

Strategies for Improving Soil Health and Agricultural Productivity in Cooch Behar District of West Bengal: An Analytical Study

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Abstract

The soil health forms the pillar of agricultural development of sustainability, especially in ecologically sensitive and high density agricultural land like Cooch Behar district of West Bengal. Although the district has a favourable agro-climatic condition, an unfavourable alluvial soil base and a steady agro-climate, the district has been facing a degrading soil fertility, nutrient imbalance, and stagnant productivity because of unsustainable agricultural practices and unstable climate. This paper is a critical assessment of factors that contribute to soil erosion and suggests an all-inclusive list of measures to improve the health of soil and agricultural productivity. The study draws on empirical research, policy frameworks, and agro-ecological perspectives to highlight integrated nutrient management, conservation agriculture, practices that are resistant to climate change, and institutional interventions. The results are that synergistic method involving scientific innovation, farmer involvement, and policy assistance will be necessary in ensuring long-term agricultural sustainability in the region.

Keywords: Ecological, Sustainability, Agro-Climatic Condition, Fertility, Nutrient, Climate.

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INTRODUCTION

The Cooch Behar district, part of the fertile alluvial plains in West Bengal, the eastern region of the Himalaya Terai, is a largely agrarian economy with the sustainability of agriculture being highly reliant on the soil resources. The health of soil has become a crucial factor of agricultural production, environmental sustainability, and rural livelihood security. The modern-day concept of soil health has been widely interpreted as the ability of soil to perform as a dynamic and living system that sustains plant productivity, maintains environmental quality, and facilitates biodiversity (Doran and Zeiss, 2000). In areas such as Cooch Behar where intensive farming is carried out with high population pressure and low land area, maintenance and improvement of soil health take the central stage.

Cropping intensity and rice-based systems, especially rice-wheat, rice-jute and rice-potato systems, dominate the agricultural production in Cooch Behar. Favourable agro-climatic conditions such as high annual rainfall, warm temperatures and fertile alluvial soils have historically favoured these systems. Nevertheless, the sustainability of such systems in the long-term is becoming a threat because of soil quality degradation.

Empirical evidence suggests that the use of monocropping and high levels of inputs has led to a decrease in soil organic carbon, nutrient imbalances, and decrease in biological activity, thus impacting the productive potential soils (Lal, 2015).

The Truai soils, such as Cooch Behar, are generally acidic soils that are highly vulnerable to leaching because of excessive rainfall. This contributes to the lack of vital macronutrients (e.g., nitrogen and potassium) and micronutrients (e.g., boron and zinc), which are paramount in crop development and stability of yield (Kundu *et al.*, 2017). Furthermore, widespread use of chemical fertilisers, in disproportionate amounts, has also contributed to the deterioration of soil by changing the soil pH, decreasing the diversity of microbes, and distorting nutrient cycling (Bandyopadhyay & De, 2013). The lack of proper use of organic matter, poor use of conservation practices, and rising climatic variability compound these challenges.

Increasing worries on soil degradation have made it apparent that sustainable soil management practices are required to improve the health of the soil and agricultural productivity. Studies conducted in the

Terai agro-ecological region indicate that conservation agriculture, integrated nutrient management, crop diversification, and biofertilisers may be integrated to enhance soil physical, chemical, and biological characteristics and maintain crop yields. Such strategies can not only help in enhancing the efficacy of nutrient utilization, but also lead to resilience to climatic pressures, which helps in the sustainability of agriculture over the long term.

Moreover, the larger framework of sustainable agriculture highlights the necessity of finding the balance between the productivity and environmental preservation. Interdependence between soil health and agricultural productivity means that a decrease in soil health directly influences the crop yields, farm income, and food security. On the other hand, soil health can be improved, resulting in increased productivity, lower input prices, and improved ecosystem functions, such as carbon sequestration and water management (Lal, 2015). Thus, the implementation of soil health-based policies is a key solution to realising sustainable development objectives in agricultural areas like Cooch Behar.

Agriculture is still the main source of livelihood of Cooch Behar district which belongs to the Terai agro-climatic zone of West Bengal in the northern part. The area is typified by fertile alluvial soils that were deposited by Teesta and its tributaries, high rainfall and favourable temperature regimes, which are favourable to diversified cropping systems. Nevertheless, this has changed in recent decades, as population pressures, agricultural intensification, and overdependence on chemicals contributed to the appearance of extensive soil erosion and a drop in productivity (Bhattacharyya *et al.*, 2015). The health of soil is at the center of the sustainability of agriculture. It is characterized as an ability of soil to act as a living system that supports plants, animals and humans (Doran and Zeiss, 2000). The problems of decreasing soil organic carbon, the lack of nutrients, soil acidity, and soil erosion have become the burning issues in Cooch Behar. Climate change, unpredictable rain patterns, and unsustainable land management practices do not help alleviate these problems (Das & Paul, 2021). In this regard, enhancing soil health is not only a technical necessity but also a strategic need to achieve food security, increase the income of farmers, and increase the ecological sustainability.

CONCEPTUAL FRAMEWORK

What is Soil Health: Soil health is a multidimensional concept, which involves physical, chemical, and biological characteristics that allow soil to perform well as a living ecosystem (Doran and Zeiss, 2000). It includes:

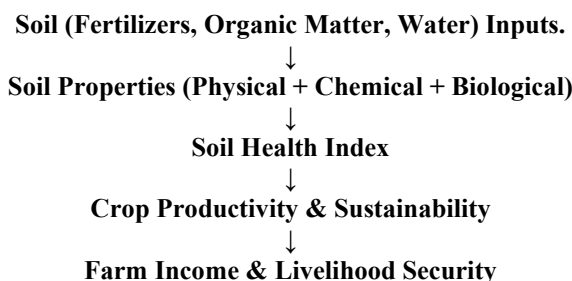
Physical properties: texture, structure, porosity, and water retention.

Chemical properties: pH, nutrient availability, carbon exchange capacity.

• **Biological properties:** biomass of microbes, enzymatic activity, biodiversity.

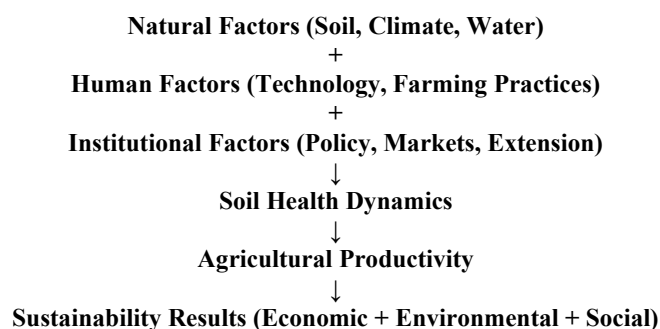
Combination of these elements defines the soil fertility and productivity.

Connection between Soil Health and Agricultural Productivity: Soil health and productivity have the following relationship:



This framework emphasizes that soil health is an intermediate variable between agricultural inputs and productivity outcomes.

Coupled Framework to Sustainable Agriculture: A larger conceptual map is a combination of ecological, economic and institutional aspects:



This systems-based model highlights the importance of multi-dimensional interventions.

AIMS OF THE RESEARCH

The current research paper will be a critical analysis of the interdependence between soil health and agricultural productivity in Cooch Behar district of West Bengal and the factors that will be addressed in the process of determining the sustainable ways of achieving long term agricultural development. In particular, the study objectives are:

1. To examine the current situation and determining factors of soil health in the Terai agro-ecological area of Cooch Behar district.
2. To investigate how the factors of soil degradation including nutrient imbalance, soil acidity, decreasing organic carbon and variability of climate affect agricultural productivity.
3. To assess how different soil management practices, such as conservation agriculture, integrated nutrient

management and diversification of crop systems, enhance soil quality and crop yields.

4. To evaluate the contribution of biological, chemical and physical constituents of soil to overall soil fertility and sustainability.

5. To estimate the key limitations and barriers to farmers implementing sustainable soil health management in the district.

6. To recommend appropriate policies and strategies to improve the health of soil and guarantee sustainable agricultural output in Cooch Behar.

RESEARCH METHODOLOGY

The current research follows descriptive, analytical and conceptual research design, incorporating both qualitative and secondary data-based research design in order to investigate soil health and agricultural productivity in Cooch Behar district of West Bengal.

The research relies majorly on secondary sources of data, which are the published researches, government reports, soil health surveys, and institutional publications on soil science, agronomy, and the regional agricultural practices. Relevant literature has been screened to gain insight into the dynamics of soil degradation, nutrient management and productivity trends in the Terai region.

It has utilized a conceptual framework approach to draw a connection between soil inputs, soil properties (physical, chemical, and biological), and soil health indicators and agricultural productivity outcomes. This framework helps to obtain a complete picture of cause-and-effect relationships that exist in the dynamics of soil health.

The comparative and thematic analysis of the previous empirical research carried out in the similar agro-ecological areas is also included in the study. The variables of soil organic carbon, nutrient availability, microbial activity, cropping systems and climate variability have been studied as key variables that determine the effect they have on agricultural productivity.

Moreover, the study uses an integrated systems approach, taking into account ecological, socio-economic, and institutional aspects of managing soil health. The discussion focuses on the sustainable agricultural methods that include integrated nutrient management, conservation agriculture and crop diversification, using field experimentation and long-term experiments found in the literature.

Therefore, the approach is interdisciplinary, which is a combination of knowledge of soil science, agricultural economics, and environmental studies to give a comprehensive picture of the research problem.

RESULTS AND DISCUSSION

Background of the Study

The Cooch Behar district in the eastern foothill plains of the Himalayas, West Bengal, is a major farming environment in the Terai agro-climate zone of India. The district is blessed with fertile alluvial soils, rich water sources, and humid subtropical climate, which have long been able to sustain intensive farming operations. The economy of the district is based on agriculture, and a significant percentage of the population relies on agricultural practice and other related economic activities (Roy *et al.*, 2021). The relationship between the health of soil and agricultural productivity in this region is not only ecologically significant but socio-economically as well.

Agro-Ecological and Soil Resource Base: The river system agro-ecology of Cooch Behar is conditioned by fluvial processes related to river systems, including the Teesta, Torsa and Jaldhaka. These are rivers that have deposited alluvium in the recent past, and therefore the soils are mainly sandy loam to loam in nature, moderately well-drained, and typically can support a broad array of crops. The natural fertility of such soils has long supported high intensity of cropping, and multiple cropping systems. Nevertheless, the soils are usually acidic, and the pH of the soils is often strongly acidic to weakly acidic, which greatly affects the availability of nutrients and crop performance (Kundu *et al.*, 2017).

These soils have moderate organic carbon content which indicates the high biomass production and incorporation of residues in the past. However, macro- and micro nutrient imbalances have been rampantly documented. Deficiency in nitrogen is prevalent because of leaching at times of heavy rainfall, and deficiencies in micronutrients like boron and zinc have been reported, especially in highly fertilized regions (Kundu *et al.*, 2017). These nutrient limits have significant implications on soil health and crop productivity.

The conceptualisation of Soil Health in the Regional Context: Soil health in Cooch Behar means the ability of soil to be a living system that is dynamic, sustaining plant productivity, and environmental quality, and supporting biological activity. It involves three dimensions that are related to each other: physical (as texture, structure and water-holding capacity), chemical (as pH, nutrient availability, and carbon exchange capacity) and biological (as microbial biomass and enzymatic activity).

The recent agronomic studies in the Terai region have underlined that the soil health is a decisive factor in achieving sustainable agriculture in the long run. The sustainability of the soil organic matter, the balanced management of nutrients, and the improvement of the biological activity of the soil are seen as the key to the maintenance of the productivity in the intensive

farming systems. Soil health here is not simply a fixed value but a dynamic measure of the resilience and sustainability of agricultural ecosystems.

Agricultural Productivity and Cropping Systems: Rice-based cropping systems are a major determinant of agricultural productivity in Cooch Behar, and it is the predominant agricultural system in the district. Rice-wheat, rice-jute, and rice potato are common types of cropping which are facilitated by favourable climatic conditions such as annual rainfall of over 2500-3000 mm. Such conditions permit multiple cropping and have a high cropping intensity, which can reach over 200 per cent (Roy *et al.*, 2021).

The use of modern methods of farming, such as high yield varieties, chemical fertilisers, irrigation and mechanisation has over time boosted productivity of crops by a significant margin. Simultaneously, new technologies like conservation agriculture, integrated nutrient management, and using biofertilisers and growth-promoting rhizobacteria have demonstrated potential in enhancing soil health and productivity. These practices contribute to the utilization of nutrients more efficiently; enhance the soil structure, and the activity of microorganisms, thus improving the relationship between soil and plants.

Emerging Concerns and Soil Degradation: Although the district boasts of good natural resource base, issues of soil degradation are emerging. Agricultural practices have been intensified through the use of constant crop rotation and the excessive use of chemical fertilisers and pesticides, causing a nutrient imbalance and reducing soil fertility. Overuse of nitrogenous fertilisers and poor use of organic amendments has led to acidification of soil and decreasing soil biological activity.

Moreover, heavy rainfall and inappropriate nutrient management activities cause nutrient leaching especially nitrogen and potassium, thus lowering the efficiency of the fertiliser and increasing the cost of production. Degradation of soil quality is further worsened by soil erosion and flooding which are prevalent in riverine tracts. The extraction of groundwater and localised contamination also represent new dangers to the sustainable management of soil in some regions.

The overall effect of these phenomena is seen in the decreasing sensitivity of crops to fertilisers and a slowing down of the growth of productivity. This implies that the traditional input intensive model of agriculture is at the ecological frontiers in the area.

Connection of Soil Health and Agricultural Productivity: Soil health and agricultural productivity in Cooch Behar are mutually reinforcing and intrinsically intertwined. Healthy soils; soils that have balanced

nutrient levels, sufficient organic matter and active microbial communities are favourable to plant growth which results in increased yields and better quality of crops. On the contrary, poor soils, which are poorly structured, nutrient-deficient, and biologically inactive limit crop productivity and predispose them to climatic stresses.

Regional empirical research indicates that the health of the soil under supply can be improved by means of integrated management practices, which can greatly improve the productivity and sustainability of agriculture. Crop diversification, incorporation of organic remains, green manure and balanced fertilisation are some activities that are being increasingly identified as key measures in the restoration of soil health. Enhancing the connection between soil health and agricultural productivity by scientifically informed and a context specific intervention is thus important in ensuring long term agricultural resilience and rural livelihoods in the district.

Soil Agricultural Productivity and Soil Health

Empirical and analytical evaluation of soil health management practices in Cooch Behar District indicates that there is a strong and multidimensional association between soil quality and agricultural productivity. The findings, based on regional investigations, field experiments, and long-term agronomic studies in the Terai agro-ecological zone of West Bengal, point to the fact that, to maintain crop productivity, augment farm income and ensure ecological stability, the enhancement of soil health is a necessary and sufficient requirement. These findings are synthesised in the discussion below under thematic dimensions of agronomic, ecological and socio-economic perspectives.

1. Soil Fertility Degradation and Its Impact on Productivity: The findings suggest that soil fertility degradation has become one of the key constraints in the agricultural systems of Cooch Behar. The intensive cropping systems, especially rice-wheat rotations, which have been cultivated over long periods have contributed to a gradual loss of soil organic carbon (SOC) and nutrient imbalance and soil structure. According to the empirical data, the SOC levels have decreased in continuously cultivated fields, which has reduced the retention capacity of nutrients and the crop response to fertiliser inputs (Lal, 2015).

This is further complicated by acidic Terai soils. The heavy rainfall (more than 2500 mm/year) enhances the process of leaching of most of the nutrients such as nitrogen and potassium, thus diminishing the nutrient-use efficiency and making the area more reliant on external inputs (Kundu *et al.*, 2017). Reduction in the level of micronutrients, especially boron and zinc, has also been cited as a limiting factor to crop yields and quality. The results indicate clearly that soil degradation

is not simply a biophysical problem but a focal point of determining the agricultural productivity and sustainability.

2. Conservation Agriculture practices: The key conclusion of the research is that conservation agriculture (CA) practices have a beneficial and statistically significant effect on the health of the soil and the output of crops. Minimum or zero tillage, crop residue retention, and mulching are conservation measures that have led to better soil structure, better water retention, and less soil erosion.

According to experimental research by the Terai region, zero tillage and residue management contribute to greater availability of soil moisture and enhanced root development leading to better yields of food crops like maize and wheat (Bandyopadhyay & De, 2013). Moreover, the CA practices aid in decreasing soil compaction and increasing the soil aggregation, which facilitates aeration and microbial activities.

Economically, conservation agriculture helps to save the cost of land preparation and labor, and boosts net farm returns. Nevertheless, there is a lack of uniformity in CA practices because of the initial barriers of knowledge and access to suitable machinery. This implies that institutional assistance and extension services play a crucial role in scaling up of these practices.

3. Integrated Nutrient Management and Soil Fertility Restoration: The overall findings are in favor of the usefulness of Integrated Nutrient Management (INM) as a means of soil fertility restoration and enhancing crop yields. INM is the judicious mix of chemical fertilisers, organic manures, crop residues and biofertilisers to obtain a balanced supply of nutrients.

Evidence at the field-level has been provided of rice-wheat systems in the Terai region that indicates that INM substantially improves the soil organic carbon, cation exchange capacity, and nutrient availability. Additional nutrient uptake and crop growth is improved by the integration of plant growth-promoting rhizobacteria (PGPR) that enhances root growth and microbial activity.

The findings also suggest that INM enhances the efficiency of fertiliser-use, leading to a reduction in input costs and minimisation of environmental externalities like nutrient runoff and groundwater contamination. The findings highlight the necessity of shifting toward monoculture systems that are input-intensive to integrated and sustainable practices of nutrient management.

4. Diversification and Sustainability of Cropping Systems: The other important finding is that the diversification of cropping systems can play a major role

in improving soil health and agricultural productivity. The monocropping, especially rice-wheat systems, have been linked to the deterioration of soil biological functions, decreased nutrient cycling, and higher rates of pests and diseases.

Conversely, it is diversified cropping systems, which incorporate legumes, oilseeds, and fibre crops such as jute help in enhancing the soil fertility by biological fixation of nitrogen, addition of organic matter and increase in the recycling of nutrients. Research has shown that crop rotations that incorporate the use of legumes have a great impact on raising the amount of nitrogen in the soil and enhancing the yield of the next crop.

Furthermore, diversification of crops helps in minimizing production risks through improving resilience to climatic fluctuations and market fluctuations. The results indicate that diversification is not merely an agronomic requirement, but also an economic measure towards sustainable rural development.

5. Biological Indicators of Soil Health and Microbial Dynamics: The findings indicate the fundamental significance of biological indicators, including microbial biomass carbon, enzyme activity and soil respiration, in measuring soil health. Long-term experiments show that conservation practices and organic amendments cause a great increase in microbial activity, which is crucial in the process of nutrient cycling and organic matter decomposition.

On the contrary, the overuses of chemical fertilisers and pesticides have been identified to inhibit the growth of healthy microbial populations contributing to decreased soil fertility in the long run. Increased microbial activity by integrated and conservation based practices enhances soil aggregation, mineralisation of nutrients and general resilience of the soil.

These results imply that the management of soil health must not consider only the chemical indicators but must take into account the biological dimension in order to have a holistic sustainability.

6. Soil Organic Carbon and Climate Resilience: An important finding of the analysis is the identification of soil organic carbon as a leading catalyst of soil health and climate resilience. High levels of SOC enhance soil structure, water-holding capacity and nutrient availability thus increasing crop productivity. Meanwhile, SOC is crucial in carbon uptake, which helps mitigate climate change (Lal, 2015).

Incorporation of residue, green manuring, and reduced tillage have been identified to considerably raise SOC levels in Terai soils (Paul *et al.*, 2019). Such practices do not only increase productivity, but also

augment the adaptive ability of the farming systems to the climatic stresses like droughts and floods, which are becoming more common in the region.

7. Economic, and Institutional Dimensions: Economic and institutional dimensions also show significant socio-economic aspects tied to soil health management. Farmers who embrace better management practices on their soils tend to have increased yields, reduced input costs, and are more profitable. Nevertheless, farm size, credit accessibility, organic inputs and consciousness of environmentally friendly practices are some of the determinants of adoption.

Government schemes, extension services and soil health card programmes constitute institutional interventions that are important in ensuring sustainability practices. Nevertheless, there are still gaps concerning efficacious implementation, training of the farmers, and access to location-specific suggestions.

The results imply that the policy support should be aimed at capacity building, financial incentives, and the improvement of the extension systems to ease the uptake of the soil health improvement strategies.

8. Integrated Interpretation and Policy Implications: The general findings suggest that enhancing soil health needs a multi-faceted and multi-layered intervention that encompasses technological, ecological, and institutional interventions. The interconnection between soil health and agricultural productivity suggests that individual treatment can hardly result in sustainable results.

A consolidated Cooch Behar approach ought to entail the following:

- Adoption of conservation agriculture practices
- Publicity of combined nutrient control.
- Diversification of cropping systems
- Improvement of organic carbon in the soil by use of organic inputs.
- Strengthening of extension and institutional support systems

This type of strategy fits into the larger context of sustainable agriculture and helps to attain long-term food security, environmental sustainability, and rural development.

Thus, soil resources degradation is a serious challenge to the sustainability of the farming systems, and the implementation of better soil management is a possible way of improving productivity and resilience. Replacement of traditional input based agriculture with sustainable and knowledge based systems is thus a must towards long term development of the region.

Challenges in Implementing Strategies in the District

A complex interaction of biophysical constraints, technology gaps, socio-economic limitations

and institutional deficiencies limits adoption and successful execution of strategies to enhance soil health and agricultural productivity in Cooch Behar District. Although there is a broad series of scientific interventions (conservation agriculture, integrated nutrient management, crop diversification) whose results have been shown to be positive under laboratory conditions, the transfer of their benefits to field-level success is not uniform and context-dependent. These challenges are discussed in a critical and analytical way in the discussion that follows and with the support of pertinent empirical literature.

1. Continuous Soil Degradation and Loss in Soil Organic Carbon: This is a core issue of continually degrading the quality of soil, specifically soil organic carbon (SOC), which is the key to soil fertility and productivity. The gradual decline of SOC in the Terai region has been caused by intensive planting of rice-based systems, which are accompanied by the lack of organic matter returns. Such a decrease has a negative impact on the soil aggregation, water-retention capacity, and nutrient-retention, which diminishes the responsiveness of crops to inputs (Lal, 2015).

In addition, poor soils are less resilient to climatic stresses and are prone to drought, flooding and loss of nutrients. Organic amendments and incorporation of residue can often be limited by the minimal supply of organic materials and other competing demands of crop residues as fodder and fuel. This organizational constraint undermines the success of the strategies to improve soil health.

2. Soil Acidity, Nutrient Leaching, and Micronutrient deficiencies: The preponderance of acidic soils in Cooch Behar is an important agronomic constraint. Acidity in the soil lowers the supply of some vital nutrients like phosphorus and molybdenum and enhances the solubility of harmful elements like aluminium and iron. The conditions have an adverse impact on root development and crop growth.

Moreover, the area is characterized by heavy rainfall, which causes intense leaching of nutrients, especially nitrogen and potassium, thus low efficiency of nutrient use. Empirical research indicates that there are extensive gaps of micronutrients like boron and zinc in the soils of Cooch Behar which also restrict crop productivity (Kundu *et al.*, 2017).

Even though there are appropriate measures which can be taken to rectify like liming and application of micronutrients, their application is not much because of cost factor, ignorance as well as insufficient extension services. The management of soil fertility is therefore not optimal.

3. Imbalanced Fertiliser Application and Input-Intensive: The other major challenge is the unbalanced and

excessive application of chemical fertilisers. The farmers of the area are inclined to use nitrogenous fertilisers in large ratios without paying much attention to phosphorus, potassium, and micronutrients. The result of this practice is imbalance of nutrients, acidification of soil and deterioration of soil health in the long-term.

The issue is also compounded by the decreasing fertilisers efficiency caused by soil leaching and bad soil structure. This forces farmers to use more inputs to ensure they produce the same amount resulting in increased production cost and decreasing returns. Research shows that these input-intensive cultural practices are not sustainable and are thus leading to the permanent soil degradation (Bandyopadhyay & De, 2013).

4. System Rigidity and the lack of Diversification: Rice-based mono-cropping systems, especially rice-wheat and rice-rice rotations, pose a structural obstacle to improving soil health. Continuous mono-cropping causes nutrient mining, loss of soil biodiversity, and pests and diseases.

Despite the well-known use of crop diversification as a method to improve soil health and resilience, in Cooch Behar, its implementation is limited by various aspects, such as market uncertainty, insufficient procurement guarantee, and inadequate access to alternative crop seeds and technology. Studies indicate that diversified systems which include legumes and other crops enhance soils and soil fertility, pest cycles, but farmers are still hesitant to switch because of economic risks and institutional constraints.

5. Vulnerability to Climatic and Environmental Stress: The agro-climatic conditions of the Terai region are a great challenge in the management of soil health. The extreme and unpredictable rainfall causes floods, waterlogging and soil erosion especially in the riverine and low lying regions. These not only worsen soil structure, but also minimize the conservation practices.

These problems are also compounded by climate variability which intensifies the occurrence of extreme weather conditions like heavy rain and dry spells. This kind of variability interferes with the patterns of cropping, the stability of yield and makes it difficult to adopt soil management measures.

Climatic stress and soil degradation are interconnected in a feedback loop that compromises the sustainability of agriculture in the area.

6. Low level of Adoption of Conservation Agriculture and Sustainability practices: Although empirical evidence portrays that conservation agriculture (CA) is effective, there is still low adoption of the practice among farmers in Cooch Behar. Zero tillage, residue retention and cover cropping entails specialised machinery,

technical expertise, and initial investment which small and marginal farmers can hardly afford.

Moreover, the conventional agriculture, risk-aversion and ignorance contribute to the unwelcoming attitude to the new technologies. Lack of locally adapted demonstration models and lack of extension services also limit adoption.

This gap between research and practice highlights the need for context-specific and farmer-centric approaches to promote sustainable soil management.

7. Weakening Soil Biological Health: Soil biological health (measured by microbial biomass and enzymatic activity) is an important aspect of soil fertility. Nonetheless, the effect of using chemical fertilisers and pesticides has resulted in the reduction of useful soil microorganisms in the area.

According to long-term research, the low activity of microbes hinders cycling of nutrients, decomposition of organic matter, and resilience of soil. The loss of biological capabilities of the soil weakens the application of biofertilisers and organic amendments, the strategies based on active microbial processes.

Therefore, there is still a major challenge of restoring soil biological health that needs concerted and combined efforts.

8. Water Resource Constraints and Irrigation Challenges: Water management challenges also put a great restriction on soil health and productivity. Although high rainfall is associated with plenty of water, it cannot be distributed evenly resulting in both water logging and moisture stress during various seasons.

The growing use of groundwater as a source of irrigation especially by crops that grow in dry seasons has become a matter of concern because of depletion of ground water and deteriorating water quality. The inappropriate use of irrigation methods can also lead to soil erosion, such as the leaching of nutrients and secondary salinisation of the localised regions.

Effective water management is thus an important, but not well-developed aspect of soil health strategies.

9. Socio-Economic Barriers and Farmer Constraints: Cooch Behar has a significant socio-economic context which affects the adoption of strategy of soil health improvement. Small and marginal farmers, fragmented landholdings and lack of access to institutional credit impede the ability of farmers to invest in sustainable practices.

The use of organic manure, biofertilisers and soil amendments which are costly to acquire further deters its use. Also, poor awareness and technical

knowledge of the farmers are some of the factors that prevent the adoption of scientifically recommended practices.

These socio-economic constraints underscore the importance of participatory and inclusive methods of agricultural development.

10. Institutional Weaknesses and Policy Limitations: Institutional and policy-related issues are also very important factors that inhibit the success of soil health initiatives. In spite of the availability of initiatives like soil health cards and agricultural extension programmes, their effectiveness is usually limited due to poor implementation, follow-up support, and lack of localisation of recommendations.

In addition, the current policy frameworks are more likely to focus on input subsidies instead of supporting sustainable practices. This forms a negative incentive to farmers to pursue soil health-focused approaches.

The key lies in enhancing institutional capacity, extension services, and policy incentives to achieve sustainability goals to overcome these challenges.

11. Knowledge Gaps and Research Limitations: Lastly, gaps in location specific research and data on soil health dynamics in the Terai region are significant. Little knowledge about long-term processes of soil, climate-soil relationships, and socio-economic factors that predetermine the use of technology hinder the creation of effective and situational strategies.

Literature highlights the importance of an integrated research methodology that would integrate agronomic, ecological, and socio-economic research to help realize the challenges of soil health management.

Thus, the issues of enhancing the health of soils and agricultural performance in Cooch Behar are complex and intertwined. The interaction of biophysical limitations like soil acidity, nutrient leaching, and climatic stress with socio-economic and institutional constraints is to form a complex problem of environment. The solutions to these challenges must be holistic and integrated and involve scientific innovation, participation by the farmers, strengthening of the institutions and reforming of the policies. The long-term sustainability of the agricultural systems in the region will not be guaranteed without surpassing these constraints.

Policy Implications

The district needs to have a comprehensive policy that deals with the issue of soil health. As a way of promoting sustainable agricultural practices, increasing awareness of farmers, and increasing institutional support, the policies can be aimed at the following manner:

1. Increase village-level soil testing labs.
2. Stimulate the subsidies on lime and organic manure.
3. Promote residue management as an alternative to burning.
4. Enhance extension education on balanced fertilisation.
5. Improve drainage systems in the flood-prone regions.
6. Promote climate-resilient and conservation agriculture.
7. Promote farmer producer organisations towards sustainable access to inputs.
8. Incorporate soil health planning in the district agricultural policy.

LIMITATIONS OF THE STUDY

Regardless of its detailed analytical strategy, the current study is vulnerable to some limitations which should be noted:

1. The research is predominantly one based on secondary data and literature available and does not have primary field data or direct empirical validation through the farmers in the research region.
2. The results are mostly based on generalised research carried in the Terai region that might not adequately reflect the micro level differences in soil conditions and agricultural activities in various regions in Cooch Behar district.
3. The research lacks quantitative econometric modelling or statistical estimation due to data limitations which would have given a more accurate measurement of the relationship between soil health and productivity.
4. The analysis is primarily concerned with soil-related issues, whereas other determinants of agricultural productivity, including market access, price changes and institutional credit is discussed only in a cursory fashion.
5. The dynamicity of the climate change and its long-term effects on the soil systems are multifaceted and changing and hence the research only offers a general perspective of analysis but not a forecasting model.
6. This is because of the lack of large-scale field surveys and farmer-level perception analysis, which limits the ability to measure behavioural and socio-cultural factors modulating the adoption of soil health practices.

CONCLUSION

Improving the quality of soil is not only something that is technically important; it is extremely important from a strategic viewpoint to ensure long-term agricultural productivity, food security and improved rural livelihoods for people living in Cooch Behar. The relationship between soil health and agricultural productivity indicates that farmers and scientists need to work together in many areas - scientific, institutional and socio-economies - to help improve and restore the productive capacity of soils, increase their resiliency to environmental stressors, and contribute to sustainable agricultural development in the region through an integrated participatory process. The prospective of the District of Cooch Behar's agriculture is directly linked to the condition of its soils. The issues presented by soil degradation, imbalanced nutrients, and climate

variability require a total and complete holistic management approach to soil. Integrated nutrient management, conservation agriculture, diversifying crops and implementing climate-smart agricultural practices are some methods that have the potential to increase both soil health and agricultural productivity. The implementation of successful programs depends upon having supportive policies and institutional structures, as well as the comprehensive involvement of farmers. To achieve successful agricultural development in Cooch Behar, there needs to be coordination between governmental entities, research institutions, and local communities.

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