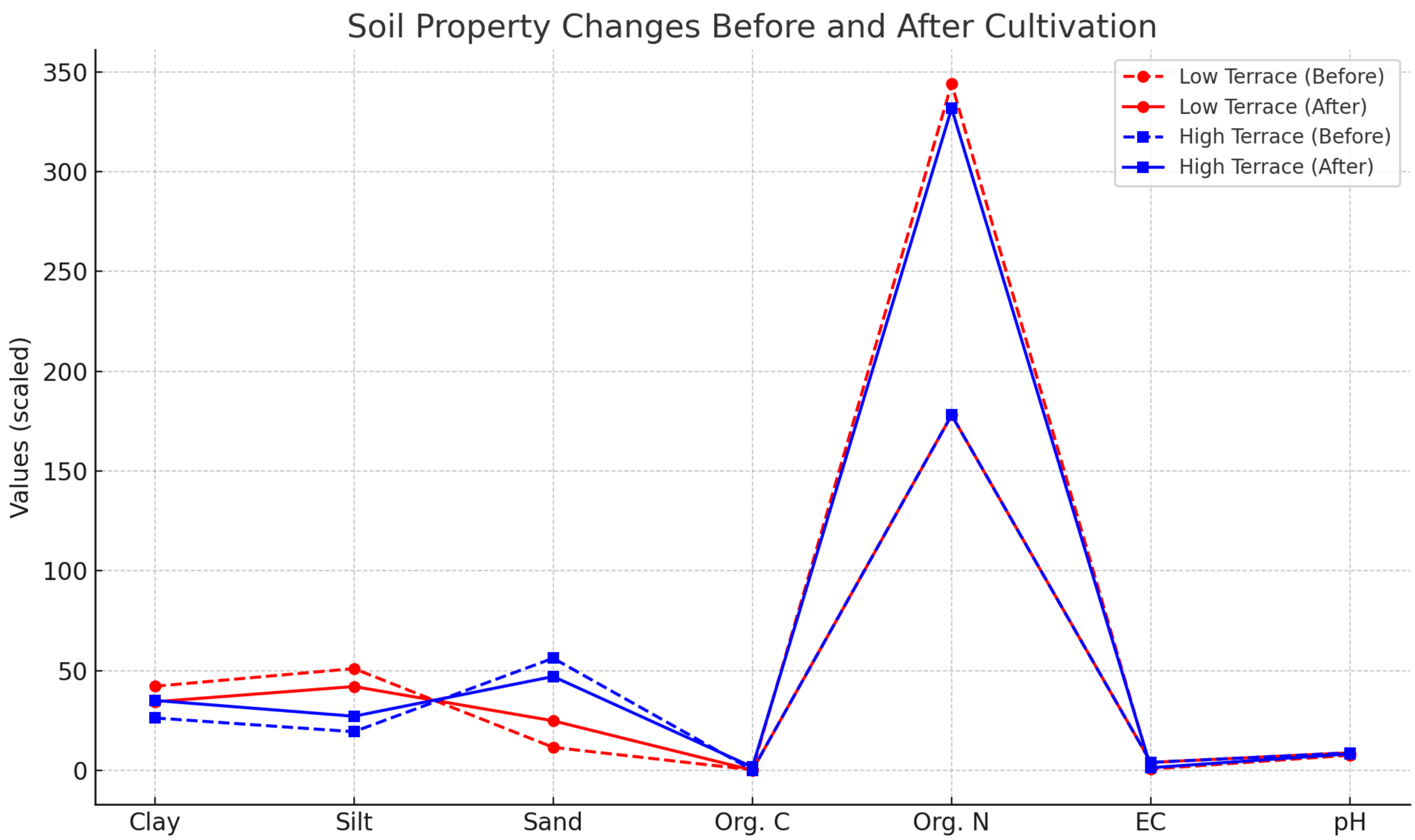

Figure 5

Changes in soil physical and chemical properties before and after cultivation in low- and high-terrace soils. OC = organic carbon; N = total nitrogen; EC = electrical conductivity.