SOIL RESEARCH IN BANGLADESH: PAST CONTRIBUTIONS, PRESENT GAPS AND FUTURE PRIORITIES

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Abstract

Soil serves as the foundation of agricultural productivity, environmental sustainability and national food security. In Bangladesh, soil research has been instrumental in supporting the Green Revolution, formulating balanced fertilizer recommendations and guiding sustainable land use practices. This keynote paper offers a comprehensive review of soil research in Bangladesh—tracing its historical development, current accomplishments and future directions. The origins of soil research in the region date back to the establishment of the Agricultural Research Institute (ARI) in 1905 at Tejgaon, Dhaka. Early studies investigated the effects of organic manure, bone meal and lime on the yields of Aus & Aman rice, jute and various vegetables. Building on the foundational soil surveys of the 1960s and the subsequent formation of key institutions including BARI, BRRI, BINA, BSRI, BJRI, BTRI, and SRDI—this paper chronicles the evolution of research in areas such as soil chemistry and fertility, salinity management, organic matter dynamics and micronutrient deficiencies. The current landscape is assessed in light of climate change, land degradation and the increasing demand for sustainable intensification. Advances in GIS-based soil mapping, precision agriculture and integrated nutrient management are examined to showcase both achievements and ongoing challenges. Looking ahead, the paper identifies strategic research priorities focused on preserving soil health, mitigating climate-related risks and boosting productivity through regenerative practices. It underscores the need for stronger inter-institutional collaboration, capacity building, digital innovation and policy support to maximize the impact of soil research. The ultimate goal is to chart a clear, actionable roadmap for revitalizing soil science in Bangladesh—ensuring sustainable agriculture and long-term environmental resilience.

Keywords: Heavy metals, Soil fertility, Soil salinity, Soil research, Soil sealing

1. Introduction

Soil is more than just the earth beneath our feet—it is the very foundation of life, agriculture, ecosystems, and human survival. In Bangladesh, more than 160 million people depend directly or indirectly on agriculture for food, income and livelihoods. Soil forms the very bedrock of national food security and rural development. It sustains the cultivation of rice, wheat, maize, jute, vegetables, fruits and other essential staples that nourish the population and support local economies. Beyond its agricultural value, soil performs multiple

ecological functions—it regulates hydrological cycles, sequesters atmospheric carbon, filters and breaks down pollutants and serves as a habitat for countless microorganisms, all of which are vital for biodiversity conservation, environmental health and climate resilience (Islam, 2024).

Over the decades, Bangladesh has made significant and commendable progress in soil research. From the foundational soil surveys initiated in the 1960s to the development of national fertilizer recommendation guidelines and the more recent adoption of digital soil mapping technologies, the country has steadily built a robust framework of knowledge, tools and institutional capacity. These advancements have supported agricultural growth and improved land-use planning. However, with the emergence of new and complex challenges—such as climate change, soil erosion, salinity intrusion, declining organic carbon, micronutrient imbalances and increasing pressure on land resources—there is a growing imperative to revisit, refine and revitalize soil research systems. Critical gaps remain in translating scientific evidence into widespread farming practice, particularly in vulnerable regions with fragile soils, low productivity and limited extension support (BARI, 2024).

The rising urgency for sustainable intensification and ecological restoration calls for an integrated and forward-looking approach that aligns soil research with national priorities and global sustainability goals. It is essential to adopt trans-disciplinary strategies, strengthen institutional partnerships and ensure that research outcomes are accessible and actionable at the grassroots level. This keynote paper aims to offer a comprehensive reflection on the evolution of soil research in Bangladesh. It revisits the country's historical achievements and foundational contributions, critically assesses current research gaps, institutional limitations and field-level adoption barriers and identifies strategic directions for the future. By weaving together lessons from the past, insights from the present and aspirations for the future, the paper seeks to inform evidence-based policy making, guide targeted research investments and inspire collaborative action to preserve health, productivity and resilience of Bangladesh's soils for generations to come.

2. Historical Perspectives

The trajectory of soil research in Bangladesh has been shaped by colonial legacies, early scientific efforts, and post-independence agricultural priorities (Islam, 2001). The nation endured two devastating famines—the Bengal Famine of 1943, which claimed nearly 3 million lives and the 1974 famine in Kurigram, which took around 60,000 lives. These tragedies underscored the urgent need for agricultural reform, catalyzing research on sustainable land management and soil productivity (Islam 2001, 2008). Tracing this journey reveals how foundational work from past decades continues to shape modern soil research—offering insights into both progress and lingering challenges.

2.1 Pre-Independence and Post-Independence Soil Surveys

Soil research in Bangladesh began during British colonial rule, with early studies examining organic manure, bone meal and lime for improving yields of Aus and Aman rice, jute and vegetables. Systematic research gained momentum in the 1960s with the Reconnaissance Soil Survey of East Pakistan (RSS, 1969)—a landmark initiative by the East Pakistan Soil Survey Directorate that mapped soil distribution, classification and constraints across agro-ecological zones.

After independence in 1971, soil research expanded through collaborations with international organizations like FAO-UNESCO Soil Map of the World Project (Brammer et al., 1988). These efforts standardized soil classification and placed Bangladesh's soils on the global stage. Early surveys provided crucial data on soil texture, fertility, salinity and erosion risks— information still vital for land-use planning.

2.2 Establishment of Key Institutions

To institutionalize soil research, the government established several specialized institutes:

- **Soil Resource Development Institute (SRDI, 1983)**—successor to the Soil Survey Directorate—spearheaded soil mapping, fertility assessment and land classification.
- **Bangladesh Agricultural Research Institute (BARI)** focused on soil fertility and nutrient management in diverse cropping systems.
- **Bangladesh Agricultural University (BAU)** became a hub for soil science education, advancing research in soil physics, chemistry, fertility, microbiology and plant nutrition.

Alongside BRRI, BINA, BJRI, and others, these institutions formed a robust national network for soil research, education and outreach.

2.3 Milestones in Fertility Research, Soil Taxonomy and Land Resource Assessment

Early breakthroughs included classifying soils using the USDA Soil Taxonomy, developing Agro-Ecological Zone (AEZ) maps (DSSR, 2004) and identifying key constraints like nutrient deficiencies (NP KSZnB), acidity in Barind and Madhupur Tracts, and coastal salinity. Fertility research gained momentum in the 1980s and 1990s, driven by national efforts to enhance crop yield through the strategic use of chemical fertilizers. Rigorous studies on nutrient response curves, fertilizer efficiency and integrated nutrient management (INM) were conducted across diverse soil types and cropping systems. These findings significantly contributed to the Department of Agricultural Extension (DAE)'s success in increasing crop productivity and promoting science-based fertilizer practices throughout the country.

2.4 Role of Long-Term Trials and National Fertilizer Recommendation Guide

A cornerstone of applied soil fertility research in Bangladesh has been the implementation of long-term fertility trials—primarily coordinated by the Bangladesh Agricultural Research

Institute (BARI, 2019-2024) and the Bangladesh Rice Research Institute (BRRI 2024). These multi-decade experiments have generated invaluable data on soil nutrient dynamics, the depletion of organic matter and the long-term sustainability of fertilizer use under intensive cropping systems.

Another significant achievement stemming from institutional research efforts is the development of the *National Fertilizer Recommendation Guide*. First introduced in the 1960s, this guide has been periodically updated by a national technical committee, with the Bangladesh Agricultural Research Council (BARC) assuming responsibility for updates every five years since 1979. The most recent edition was published in 2024 (BARC, 2024).

The guide has become an essential resource for extension agents, soil scientists, agronomists, and farmers—providing location-specific fertilizer recommendations tailored to crop requirements and soil test results. It has played a pivotal role in enhancing agricultural productivity, promoting efficient input use and supporting balanced fertilization strategies nationwide.

3. Current State of Soil Research in Bangladesh

Soil research in Bangladesh has come a long way in recent decades, adapting to the country's shifting agricultural needs and the growing threats of land degradation, climate change and sustainability challenges. While we've made significant progress in understanding soil fertility and nutrient dynamics, new complexities—ecological shifts, economic pressures and rapid technological advancements—are pushing researchers to rethink traditional approaches. This section explores the most pressing soil-related issues, key research areas and institutional efforts shaping soil research in Bangladesh.

3.1 Major Soil-Related Challenges

Despite decades of research, investment and agricultural intervention, soil degradation remains one of the most pressing threats to agricultural productivity and sustainability in Bangladesh (Islam, 2024). The country faces a complex array of interrelated soil issues that continue to hinder crop performance, strain natural resources and compromise long-term food security. Key challenges include:

- Soil degradation: Continuous cultivation without proper nutrient replenishment, coupled with unsustainable farming practices such as over-tillage and improper irrigation, has led to widespread deterioration in soil fertility and structure. Many regions now suffer from nutrient imbalances and reduced biological activity, which affect both yield and sustainability (LDB, 2022).

- Soil salinity: Salinity has emerged as a major concern in coastal and estuarine zones—driven by sea-level rise, tidal saltwater intrusion, decreased freshwater flow from

upstream and poor drainage infrastructure. Over 1 million hectares of arable land are affected, limiting crop options and reducing productivity in these vulnerable areas (SSB, 2009).

- Soil acidification: Particularly prevalent in high-rainfall regions and upland areas such as the Old Himalayan Piedmontplain, Barind and Madhupur Tracts and hill districts, soil acidification is aggravated by the long-term use of urea fertilizers and the leaching of essential base cations. Increasing acidity restricts nutrient availability, alters microbial activity and poses challenges for sustainable crop production.

- Soil erosion: Deforestation, unprotected slope farming and unsound land use practices have triggered serious erosion in hilly regions and along riverbanks. The resulting loss of topsoil diminishes land productivity, threatens infrastructure and accelerates sedimentation in water bodies.

- Organic matter depletion: The widespread adoption of high-input and intensive cropping systems has largely neglected the role of organic amendments. This has led to a decline in soil organic carbon, affecting soil structure, water-holding capacity, nutrient cycling and overall soil resilience.

These problems don't exist in isolation—they feed into each other, making solutions harder. Fixing them will require location-specific strategies that combine better research, sustainable farming methods, farmer education and smarter policies.

3.2 Current Research Focus Areas

To address the multifaceted challenges facing Bangladesh's soils, contemporary research has expanded across several thematic domains. These focus areas reflect both the urgency of environmental constraints and the evolving priorities of sustainable agriculture and climate resilience:

a) Soil Fertility and Nutrient Management

Ongoing studies are refining crop- and location-specific nutrient recommendations to optimize fertilizer use. Emphasis is placed on macronutrients (NPKSMg) and critical micronutrients such as zinc (Zn), boron (B) which are often deficient in Bangladeshi soils. Experimental approaches include balanced fertilization, split applications, deep placement techniques—particularly for urea supergranule (USG)—and integrated nutrient management (INM) systems combining organic and inorganic sources. These efforts aim to maximize yield while preserving soil health.

b) Soil Salinity and Coastal Soil Management

With salinity posing an increasing threat to coastal agriculture, research is focused on

mapping its spatial and seasonal variation, screening salt-tolerant crop varieties, and developing adaptive management strategies. Techniques such as raised bed cultivation, mulching and organic amendments are being tested to mitigate salt stress. Alternative cropping systems suitable for saline-prone environments are also under development to improve resilience and productivity.

c) Soil Health Indicators and Monitoring

The scope of soil research is broadening to encompass soil health beyond traditional fertility metrics. Integrated assessments now include:

- *Physical indicators:* bulk density, infiltration rate and soil compaction
- *Chemical indicators:* pH, electrical conductivity (EC) and nutrient status
- *Biological indicators:* microbial biomass, enzymatic activity and biodiversity

Pilot initiatives are underway to develop region-specific soil health cards and reference benchmarks to aid farmers and extension workers in making informed management decisions.

d) GIS and Digital Soil Mapping

The Soil Resource Development Institute (SRDI) has achieved notable progress in generating GIS-based digital soil maps accessible through online platforms. These maps present crucial data on fertility levels, salinity, land suitability and nutrient deficiencies, serving as powerful decision-support tools for policymakers, researchers and farmers. A complementary initiative under the Bangladesh Agricultural Research Council (BARC) has produced comprehensive crop zoning models incorporating soil parameters—now integrated into the *Khamari App*, which guides farmers in selecting crops and applying appropriate fertilizer and soil amendments (CZP, 2025).

e) Farmer-Centric Technology Transfer

Ensuring that scientific advancements reach the field level is a core priority. Farmer engagement is being strengthened through adaptive trials, demonstration plots and field schools that showcase improved soil management practices. Participatory approaches—incorporating farmer feedback into the research cycle—are increasingly employed to refine recommendations and improve adoption. Extension materials and digital platforms are also being leveraged to disseminate customized and actionable guidance.

3. 3 Institutional Landscape and Partnerships

Bangladesh possesses a well-structured and steadily expanding institutional network dedicated to soil research and its practical applications in agriculture, land management and climate resilience (Islam, 2001). This network combines national expertise with strong international collaboration to build a comprehensive research and innovation ecosystem.

- **Soil Resource Development Institute (SRDI)** serves as the central institution for soil mapping, classification and fertility evaluation. Beyond research, SRDI plays a key role in national land-use planning, agro ecological zoning, digital soil mapping and advising policymakers and farmers on sustainable land management practices (MoA, 2024).

- **Bangladesh Agricultural Research Institute (BARI)** conducts extensive applied research focusing on soil fertility, integrated nutrient management (INM), crop-soil interactions, nutrient use efficiency, physical parameters and microbes. Its long-term field trials and multidisciplinary programs contribute significantly to sustainable intensification across diverse agro-climatic zones (BARI, 2019-2024).

- **Bangladesh Agricultural University (BAU)** acts as a center of academic excellence, conducting in-depth research on soil chemistry, fertility, nutrient cycling, microbes, physics, salinity management and soil-environment interactions. It also provides postgraduate education and professional training to build scientific and leadership capacity for future generations of soil experts and decision-makers.

- **Bangladesh Rice Research Institute (BRRI) and Bangladesh Institute of Nuclear Agriculture (BINA)** form important pillars of the research ecosystem.
  - BRRI specializes in soil and water management for rice-based cropping systems.
  - BINA utilizes nuclear and isotopic techniques to study nutrient dynamics, particularly in rice, oilseeds and pulse crops.

- **Bangladesh Agricultural Research Council (BARC)** ensures alignment of national research priorities, fosters inter-institutional linkages, and plays a key role in policy coordination and resource mobilization. **Krishi Gobeshona Foundation (KGF)** under the control of BARC has emerged as a major funding body, supporting strategic soil research projects focused on nutrient efficiency, bio-fertilizers, organic amendments and climate-adaptive land management practices.

- **International Partnerships** with CGIAR centers—including **IRRI, CIMMYT, ICRISAT** and **IFDC**—have further enriched Bangladesh's soil research capacity by introducing cutting-edge technologies, global best practices and advanced analytical tools for data-driven decision making.

Together, these institutions provide a solid foundation for addressing soil-related challenges. However, to meet the escalating demands of climate-smart agriculture and sustainable development, future efforts must prioritize integration of digital innovation, policy reform and farmer-centric approaches.

4. New Challenges and Knowledge Gaps

Bangladesh has made impressive progress in soil science, but farming landscapes now face fresh, interconnected threats—many worsened by climate change and poor land management. These emerging issues demand urgent action, new research methods and even shifts in how we think about soil health. Below, we outline the biggest concerns and critical gaps that must be filled to protect Bangladesh's soils for the future.

Key Emerging Threats:

- **Climate-driven soil damage** – Rising heat, unpredictable rains and sea-level rise are making salinity, erosion and acidification worse, especially in coastal, hilly and flood-prone areas.
- **Cities eating up farmland** – Fertile fields are being paved over for housing, factories and roads, shrinking the land available for crops and disrupting soil functions.
- **Toxic soil pollution** – Untreated industrial waste, arsenic-laced irrigation water and overuse of farm chemicals are poisoning soils in peri-urban and industrial zones.
- **Policy blind spots** – Even with good data, soil health metrics rarely shape national farming or land-use plans, leading to scattered and ineffective solutions.
- **Farmers left out** – Many still rely on guesswork or generic advice, missing access to site-specific soil tests and modern tools.
- **No long-term tracking** – Without consistent monitoring, we're losing sight of trends in soil carbon, microbes and gradual degradation.

Fixing these gaps will require:

- **Breaking down research silos** – Linking soil science with climate studies, economics and technologies
- **Stronger partnerships** – Government, universities and private sector working together.
- **Grassroots outreach** – Getting innovations directly to farmers through apps, field schools and demo-plots.
- **Smarter policies** – Making soil health a core part of national climate and farming plans.

4.1 Climate Change Impact on Soil

Climate change has emerged as a formidable threat to soil health and its enduring capacity to sustain resilient and productive agriculture. In Bangladesh, the impacts are already manifesting through shifting rainfall patterns, prolonged dry spells, erratic monsoons, rising sea levels and an increasing frequency of extreme weather events. These climate-induced changes are affecting soil systems in complex, interrelated ways:

- **Drought and Desiccation**: Extended periods of drought lead to excessive drying of soils,

promoting the formation of hardpan layers and triggering nutrient fixation—particularly of phosphorus and micronutrients. These conditions restrict root development, reduce water infiltration, limit the availability of moisture and essential nutrients, thereby compromising plant growth.

- **Flooding and Waterlogging:** Recurrent flooding and stagnant water conditions, especially in low-lying and haor areas, create anaerobic environments that disrupt microbial processes. Denitrification losses increase, while erosion strips away nutrient-rich topsoil, weakening soil structure and lowering fertility in flood-prone regions.

- **Soil Salinization in Coastal Areas:** Rising sea levels and reduced upstream freshwater flows are intensifying salinity in coastal belts. Saline water intrusion, especially during the dry season, is rendering vast tracts of land less productive and increasingly unsuitable for traditional cropping patterns, thereby threatening local food systems and farmer livelihoods.

Despite the growing urgency, notable gaps persist in understanding and addressing the nuanced effects of climate stress on soil biology. There is limited research on the influence of climate variables on microbial diversity, enzymatic activity, nutrient cycling processes and long-term soil fertility under different agro ecosystems.

Furthermore, predictive models that capture the interactions between climate, soil and crops remain underdeveloped. Existing frameworks are often fragmented and poorly integrated into agricultural planning and extension services, resulting in missed opportunities for proactive adaptation and resource management.

To build climate-resilient soil systems, Bangladesh must invest in multidisciplinary research that links soil science with climate modeling, agronomy and socio-economic dimensions. Strengthening real-time monitoring, expanding adaptive field trials and embedding climate-smart soil strategies into national policy and outreach programs will be critical in safeguarding the country's agricultural future.

4.2 Silent Poison: Heavy Metals, Arsenic and Agro Chemicals

The accelerated intensification of agriculture—coupled with unregulated industrial expansion—has led to significant soil contamination across Bangladesh, particularly in peri-urban zones, industrial belts and areas reliant on groundwater-based irrigation. These pollutants not only degrade soil quality but also threaten ecosystem integrity, public health and agricultural sustainability (Islam, 2024).

- **Heavy Metal Accumulation:** Industrial discharge containing toxic elements such as lead (Pb), cadmium (Cd) and chromium (Cr) is often released without proper treatment. These

metals accumulate gradually in the soil, compromising soil structure and fertility. Once absorbed by plants, they enter the food chain, posing serious health risks to humans and animals through bioaccumulation and exposure.

- **Arsenic Contamination:** The prolonged use of arsenic-contaminated groundwater for irrigation—especially in rice-dominant regions—has resulted in substantial surface soil accumulation. Elevated arsenic levels impede plant physiological processes, reduce crop productivity and present grave risks to food safety and nutritional security.

- **Agrochemical Overuse:** Excessive and indiscriminate use of synthetic fertilizers, pesticides and herbicides has severely disrupted the natural balance of soil ecosystems.

- These chemicals inhibit microbial diversity, diminish enzymatic activity and lead to long-term declines in organic matter and nutrient cycling. As a result, soils become less resilient and increasingly dependent on chemical inputs.

While some isolated efforts have attempted to monitor and address soil pollution, existing research and mitigation strategies remain limited in scale and scope. There is a pressing need for:

- Comprehensive, nationwide soil pollution mapping to identify and quantify contamination hotspots.
- Integrated risk assessment frameworks that link soil toxicity with environmental and public health indicators.
- Scalable remediation techniques—such as phytoremediation, biochar application and microbial detoxification—to rehabilitate contaminated soils and restore fertility.
- Stronger policy enforcement and inter-agency coordination to regulate industrial waste management and agrochemical usage.

Addressing soil pollution must be treated as a national priority—one that requires coordinated action, inclusive research and investment in sustainable land stewardship. Without such measures, the long-term viability of agriculture and environmental health will remain at serious risk.

4.3 Soil Sealing

Rapid and unplanned urban expansion is contributing to significant soil degradation in Bangladesh through a process known as soil sealing—the permanent covering of fertile land with buildings, roads and urban infrastructure. As cities grow outward, large swathes of productive agricultural land in peri-urban zones are being irreversibly converted, leading to a loss not only in food production capacity but also in critical ecological functions.

Sealed soils are deprived of their natural abilities to:

- Facilitate water infiltration and groundwater recharge
- Store carbon and regulate greenhouse gas emissions
- Buffer urban heat through temperature regulation
- Support biological activity vital to ecosystem health

Despite the severity of this issue, current soil research in Bangladesh has predominantly centered on rural and agro ecological systems. The consequences of urbanization—particularly soil degradation in peri-urban areas, the potential for brownfield restoration and sustainable urban soil management—remain largely overlooked in national research agendas.

The lack of attention to urban soils poses a strategic gap, especially as Bangladesh's urban population continues to expand. Without proper planning and research, urbanization may permanently compromise vital soil functions, diminish landscape resilience and exacerbate climate and health vulnerabilities.

There is an urgent need to:

- Expand soil research into urban and peri-urban contexts
- Map and monitor sealed and degraded lands surrounding major cities
- Develop frameworks for reclaiming and restoring brownfields
- Integrate soil health metrics into urban planning, green infrastructure and zoning regulations

A more inclusive research agenda—one that bridges rural and urban soil dynamics—is essential for safeguarding the multifunctionality of soil and ensuring that development does not come at the cost of environmental sustainability.

4.4 Strategic Soil Research Frontiers

While Bangladesh has made commendable strides in conventional soil science, several globally significant and innovative research domains remain underexplored or are only beginning to gain traction. These strategic frontiers are crucial for enhancing long-term agricultural resilience, environmental health and climate adaptation:

a) Soil Carbon Sequestration

Amid growing global emphasis on carbon farming and climate mitigation, the potential of soil as a carbon sink in Bangladesh remains largely untapped. Research on enhancing soil organic carbon through conservation tillage, crop residue management, cover cropping, biochar and vermicompost application and agroforestry practices is still in its early stages. These approaches offer critical opportunities not only to improve soil health and fertility, and also to contribute to climate goals through carbon storage.

b) Regenerative Agriculture

Although sustainable intensification has received considerable attention, the holistic principles of regenerative agriculture—such as restoring soil biodiversity, reducing mechanical and chemical disturbance and designing circular nutrient systems—are not yet well-integrated into national research agenda. This paradigm shift, rooted in ecological balance and long-term soil vitality, could play a transformative role in building resilient agro ecosystems.

c) Soil Microbiome and Biotechnology

Soil microbial communities are hidden goldmine and fundamental to nutrient cycling, plant health and abiotic stress tolerance. However, the study of soil micro biomes, beneficial microbial consortia and bio-fertilizer development remains in its infancy in Bangladesh. Advanced biotechnological tools—including met genomics, enzyme assays and microbial fingerprinting—are underutilized, limiting progress in harnessing biological solutions for sustainable soil management.

d) Soil-Water-Plant Interactions under Stress

Understanding the dynamic relationships among soil properties, water retention, root architecture and nutrient uptake under stress conditions (e.g., salinity, drought, waterlogging) is essential for climate-resilient crop production. Yet, research efforts that integrate soil physics, hydrology, plant physiology and stress-adaptive agronomy remain limited. Bridging these disciplines can unlock critical innovations in water-efficient farming and adaptive land management.

Addressing these emerging challenges and knowledge gaps calls for a forward-looking, interdisciplinary approach to soil research. Key priorities could include:

- Strategic investment in advanced research infrastructure and diagnostic tools
- Cross-sectoral collaboration among soil scientists, climate experts, agronomists and technologists
- Integration of frontier topics into national soil science curricula and research programs
- Policy-oriented studies that align cutting-edge science with sustainable land-use planning

Without focused attention to these strategic areas, Bangladesh risks falling behind in preparing its agricultural sector for future environmental and socio-economic shocks. Embracing these frontiers will be vital to ensure soil systems remain productive, resilient and aligned with global sustainability goals.

5. Future Directions for Soil Research in Bangladesh

As Bangladesh moves toward a future shaped by climate uncertainties, food security demands and sustainability imperatives, the role of soil research must evolve accordingly. To

meet the complex needs of modern agriculture while safeguarding natural resources, soil science in Bangladesh must transition from traditional fertility management to a holistic and data-driven ecosystem approach. This section outlines strategic priorities and institutional recommendations that can guide the next generation of soil research towards national development goals and global sustainability targets.

5.1 Strategic Priorities

a) Establishing a Comprehensive Soil Health Framework

There is an urgent need to redefine soil assessment standards beyond narrow fertility metrics. A national soil health framework should integrate physical (e.g., compaction, porosity), chemical (e.g., pH, nutrient profiles) and biological (e.g., microbial biomass, enzyme activity) indicators. Developing region-specific benchmarks and standardized Soil Health Cards—combined with a regular monitoring system can empower both policymakers and farmers with the insights needed for adaptive land management. These tools will facilitate long-term trend analysis and encourage evidence-based interventions at scale.

b) Climate-Smart and Site-Specific Nutrient Management

Future research must accelerate the development of climate-resilient nutrient strategies, accounting for weather variability, moisture availability and the need for reduced greenhouse gas emissions. GIS-integrated soil data, real-time testing tools and predictive models can support precision fertilization, improving input efficiency and minimizing environmental risks. Scalable innovations—such as mobile soil labs, leaf color charts and decision-support apps—should be deployed to enhance farmer adoption and strengthen local extension systems.

c) Leveraging Digital Tools: AI, Remote Sensing, and Big Data

To modernize soil research and bridge the gap between analysis and action, Bangladesh must invest in digital capabilities:

- Remote sensing and satellite imagery for real-time monitoring of salinity, moisture, erosion and land-use changes
- AI-powered analytics to detect patterns, predict degradation risks and optimize nutrient strategies
- Digital platforms and dashboards to enable researchers, planners and farmers to interact with data in actionable ways. Partnerships with universities, start-ups and international technology providers will be the key to scaling these tools nationwide.

d) Advancing Conservation Agriculture and Agro ecological Practices

oil degradation and declining resilience can be addressed through nature-based solutions. Conservation agriculture—characterized by minimum soil disturbance, permanent cover and

diverse crop rotations—should be mainstreamed across agro ecological zones. Agro ecological approaches such as mixed cropping, green manures, organic amendments and agroforestry should be prioritized for their dual benefits: enhancing productivity while restoring ecological balance. These methods also align with SDG targets for climate action, land restoration and biodiversity protection.

e) Promoting Carbon Farming and Ecosystem Service Valuation

Soils play a central role in climate mitigation through carbon sequestration and in supporting hydrological regulation, habitat provision and nutrient cycling. Future research should:

- Quantify carbon storage potential under different cropping and land use systems
- Develop protocols for carbon credit accounting and integration into climate finance mechanisms
- Promote carbon farming practices, including composting, cover cropping and reduced tillage, to enhance soil health and provide economic opportunities for farmers recognizing and valuing ecosystem services from soils will help position Bangladesh as a proactive participant in emerging environmental markets and international climate agreements.

5.2 Institutional and Policy Recommendations

a) Strengthen Coordination among Research and Extension

A major challenge in Bangladesh is the weak connection between soil research findings and field-level adoption. It is critical to foster better collaboration among research institutes (SRDI, BARI, BRRI, BINA, BJRI, BSRI, BTRI and universities (BAU, SAU and like others), extension services, NGOs and the private sector. Joint programming, shared data platforms, and cross-training of personnel can improve knowledge dissemination and farmer impact.

b) Enhance Funding, Training and Young Scientist Engagement

Sustained investment in soil research infrastructure, and advanced laboratories and field trials are needed to ensure innovation and continuity. Special programs should be introduced to train young scientists, promote interdisciplinary research and encourage women's participation in soil science. Competitive grants and international exchanges can attract fresh talent and global perspectives.

c) Update Soil Policies and Land Use Planning Tools

Bangladesh's current soil and land policies need to be modernized to reflect emerging environmental and economic realities. There is an urgent need for:

- A National Soil Health Policy
- Integration of soil quality indicators into land zoning and agricultural investment plans

- Clear guidelines for sustainable land conversion, urban expansion, and conservation of prime agricultural lands

Policymakers must recognize soils as a strategic national asset and incorporate soil governance into broader development and climate action frameworks. The future of agriculture, environment and food systems in Bangladesh hinges on how well the country understands, manages and nurtures its soils. By embracing innovation, strengthening institutions and aligning policy with science, Bangladesh can lead the way in developing resilient, productive and sustainable soil systems that serve both people and the planet

6. Conclusions and Recommendations

Over the decades, soil research in Bangladesh has made remarkable strides—from the early soil surveys and fertility trials to the development of fertilizer recommendations, digital soil mapping and efforts to address nutrient deficiencies. Institutions like SRDI, BARI, BRRI, BINA and BAU, in collaboration with international partners, have played vital roles in building scientific capacity and generating valuable knowledge that has supported agricultural productivity and rural livelihoods.

Yet, as we confront the growing challenges of climate change, land degradation, salinization and pollution, it is evident that current approaches and research frameworks must evolve. Critical gaps remain in the areas of soil health monitoring, carbon sequestration, regenerative practices, microbiome research, and farmer-oriented innovations. The lack of robust coordination among institutions, insufficient policy integration and underinvestment in young scientists further limit the impact of soil science on national development goals.

Looking ahead to 2050 and beyond, our collective vision should be clear: to ensure resilient, healthy soils that sustain food security, environmental integrity and climate resilience for future generations. Achieving this vision will require transforming soil research from a purely technical endeavor into a strategic national priority that links science, policy and practice.

This is a call to action:

- To policymakers: recognize soil as a critical natural resource and integrate soil health into national development, food security and climate strategies.
- To scientists and educators: embrace innovation, foster interdisciplinary research and train a new generation of soil stewards equipped to tackle 21st-century challenges.
- To extension agents, NGOs and private sector actors: actively engage with farmers, co-create solutions and ensure that technologies and knowledge reach those who need them most.

The soil beneath us holds the promise of our future. If we care for it wisely, it will continue to nourish our nation—quietly, faithfully and abundantly—for generations to come.

Conflicts of Interest

The author declares no conflicts of interest regarding publication of this paper.

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