International Journal of Applied Research
Journal HP: www.intjar.com; ISSN: 2411-6610

Assessment of soil health in indigo cultivated land at Northern Bangladesh

Afsana Mimi Eiti Mony[1], Syed Musfekus Salehin Sian[2], Md. Shahiduzzaman[3], Mohammad Mofizur Rahman Jahangir[1]*

[1]Department of Soil Science, Bangladesh Agricultural University, Mymensingh-2202, Bangladesh
[2]Department of JIDPUS, Bangladesh University of Engineering and Technology, Bangladesh
[3]Department of Parasitology, Bangladesh Agricultural University, Mymensingh-2202, Bangladesh

ARTICLE INFO

Article history

Received: 17 July 2025
Accepted: 17 August 2025

Keywords

Indigo (*Indigofera tinctoria*), Soil Fertility, Soil Organic Carbon, Total Nitrogen, Microbial Biomass Carbon, Sustainable Agriculture

Corresponding Author

M.M.R. Jahangir
Email: mmrjahangir@bau.edu.bd

ABSTRACT

Indigo (*Indigofera tinctoria* L.), a nitrogen-fixing legume, has re-emerged in Northern Bangladesh as a sustainable cash crop with agronomic, ecological, and socio-economic benefits. However, its long-term effects on soil health remain poorly quantified. This study assessed key physicochemical and biological properties like pH, soil organic carbon (SOC), total nitrogen (TN), available phosphorus (P) and sulphur (S), and microbial biomass carbon (MBC) across eight indigo cultivation sites representing diverse soils and management histories. Results revealed substantial spatial heterogeneity, with pH ranging from 5.09 to 6.31, SOC from 0.57% to 2.24%, and TN from 0.08% to 0.17% ($p < 0.001$ for SOC and TN). The majority of sites (62.5%) exhibited SOC < 1.0%, indicating organic matter depletion, while Leavens Blue emerged as a fertility hotspot with SOC levels four times greater than in the most degraded site. Available P (14.85–33.69 ppm) and S (0.14–12.00 ppm) showed high within-site variability without significant regional differences, and MBC ranged from 187.29 to 637.20 mg kg^{-1}, reflecting sensitivity to micro-environmental conditions. These findings highlight that while indigo can sustain soil fertility under appropriate management, notable differences between sites demand tailored interventions particularly pH correction and organic matter enhancement to optimize productivity and ecological resilience. This work provides the first comprehensive evidence base for developing region-specific soil management strategies in support of indigo's role in sustainable agriculture and rural livelihoods in Bangladesh.

1. Introduction

Indigo (*Indigofera tinctoria* L.) has been one of the most valued dye crops in human history, renowned for producing the deep blue pigment that shaped global textile trade for centuries. Archaeological evidence traces its use in textile dyeing as far back as 4,000 years ago in the Indus Valley Civilization (Fuller, 2006), with later widespread cultivation and commerce across Asia, Africa, and Europe (Fischer, 2016). During the colonial period, indigo production thrived in Bengal including the northern districts of present-day Bangladesh where fertile alluvial soils and favorable climatic conditions made it a cornerstone cash crop. Although synthetic indigo production in the late 19th century caused a global collapse in natural dye markets (Cardon, 2007), the crop's legacy endures in the cultural memory of Bangladesh, particularly in communities shaped by the history of the Nilkuthis and the indigo revolts (Guha, 1982; Chakrabarty, 1992). In recent decades, rising environmental concerns over synthetic dyes and renewed demand for sustainable textiles have brought natural indigo cultivation back into focus (Bechtold & Mussak, 2009).

Indigo is known as a green and eco-friendly crop because of the many benefits it brings to soil and the environment. Being a legume, indigo has the special ability to fix nitrogen from the air and add it naturally to the soil (Peoples et al., 2009; Sprent & Parsons, 2000). This reduces the need for chemical fertilizers, helping to lower pollution and greenhouse gas emissions (Peoples et al., 2009). Indigo's deep root system improves soil structure by loosening the soil and enhancing water retention, which protects land from erosion and aids during dry periods (Blanco-Canqui et al., 2015; Jobbágy & Jackson, 2000). Compared to many other cash crops that harm soil and the environment, indigo supports biodiversity and helps maintain sustainable farming systems (Bechtold & Mussak, 2009). Indigo increases soil earth worm population, ant population, reduces soil erosion and suppresses grasses in crop land (Hossain, 2019). Indigo requires no or very little irrigation water supply and soil tillage.

Indigo's history in Bengal is not only agricultural. During British colonial rule, indigo became a highly valuable but often exploitative crop. The British East India Company established large plantations on Bengal's fertile soils and coerced

Cite this article: *Mony, A. M. E., Sian, S. M. S., Shahiduzzaman, M., & Jahangir, M. M. R. (2025). Assessment of soil health in indigo cultivated land at Northern Bangladesh. International Journal of Applied Research, 11: 54-62. DOI: 10.5281/zenodo.16896280*

many local farmers, known as Nilkuthis, into growing indigo under harsh conditions (Guha, 1982). This exploitation caused widespread suffering and unrest, sparking the Indigo Revolt of (1859–1860), a significant peasant uprising against colonial indigo planters that remains a powerful symbol of resistance (Chakrabarty, 1992).

In Northern Bangladesh today, the revival of indigo goes beyond cultural heritage; it represents a promising green crop with nil adverse impact on soil properties. Indigo offers a sustainable livelihood alternative to environmentally damaging cash crops like tobacco, which degrade soil and carry health risks (World Health Organization (WHO, 2017). Beyond agronomic and environmental benefits, indigo production supports socio-economic development. Artisanal dye production under initiatives such as Living Blue in Bangladesh currently employs over 240 artisans, many of whom are women, providing rural income and empowering communities (Living Blue, 2022). This integration of environmental stewardship with economic opportunity aligns indigo cultivation with global sustainable development goals (United Nations, 2015).

In Rangpur and Nilphamari, limited-scale cultivation of indigo has already begun in about 10 unions across two or three upazilas. Locally, indigo farming is referred to as "*maal chash*". Small factories have also started to emerge. Using this indigo, colorful bags, *Fatuas*, bed sheets, *nakshi kanthas*, and various decorative items are being produced. These products are in high demand both domestically and internationally. Judging by the enthusiasm of the indigo farmers, it seems that the once-lost indigo is now opening doors to immense new possibilities (Shahiduzzaman, 2021). Both nationally and internationally indigo has good market where one kg indigo costs about 40 USD (Sumontho, 2025).

Preliminary research indicates that indigo cultivation enhances the physical and biochemical properties of soil. As a result, when Aman rice is grown on land previously used for indigo, it requires less fertilizer. Furthermore, if tobacco or other vegetables are cultivated after indigo, pest infestations tend to decrease significantly. Planting indigo along the borders of vegetable plots also helps suppress the spread of various pests (Shahiduzzaman, 2021).

Despite its promising profile, there remains limited empirical evidence on the long-term impacts of continuous indigo cultivation on soil health in Bangladesh. While anecdotal reports and preliminary studies indicate indigo does not degrade soil quality (Ahmed, Islam, & Hossain, 2019) but rigorous scientific evaluation is lacking. This study aims to fill that gap by assessing physical quality parameters like, bulk density, pH, organic carbon, total nitrogen, available phosphorus and sulphur, exchangeable potassium and microbial biomass carbon under prolonged indigo cultivation in Northern Bangladesh. The findings will guide evaluate indigo as a source of natural dye crop and inform sustainable agricultural policies in the region.

2. Materials and Methods

2.1. Study sites

The study was conducted across eight distinct indigo cultivation sites at Northern Bangladesh: East Gilabari, Uttam Hazir Hut, Uttam, Fakir Para, Leavens Blue, Bari Para, Kamar Para, and Kustia. Indigo was selected as the focal crop to capture the spatial variability of soil physicochemical and microbial properties across the region.. These sites represent diverse soil types, topography, and management histories, providing a robust framework for assessing soil fertility, nutrient availability, and microbial biomass across heterogeneous landscapes.

East Gilabari: Slightly acidic soils with moderate organic carbon, low-lying fields prone to intermittent flooding and intensive cropping (SRDI, 2025).
Uttam Hazir Hut: Moderately acidic soils with intermediate nutrient status, historically amended with organic fertilizers.
Uttam: Sandy-silt textured soils, low SOC and TN, minimal fertilization.
Fakir Para: Mid-elevation fields with moderate fertility, partial crop residue retention enhancing soil organic matter.
Leavens Blue: High SOC and TN, near-neutral pH, intensive cropping with residue management.
Bari Para: Slightly acidic to neutral soils, moderate fertility, variable phosphorus availability.
Kamar Para: Near-neutral pH, high microbial biomass, well-drained soils, moderate SOC.

Kustia Indigo: Higher pH values, moderately high SOC and TN, reflecting fertile soils under sustainable indigo cultivation practices.

These sites provide a continuum of soil chemical and biological conditions, enabling a comprehensive evaluation of soil fertility, microbial dynamics, and nutrient distribution.

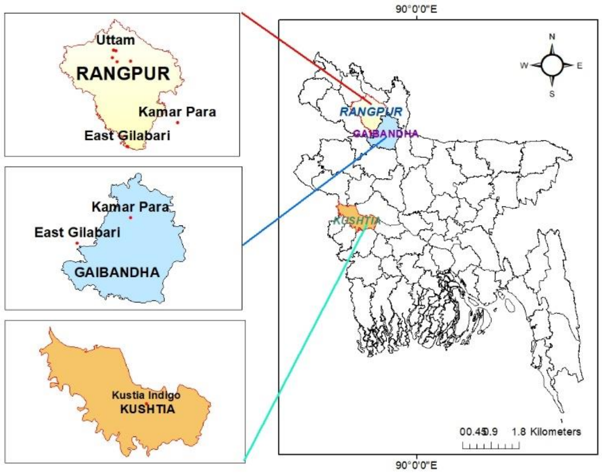

Figure 1: The study sites at Northern Bangladesh

2.2. Land selection

The experiment was conducted over a full annual cycle, beginning in the winter 2024 and concluding in the post-harvest period of 2025, to capture the dynamic interplay between seasonal changes, crop growth stages, and soil processes. The field sites were selected based on unique combinations of soil type, management history, and microclimatic conditions.

At each site, the experimental unit consisted of an about 1000 m^2 field plot, managed according to locally practiced indigo cultivation methods but standardized for planting density, weeding frequency, and irrigation scheduling to ensure comparability across locations. Each site was replicated minimum three times to allow robust statistical inference.

Soil sampling was done to analyse for pH, organic carbon, total nitrogen, available phosphorus, available sulphur, and microbial biomass carbon. These parameters were selected because they are not merely chemical indicators but drivers of soil resilience, plant productivity, and ecosystem function. This design intentionally bridges traditional agricultural heritage with modern soil science, recognizing that the landscapes under indigo cultivation are more than production units they are living cultural and ecological archives. By capturing site-specific management nuances while maintaining scientific standardization, the design ensures that findings are both statistically rigorous and deeply grounded in the lived reality of farmers who sustain these systems.

2.3. Cultural practices

Indigo cultivation at all sites followed traditional yet carefully managed agronomic practices to optimize plant growth while preserving soil health. Fields were prepared manually by one or two passes of a rotary tiller followed by laddering at an optimum moisture contents like field capacity. Indigo seeds were broadcast or sown in furrows spaced to enhance aeration and root development. Nutrient management combined organic amendments with only nitrogenous fertilizer application at a rate of 50 kg N ha^{-1}. No pesticide or herbicide was used at all which showed the potential of indigo as a low input environmentally friendly economic crop. Irrigation was applied sparingly to maintain soil moisture without waterlogging, generally once in a season. These humanized, site-specific practices ensured that soil and crop performance were optimized in a way that respected both ecological and cultural dimensions of indigo farming.

2.4. Soil sampling and analysis

At each site, composite soil samples were collected from the biologically and chemically active 0–15 cm soil layer. Five to seven soil cores per field were randomly collected using a stainless steel auger and combined to form a composite sample (~1 kg per site). Samples were transported in sterile polyethylene bags under cooled conditions and processed within 48 hours. Each composite sample was divided into: Field-moist portion: Sieved through a 2-mm mesh for microbial biomass carbon (MBC), Air-dried portion: Air-dried at room temperature (~25 °C) for two weeks, sieved through a 2-mm mesh, and used for physicochemical analyses.

2.5. Soil pH

Soil pH was measured in a 1:2.5 soil-to-water suspension using a calibrated glass electrode pH meter at room temperature. Each sample was measured in triplicate to ensure precision. Soil pH is a fundamental indicator of soil chemical environment, shaping nutrient availability, microbial activity, and the overall productivity of indigo fields.

2.6. Soil Organic Carbon (SOC)

SOC was determined using the modified Walkley-Black dichromate oxidation method (Walkley & Black, 1934). Briefly, 1 g of air-dried soil was digested with 10 mL of 1 N $K_2Cr_2O_7$ and concentrated H_2SO_4, and oxidized carbon was quantified calorimetrically. SOC values were expressed as a percentage of dry soil. SOC is central to indigo field ecosystems, driving soil fertility, nutrient cycling, and microbial dynamics, influencing structure, water retention, and long-term soil health.

2.7. Total Nitrogen (TN)

TN was measured using the Kjeldahl digestion and distillation method (Bremner & Mulvaney, 1982). Approximately 0.5 g of soil was digested with concentrated H_2SO_4 and a catalyst mixture, distilled, and captured in boric acid, then titrated with 0.01 N HCl. TN was expressed as a percentage of dry soil. TN is a key nutrient underpinning crop productivity and supporting microbial growth and soil ecological functioning.

2.8. Available Phosphorus (P)

Available phosphorus was extracted using the Olsen bicarbonate method (Olsen et al., 1954). Two grams of air-dried soil were shaken with 50 mL of 0.5 M $NaHCO_3$ (pH 8.5) for 30 minutes, filtered, and phosphorus concentration measured colorimetrically. Phosphorus is critical for energy transfer and root development, enhancing nutrient use efficiency and plant resilience in indigo fields.

2.9. Available sulphur (S)

Available sulphur was determined via the turbidimetric method (Chesin & Yien, 1951). Five grams of soil were extracted with 0.15% $Ca(H_2PO_4)_2$ solution, filtered, and reacted with barium chloride to form a $BaSO_4$ precipitate. Turbidity was measured spectrophotometrically. Sulphur is essential for protein synthesis, enzymatic activity, and overall plant health, contributing to sustainable productivity in indigo cultivation.

2.10. Microbial Biomass Carbon (MBC)

MBC was determined using the chloroform fumigation-extraction method (Vance et al., 1987). Field-moist soil (~25 g) was fumigated with ethanol-free chloroform for 24 hours, extracted with 0.5 M K_2SO_4, and the difference in extractable organic carbon between fumigated and non-fumigated soils was used to calculate MBC. Values were expressed in mg C kg^{-1} soil. MBC as a percentage of total soil carbon was also calculated, reflecting microbial contributions to soil carbon cycling and fertility.

2.11. Statistical analysis

All analyses were conducted in triplicate. Data were checked for normality and homogeneity of variance. One-way Analysis of Variance (ANOVA) was performed to assess differences among sites for each soil property. Where significant differences were detected ($p < 0.05$), Fisher's Least Significant Difference (LSD) test was applied for pairwise comparisons. Statistical analyses were conducted using SPSS v.26. Regression and correlation analyses were performed to examine relationships among soil chemical, biological, and carbon parameters.

3. Results

3.1. Soil chemical characterization

The comprehensive analysis of soil samples across eight distinct regions revealed substantial heterogeneity in key physicochemical parameters. Soil pH exhibited significant regional variation ($p<0.01$), ranging from strongly acidic conditions in East gilabari (pH 5.09) to moderately acidic conditions in Kustia indigo (pH 6.31) (Figure 1). The mean pH across all regions was 5.74 ± 0.18, indicating predominantly acidic soil conditions throughout the study area.

3.2. Soil organic matter dynamics

Soil organic carbon (SOC) content demonstrated highly significant regional differences ($p<0.001$), with values ranging from 0.57% in Uttam Hazir hut to 2.24% in Leavens Blue. The overall mean SOC content was 1.09 ± 0.082%, with a coefficient of variation of 20.59%.

3.3. Total nitrogen

Total nitrogen (TN) content varied significantly ($p < 0.001$) among the studied regions. The highest

TN was recorded in Leavens Blue (0.17 %), followed closely by Kustia Indigo (0.16 %) and Fakir Para (0.15 %). Intermediate values were observed in East Gilabari, Kamar Para, and Bari Para (all 0.11 %). Uttam Hazir Hut (0.09 %) and Uttam (0.08 %) exhibited the lowest TN concentrations. The range of TN values (0.08–0.17 %) reflects more than a two-fold difference between the most nitrogen-rich and nitrogen-poor sites, indicating marked regional variation in soil nitrogen reserves (Figure 2).

Available phosphorus concentrations showed considerable absolute variation (14.85-33.69 ppm) but lacked statistical significance across regions. The mean available P was 27.80 ± 3.68 ppm, with a high coefficient of variation (36.24%), indicating substantial within-region heterogeneity. Despite the lack of statistical significance, the numerical differences suggest potential agronomic importance, particularly for regions showing values below 20 ppm (Kustia indigo and Uttam), which may require targeted phosphorus management strategies.

3.4. Sulfur dynamics

Available sulfur exhibited the highest coefficient of variation among all measured parameters (218.59%), ranging from extremely low levels in Kamar para (0.14 ppm) to moderate levels in East Gilabari (12.00 ppm).

3.5. Microbial biomass carbon and total soil organic carbon

Microbial biomass carbon (MBC) values ranged from 187.29 to 637.20 mg/kg, with no statistically significant differences among regions despite the three-fold variation in absolute values. The high coefficient of variation (116.6%) suggests that microbial biomass is highly responsive to micro-environmental conditions and management practices rather than regional factors.

The ratio of MBC to total carbon provides insight into the efficiency of carbon utilization by soil microorganisms. This ratio varied dramatically from 2.14% in Uttam region to 10.67% in Kamar para, with an extremely high coefficient of variation (128.87%).

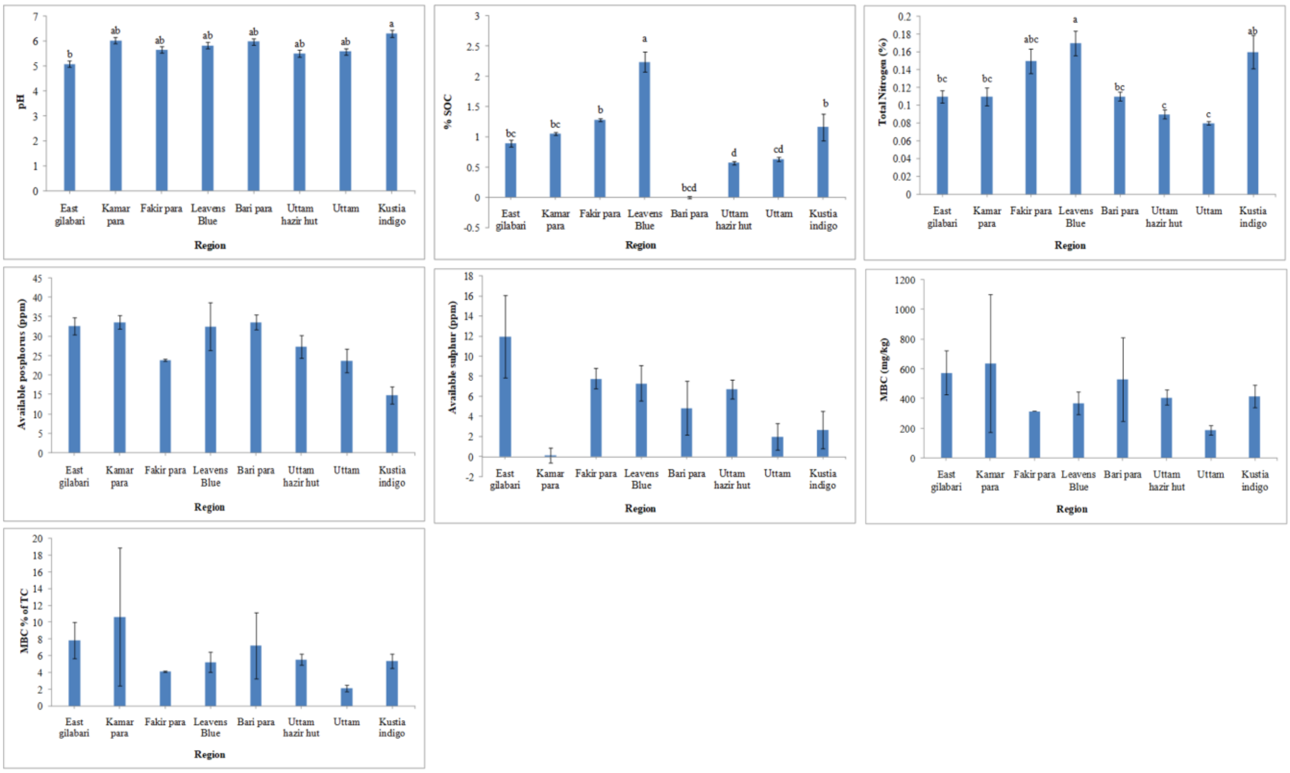

Figure 2: Comparative distribution of key soil parameters across eight indigo cultivation sites, including soil pH, organic matter, total nitrogen, available phosphorus, microbial biomass carbon, total soil organic carbon, and available sulphur.

4. Discussion

Soil properties varied markedly across the studied regions, reflecting distinct pedological conditions and likely differences in land management. Soil pH ranged from moderately acidic (5.09 in East Gilabari) to near-neutral (6.31 in Kustia Indigo), a statistically significant range ($p < 0.01$) with important agronomic implications. Such variability is often governed by parent material, historical fertilization, and organic matter turnover (Brady & Weil, 2016). Acidic soils (pH < 5.5) can limit phosphorus, calcium, and magnesium availability while increasing aluminum and manganese toxicity, whereas pH values between 5.5 and 7.0 optimize nutrient solubility and microbial activity (Fageria & Baligar, 2008). This underscores the potential need for site-specific pH management, including liming in more acidic areas (Lal, 2015). The coefficient of variation for pH was relatively low (8.56%), suggesting that acidity levels, while variable, maintained consistent patterns within regional boundaries. The acidic nature of these soils has important implications for nutrient availability and microbial activity. Soils with pH values below 5.5 (East gilabari, Uttam hazir hut, and Uttam regions) may experience reduced availability of essential nutrients manganese to potentially toxic levels. Conversely, regions with pH values approaching neutrality (Kamar para and Kustia indigo) are more likely to support optimal nutrient cycling and enhanced biological activity.

Soil organic carbon (SOC) differed highly significantly ($p < 0.001$), with Leavens Blue having the highest SOC (2.24%) and Uttam Hazir Hut the lowest (0.57%). Elevated SOC in Leavens Blue likely results from greater biomass inputs, residue retention, and reduced tillage — practices known to enhance carbon stabilization through physical protection within aggregates and biochemical recalcitrance (Six et al., 2002; Lal, 2015). Conversely, low SOC in some sites may be due to continuous cultivation, minimal organic inputs, and rapid decomposition under aerobic conditions (Post & Kwon, 2000). This variation reflects the complex interplay of climatic conditions, vegetation cover, land use practices, and soil management strategies across the study regions.

Leavens Blue region exhibited exceptional organic carbon accumulation (2.24%), nearly four times higher than the lowest recorded value. This elevated SOC content suggests favorable conditions for organic matter preservation, potentially due to higher biomass inputs, reduced decomposition rates, or superior soil management practices. The majority of regions (62.5%) fell below the critical threshold of 1.0% SOC, indicating potential soil quality degradation and reduced sustainability of agricultural systems.

The relationship between SOC and total nitrogen was strongly positive, as evidenced by their similar distribution patterns across regions. Total nitrogen content ranged from 0.08% to 0.17%, with highly significant regional differences ($p<0.001$). The C:N ratios, calculated from these values, ranged from approximately 3.7:1 to 13.2:1, with most regions maintaining ratios between 7:1 and 11:1, suggesting balanced organic matter decomposition processes.

Total nitrogen (TN) followed a similar pattern, with the highest values in Leavens Blue (0.17%) and the lowest in Uttam (0.08%), consistent with the tight coupling of soil C and N pools (Gregorich et al., 2006). This relationship reflects the fact that organic matter serves as the primary nitrogen reservoir in most agricultural soils (Lal, 2004).

Available phosphorus (P) and available sulphur (S) showed large mean differences (P: 14.85–33.69 ppm; S: 0.14–12.00 ppm) but no statistically significant variation among regions. High coefficients of variation (36.24% for P; 218.59% for S) indicate strong within-region heterogeneity, likely caused by patchy fertilizer distribution, organic inputs, or microtopographic nutrient redistribution (McKenzie, 2011). Extremely low sulphur in Kamar Para (0.14 ppm) may reflect leaching losses under high rainfall, while elevated levels in East Gilabari (12.00 ppm) could result from organic matter mineralization or atmospheric deposition (Blair, 2008). The relatively uniform distribution of available phosphorus across most regions (excluding the two lowest values) suggests either similar parent material characteristics or comparable phosphorus management practices. However, the high variability (CV = 36.24%) indicates significant spatial heterogeneity within regions, highlighting the need for site-specific nutrient management approaches.

This extreme variability suggests that sulfur availability is highly sensitive to local environmental conditions, including redox status, organic matter decomposition rates, and anthropogenic inputs.

The extraordinarily low sulfur availability in Kamar para (0.14 ppm) indicates potential sulfur deficiency, which could limit protein synthesis in plants and overall crop productivity. Conversely, regions with higher sulfur availability (> 7 ppm) may support more robust plant growth and improved crop quality, particularly for sulfur-demanding crops such as oilseeds and legumes.

Although microbial biomass carbon (MBC) and MBC % did not differ significantly, their absolute values varied widely (187.29–637.20 mg kg^{-1}). MBC is a sensitive indicator of soil biological activity and responds to organic carbon availability and nutrient status (Anderson & Domsch, 1989). The high MBC % in Kamar Para (10.67%) suggests a highly active microbial community with efficient carbon utilization, while the low value in Uttam (2.14%) could indicate substrate limitation or environmental stressors restricting microbial proliferation (Wardle, 1992). These values fall within the typical range for agricultural soils (2-8%), though several regions exceeded this range, suggesting either enhanced microbial activity or altered carbon pool dynamics.

Regions with higher MBC:TC ratios (Kamar para, East Gilabari, Bari para) may indicate more active soil biological processes, potentially contributing to enhanced nutrient cycling and soil health. Conversely, regions with lower ratios (Uttam, Fakir para, Leavens Blue) may suggest either carbon stabilization in more recalcitrant forms or reduced microbial activity due to limiting factors such as pH, moisture, or nutrient availability.

Collectively, these findings identify Leavens Blue as a soil fertility hotspot, given its elevated SOC and TN, while Uttam and Uttam Hazir Hut emerge as nutrient-depleted sites requiring targeted soil restoration strategies. The pronounced pH variation highlights the importance of tailored management to optimize nutrient availability and microbial function. The non-significant differences in P, S, and MBC suggest that seasonal or finer-scale monitoring may be necessary to capture short-term nutrient and microbial dynamics.

4.1. Integrated soil quality assessment

The statistical analysis revealed distinct patterns of significance among soil parameters (Figure 2). Soil pH, SOC, and total nitrogen showed highly significant regional differences, indicating these parameters are primarily controlled by regional factors such as climate, geology, and land use history. In contrast, available nutrients (P, S) and microbial parameters showed high variability but lacked statistical significance, suggesting these properties are more influenced by local management practices and micro-environmental conditions. The spatial distribution patterns illustrated in figure 2 demonstrate clear regional clustering for certain parameters while showing more random distribution for others. This spatial analysis supports the statistical findings and provides valuable insights for developing region-specific soil management strategies including.

4.2. Implications for soil management

The results indicate that soil quality varies substantially across the study area, with certain regions (particularly Leavens Blue) showing superior soil health indicators, while others (Uttam Hazir hut, Uttam) show signs of degradation. The high variability in microbial parameters and available nutrients suggests that targeted, site-specific management interventions could significantly improve soil quality and productivity. The predominance of acidic conditions across regions indicates a widespread need for pH management, potentially through liming programs. Similarly, the low SOC content in most regions suggests that organic matter enhancement should be a priority for sustainable soil management in this area.

5. Conclusion

Our findings reveal that indigo cultivation in Northern Bangladesh is more than an agricultural practice, it is a living bridge between cultural heritage, rural livelihoods, and ecological stewardship. The soils under indigo show the capacity to maintain fertility, but the distinct disparities in pH, organic carbon, nitrogen, and microbial activity across sites highlights that sustainability cannot be assumed; it must be managed. Fertility hotspots like Leavens Blue demonstrate the potential for thriving soils when organic matter inputs, balanced nutrition, and favorable conditions align, while nutrient depleted areas such as Uttam and Uttam Hazir Hut signal an urgent call for restoration through pH correction, organic enrichment, and precise nutrient management.

Despite strong global demand for natural indigo as an alternative to synthetic dyes, supply remains limited due to insufficient production. If this opportunity is seized, Bangladesh's naturally produced indigo being both eco-friendly and health-conscious could emerge as one of the country's most promising cash crops. This would not only increase farmers' income but also enhance the physical and biochemical properties of soil, thereby improving the long-term sustainability of agricultural land.

By embracing site-specific strategies, policymakers, development agencies, and farming communities can transform indigo from a traditional cash crop into a flagship model for climate-resilient, low-input, and culturally rooted agriculture. Protecting and enhancing these soils is not only an agronomic necessity, it is an investment in the resilience of landscapes, the dignity of farming communities, and the sustainable future of Bangladesh's agro-ecosystems. However, further research on systematic investigation into an improved indigo leaf yield; blue quality and contents; effects on soil health and microbial diversity; and indigo processing may help explore the economic and environmental potential of indigo as an eco-friendly green crop is required.

References

Ahmed, S., Islam, M. R. & Hossain, M. M. (2019). Effects of leguminous cover crops on soil health and crop productivity in Bangladesh. Soil and Tillage Research, 191, 58–65. https://doi.org/10.1016/j.still.2019.03.002.

Anderson, T. H. & Domsch, K. H. (1989). Ratios of microbial biomass carbon to total organic carbon in arable soils. Soil Biology and Biochemistry, 21(4), 471–479. https://doi.org/10.1016/0038-0717(89)90117-X

Bechtold, T. & Mussak, R. (2009). Handbook of Natural Colorants. Wiley. https://www.wiley.com/en-us/Handbook+of+Natural+Colorants-p-9783527317197.

Blair, G. J. (2008). Sulfur management for sustainable agriculture. Agronomy Journal, 100(1), 176–183. https://doi.org/10.2134/agronj2007.0147

Blanco-Canqui, H., Shapiro, C. A., Wortmann, C. S., Drijber, R. A. & Guzman, J. G. (2015). Cover crops and ecosystem services: insights from studies in temperate soils. Agronomy Journal, 107(6), 2449–2474. https://doi.org/10.2134/agronj15.0054.

Brady, N. C. & Weil, R. R. (2016). The nature and properties of soils (15th ed.). Pearson.

Cardon, D. (2007). Natural Dyes: Sources, Tradition, Technology and Science. Archetype Publications.

Chakrabarty, D. (1992). Revolt of the Indigo Farmers. Economic and Political Weekly, 27(12), 588–590.

Fageria, N. K. & Baligar, V. C. (2008). Ameliorating soil acidity of tropical oxisols by liming for sustainable crop production. Advances in Agronomy, 99, 345–399. https://doi.org/10.1016/S0065-2113(08)00407-0

Fischer, A. (2016). Indigo: The Color that Changed the World. Thames & Hudson.

Fuller, D. Q. (2006). Early textiles and dyes as indicators of agriculture and trade in South Asia. Journal of Archaeological Science, 33(3), 383–399. https://doi.org/10.1016/j.jas.2005.06.008.

Gregorich, E. G., Rochette, P., Vanden Bygaart, A. J. & Angers, D. A. (2006). Greenhouse gas contributions of agricultural soils and potential mitigation practices in Eastern Canada. Soil and Tillage Research, 83(1), 53–72. https://doi.org/10.1016/j.still.2005.02.009

Guha, R. (1982). Elementary Aspects of Peasant Insurgency in Colonial India. Oxford University Press.

Jobbágy, E. G. & Jackson, R. B. (2000). The vertical distribution of soil organic carbon and its relation to climate and vegetation. Ecological Applications, 10(2), 423–436. https://doi.org/10.1890/1051-0761(2000)010

Lal, R. (2004). Soil carbon sequestration impacts on global climate change and food security. Science, 304(5677), 1623–1627. https://doi.org/10.1126/science.1097396

Lal, R. (2015). Restoring soil quality to mitigate soil degradation. Sustainability, 7(5), 5875–5895. https://doi.org/10.3390/su7055875

Living Blue. (2022). Living Blue Bangladesh Annual Report 2022. https://livingblue.org.bd/reports.

McKenzie, N. J. (2011). Soil properties and management. CSIRO Publishing.

Peoples, M. B., Brockwell, J., Herridge, D. F., Rochester, I. J., Alves, B. J. R., Urquiaga, S. & Singleton, P. W. (2009). The contributions of nitrogen-fixing crop legumes to the productivity of agricultural systems. Symbiosis, 48(1-3), 1–17. https://doi.org/10.1007/BF03179980.

Post, W. M. & Kwon, K. C. (2000). Soil carbon sequestration and land-use change: Processes and potential. Global Change Biology, 6(3), 317–327. https://doi.org/10.1046/j.1365-486.2000.00308.x

Shahiduzzaman, M (2021). Indigo could become one of the country's most profitable crops. Kaler Kantho, https://www.kalerkantho.com/online/national/2021/02/12/1004190

Six, J., Conant, R. T., Paul, E. A., & Paustian, K. (2002). Stabilization mechanisms of soil organic matter: Implications for C-saturation of soils. Plant and Soil, 241(2), 155–176. https://doi.org/10.1023/A:1016125726789

Soil Resources Development Institute (SRDI). (2025). Annual Report. SRDI, Regional Laboratory, Rangpur.

Sprent, J. I. & Parsons, R. (2000). Nitrogen fixation in legume crops. Plant and Soil, 18(2), 157–170. https://doi.org/10.1023/A:1004273614429.

United Nations (2015). Transforming our world: The 2030 Agenda for Sustainable Development. https://sdgs.un.org/2030agenda.

Wardle, D. A. (1992). A comparative assessment of factors which influence microbial biomass carbon and nitrogen levels in soil. Biological Reviews, 67(3), 321–358. https://doi.org/10.1111/j.1469-185X.1992.tb00728.x

World Health Organization (WHO) (2017). Tobacco and its environmental impact: an overview. Geneva: WHO. https://www.who.int/publications/i/item/9789241512497