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Framework For
Ecosystem Services Assessment in Organic and Natural Farming Systems

ICAR-Indian Institute of Farming Systems Research
Modipuram - 250110, Uttar Pradesh, India

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Foreword

The increasing challenges of climate change, environmental degradation, and the need for sustainable food systems have highlighted the importance of ecosystem services (ESS) in modern agricultural practices. The interdependence between agriculture and nature is clear, and sustainable management of natural resources is essential for enhancing farm productivity and protecting the environment. In this context, I present the critical resource, "**Framework for Ecosystem Services Assessment in Organic and Natural Farming Systems**". This Framework Bulletin explores how ESS estimation and valuation can be integrated into agri-food systems, especially in organic and natural farming, to promote resilience and sustainability.

The role of ecosystem services in agriculture is vital. Services like carbon sequestration, nutrient cycling, water recharge, pollination, water regulation, and pest management are essential for soil health, crop productivity, and ecological balance. Organic and natural farming systems, which prioritize ecological harmony, effectively leverage these processes. This Bulletin provides a framework for assessing and valuing these services, demonstrating both their tangible and intangible benefits and encouraging sustainable farming practices.

A key objective of this bulletin is to provide policymakers, researchers, and farmers with practical tools for quantifying and valuing natural, produced, human, and social capital within farming systems. It also promotes the valuation of ecosystem services in agri-food systems, incentivizing farmers to adopt practices that enhance biodiversity, soil health, and resilience to climate change.

As we move toward a future that balances food security with the preservation of natural resources, integrating ESS into farming systems is crucial. This bulletin serves as a valuable resource for shaping agricultural strategies in harmony with nature. I hope it inspires and guides readers in transforming agriculture for the benefit of both people and the planet.

(S.K. Chaudhari)

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PREFACE

Estimating and valuing AgriFood systems', ecosystem services is crucial to incentivizing farming communities, driving sustainable practices by rewarding efforts that boost soil health, biodiversity, and climate resilience through sustainable nature positive farming practices. This bulletin *"Framework for Ecosystem Services Assessment in Organic and Natural Farming Systems"* offers a comprehensive guide for researchers, farmers, and policymakers to integrate ecosystem services (ESS) into sustainable farming practices. This bulletin demonstrates how ESS, such as nutrient cycling, water conservation, pest regulation, and biodiversity, are vital to promoting climate resilience and enhancing farm productivity without relying on synthetic inputs.

It covers 8 sections, Introduction, presenting the concept of ESS and their importance in both global and local contexts, especially in organic and natural farming systems. *AgriFood Systems* and *Ecosystem Services* section, explains the role of ESS in agriculture and highlights the environmental impacts of conventional farming, including emissions and resource depletion. *The TEEB Framework* section is outlining a structured approach to valuing ESS by evaluating natural, produced, human, and social capital in farming systems. *Natural Capital* section explores soil health, water resources, and biodiversity, offering practical tools to assess and improve these elements in organic farming. *Produced Capital* section discusses the role of infrastructure, machinery, and technology in supporting sustainable farming, while *Human Capital* section emphasizes the critical importance of farmer knowledge, skills, and well-being for implementing resilient farming practices. *Social Capital* section highlights the value of community networks, cooperatives, and collaboration in fostering collective action and resource-sharing in farming communities.

The *Way Forward* section offers actionable recommendations for policymakers, emphasizing the integration of ecosystem services (ESS) into agricultural strategies. It advocates for data standardization, inclusivity, and active farmer participation. This bulletin is a vital resource for developing sustainable agricultural systems that align with nature. Valuing ESS in AgriFood systems is essential for recognizing their economic and ecological benefits, promoting sustainable practices, and incentivizing farmers to enhance biodiversity, soil health, and climate resilience, ensuring long-term agricultural sustainability.

(Authors)

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INTRODUCTION

1.1. Context and Relevance

1.1.1. Overview

Ecosystem services (ESS) are the benefits that humans obtain from ecosystems, which include provisioning (tangible outputs like food, water, and raw materials), regulating (processes such as climate regulation, water purification, pest control, etc.), supporting (processes like soil formation, nutrient cycling, etc.), and cultural (recreational, aesthetic, and spiritual benefits) services (MEA, 2005). These are the foundation of ecological balance, directly supporting agricultural systems by ensuring water availability, enhancing soil fertility, and regulating pests & diseases. In sustainable agriculture, particularly in organic farming (OF) and natural farming (NF) systems, the reliance on ESS is paramount, as these farming systems focus on working with natural processes rather than relying on synthetic inputs (FAO, 2015). The restoration and preservation of ESS lead to healthier soils, resilient crops, and improved biodiversity, which ultimately contribute to farm productivity and environmental sustainability (TEEB, 2010; UNEP, 2024).

1.1.2. Relevance to Natural and Organic Farming

OF and NF systems are deeply intertwined with ESS via leveraging natural mechanisms for pest control, nutrient cycling, and water regulation, OF and NF reduce the chemical inputs, thus fostering healthier ecosystems. Key practices in OF and NF such as crop rotation, cover cropping, green manuring, residue recycling, composting, biofertilizers integration etc., contribute towards soil fertility, improve carbon sequestration, and minimize carbon footprint following the reduction in greenhouse gases (GHG) emissions when compared to conventional agriculture creating a relatively self-sustaining agricultural enterprise (Project Drawdown, 2020; Ravisankar et al., 2021; Panwar et al., 2022; Ansari et al., 2023). This integration of ecosystem-based practices highlights the importance of OF and NF as drivers of sustainable agricultural productivity.


Azolla application


Sesbania intercropping

Sesbania green manuring

1.1.3. Global and Local Significance

Globally, ESS are integral to address critical environmental issues such as climate change (CC), biodiversity loss, and land degradation. The MEA (2005) emphasized the need for the integration of ESS into policy frameworks to ensure global sustainability. Additionally, the TEEB (2010) highlighted the economic value of ESS in both environmental and policy contexts. ESS are also central to achieving several United Nations Sustainable Development Goals (UN-SDGs), particularly Goal 13: Climate Action (13.1, 13.2 & 13.3) and 15: Life on Land (15.1, 15.3 & 15.5). In India, ESS are vital for supporting smallholder farming systems, which form the backbone of agricultural production. OF and NF contribute to rural sustainability by conserving soil and water resources, and reducing reliance on external inputs (Panwar et al., 2021; Ravisankar et al., 2021; Panwar et al., 2022; Ansari et al., 2023). These practices are also closely aligned with India's Nationally Determined Contributions (NDCs) under the Paris Agreement, specifically the NDC 1 (Mission LiFE), 2 (adopt a climate-friendly and cleaner path), 3 (reduce emission intensity of its GDP by 45% by 2030 from 2005 level), 5 (create additional carbon sink of 2.5-3 billion tonnes by 2030), and 6 (better adapt to CC by enhancing investments in sectors vulnerable to CC impacts). Furthermore, this thread finds close association with the recent Green Credit Program (GCP) under the GCP-3 (Sustainable Agriculture-based Green Credit) of MOEFCC, GOI (MOEFCC, 2023).

1.2. Objectives of the Manual

- Provide a clear understanding of ecosystem services in agriculture, focusing on nature positive farming (NPF) practices,
- Demonstrate integration of ecosystem services using the TEEB framework for assessment and valuation,
- Equip stakeholders with practical tools to assess and quantify natural, produced, human, and social capital,
- Offer recommendations to enhance sustainability in farming practices, aligned with national and global initiatives

1.3. Ecosystem Services and Sustainability

1.3.1. Introduction to Ecosystem Services Frameworks

ESS has been increasingly recognized as vital to sustainable agricultural systems. Many frameworks like the MEA, TEEB, etc., have been formulated and have provided structured approaches to assess and value the benefits ecosystems provide to human well-being. These frameworks help in understanding the interactions between agriculture and ecosystems, making them critical tools for integrating sustainability into agricultural practices. In the context of farming, the TEEB framework specifically addresses the economic valuation of ESS, helping policymakers and stakeholders realize the importance of preserving ecosystems. This framework is particularly relevant for OF and NF systems, as they naturally leverage ESS to improve productivity and resilience.

1.3.2. Synergy Between Ecosystem Services and Farming Systems

NPF practices inherently rely on ESS, creating a synergistic relationship between agriculture and nature. This synergy means that healthy ecosystems support sustainable farming, and in return, OF and NF systems help maintain or restore ecosystem functions (Ansari et al., 2023; 2024). This mutual benefit highlights the importance of preserving ESS as a core strategy for improving long-term agricultural productivity while reducing environmental impacts.

1.3.3. Long-term Sustainability

The OF and NF systems, by maximizing the use of ESS, align closely with long-term sustainability goals such as those outlined in section 1.1.3. These farming systems contribute to carbon sequestration, water conservation, and biodiversity enhancement, all of which are critical for achieving long-term sustainability. By adopting practices that enhance these services, OF and NF systems help achieve resilience against climate change and reduce the agricultural carbon footprint, promoting both environmental and economic sustainability (Rodale Institute, 2021; Ansari et al., 2022a, 2022b).

1.4. Why Quantification and Valuation of Ecosystem Services?

1.4.1. Decision-Making and Policy Formulation

Quantifying and valuing ESS allows policymakers to make informed decisions that balance economic development with ecological sustainability. By placing an economic value on ESS decision-makers can recognize their critical contributions to the economy and human well-being. This is particularly important for sustainable agricultural policies, where OF and NF systems depend heavily on these services. Quantifying these services helps incorporate them into national strategies (such as NDCs and GCP) which aim to promote sustainable land-use practices (Costanza et al., 1997; Burkhard and Maes, 2017). Moreover, this valuation helps align farming practices with environmental goals by providing policymakers with the necessary data to justify investments in sustainable agriculture, agroecology, and ecosystem restoration.

1.4.2. Realization of Financial and Non-financial Benefits

Valuing ESS also brings significant financial benefits, encouraging investment in sustainable practices, e.g., services like pollination, nutrient cycling, water retention, etc., if disrupted, would require costly artificial alternatives (de Groot et al., 2012). Farmers adopting OF and NF benefit financially by reducing the need for expensive chemical inputs, while the ecosystem gains through increased biodiversity and improved soil health (Christie et al., 2012). These non-financial benefits, like resilience against climate change and improved water conservation, contribute to long-term farm sustainability. Recently, the GOI has been scoping for the payment of ESS in the agri-sector following the induction of GCP in 2023.

1.4.3. Improved Farm Management

For farmers, understanding the value of ESS enables better resource management, leading to more efficient and sustainable agricultural practices. Natural pest control and nutrient cycling reduce dependence on external inputs, while improving productivity and farm profitability (Power, 2010). By recognizing the economic value of these services, farmers are more likely to adopt sustainable practices like crop diversification and organic composting, which also align with climate-smart agriculture principles (Lescourret et al., 2015).

1.5. Why Restoration?

Restoration of ESS is essential for ensuring long-term sustainability and building resilience against environmental challenges. Investing in ecosystem restoration enhances agricultural productivity, which is vital for sustainable farming systems. By restoring these services, farmers reduce their dependence on synthetic inputs, lower their carbon footprints, and contribute to global CC mitigation efforts (Rey Benayas et al., 2009). Moreover, ecosystem restoration helps in mitigating environmental degradation by enhancing biodiversity, improving air and water quality, sequestering carbon, etc. (Aronson et al., 2010). Restoration also strengthens ecosystem resilience, enabling OF and NF ventures to better withstand extreme weather events, such as droughts, floods, etc., thus serving as a strategic investment in both ecological health and economic sustainability (Suding, 2011).

AGRIFOOD SYSTEMS: ECOSYSTEM SERVICES

AgriFood systems refer to the entire process of producing, processing, distributing, and consuming food, encompassing activities from farm to fork. These systems are critical for global food security, nutrition, and livelihoods. Sustainable AgriFood systems aim to balance productivity with environmental health, ensuring long-term resilience and equitable access to resources.

Agriculture operates as a dynamic ecosystem where living organisms, environmental factors, and human interventions interact to produce food, fiber, and other essential goods. In the context of AgriFood systems, it is crucial to unravel, understand, and evaluate the hidden costs and benefits that affect both people and the environment. Sustainable AgriFood systems must provide adequate nutrition for all in an equitable manner, without compromising ecological security or environmental sustainability. This requires recognizing the interconnectedness of agriculture with biodiversity, soil health, water resources, and climate change, and ensuring that these systems are managed for long-term resilience and global food security.

AgriFood systems and emissions

The AgriFood systems are responsible for 16 billion tonnes of CO_2 equivalent emissions, accounting for 30% of global greenhouse gas emissions (FAO, 2023). This includes 8 billion tonnes (14%) emitted within the farm gate, primarily from agricultural production, 3 billion tonnes (6%) from land-use change, such as deforestation for agriculture, and 5 billion tonnes (10%) from pre- and post-production activities like food processing, transportation, and waste (Figure 2.1). The significant carbon footprint of AgriFood systems highlights the urgent need for sustainable practices that not only reduce emissions but also enhance carbon sequestration through improved land management, agroforestry, and soil health practices.

Figure 2.1 Agrifood systems and land-related emissions. (FAO, 2023)

Largest contributors in AgriFood Emissions

In 2021, the main contributors to emissions within Agrifood systems were CO_2 emissions from deforestation, and methane (CH_4) emissions due to enteric fermentation in ruminant livestock, both amounting to 2.9 Gt CO_2-eq each and together accounting for 40% of total Agrifood system emissions. Other significant sources included CH_4 emissions from livestock manure (manure management, soil application and manure deposition) as well as Agrifood system waste disposal, each contributing around 1.3 Gt CO_2-eq. Within the farm gate, total livestock emissions (enteric fermentation, manure management, manure applied to soils and manure left on pasture) amounted to 4.2 Gt CO_2-eq, representing 54% of farm-gate emissions. In pre- and post-production activities, household food consumption and waste disposal were the largest contributors, each generating approximately 1.2 Gt CO_2-eq. (FAO, 2023).

2.1 Ecosystem Service in AgriFood Systems

Ecosystem services are the benefits that people derive from nature, and in the AgriFood context, they play a crucial role in maintaining and enhancing agricultural productivity, while preserving natural resources. There are four types of ecosystem services that an AgriFood systems provide

Provisioning Services: These include the direct benefits we receive, such as food, water, fuel, and fiber. Agricultural ecosystems provide essential crops such as rice, wheat, pulses, and a variety of fruits and vegetables, which are critical for food security. Additionally, agricultural landscapes can support livestock rearing, providing dairy, meat, eggs, and other animal products.

Regulating Services: These are the natural processes that help regulate environmental conditions include nutrient regulation, pollination, and pest management. Many crops, such as fruits, vegetables, and nuts, depend on pollinators like bees, butterflies, and other insects for the fertilization of flowers and the production of fruits and seeds. Agricultural practices support habitat for pollinators, such as planting hedgerows, maintaining flowering cover crops, can enhance the pollination service. This not only improves crop yields and quality but also helps maintain the health and diversity of the pollinator populations, which are essential for the resilience of agricultural ecosystems.

Supporting Services: These are foundational processes, support the functioning of all other ecosystem services such as soil formation & nutrient cycling, that sustain agricultural productivity. In agricultural ecosystems, processes like the breakdown of organic matter, decomposition by soil organisms (such as earthworms and microbes), and the incorporation of plant residues contribute to the formation of fertile topsoil. This supports nutrient availability for crops, which is essential for maintaining long-term soil health and productivity.

Cultural Services: These include the non-material benefits people derive from ecosystems, such as recreation, cultural heritage, and spiritual fulfilment. In rural India, agriculture is deeply intertwined with culture, and many agricultural practices are rooted in traditional knowledge systems that respect and conserve the natural environment.

Table 2.1. Valuing ecosystem services in the total economic value (TEV) framework

Group	Service	Direct use	Indirect use	Option value	Non-use value
Provisioning	Includes: food; fiber and fuel; biochemicals; natural medicines, pharmaceuticals; fresh water supply	[green]	[red]	[green]	[red]
Regulating	Includes: air-quality regulation; climate regulation; water regulation; natural hazard regulation, carbon storage, nutrient recycling, microclimatic functions	[red]	[green]	[green]	[red]
Cultural	Includes: cultural heritage; recreation and tourism; aesthetic values	[green]	[red]	[green]	[green]
Supporting (Habitat)	Includes: primary production; nutrient cycling; soil formation	[red]	[green]	[green]	[green]

Source: TEEB (2012), NAAS (2020)

[green]	[red]	Green box represents (✓) and red box indicate not applicable

2.2 Organic Farming and Natural Farming: why important for sustainable and enhanced ecosystem services?

Organic and natural farming play a crucial role in enhancing and sustaining ecosystem services in agriculture by fostering environmental health, promoting biodiversity, and ensuring long-term productivity.

Organic Farming

Organic farming eliminates the use of synthetic chemicals, focusing on natural inputs and biological processes to improve soil health, biodiversity, and overall sustainability. Organic farming, also known as ecological farming or biological farming, uses fertilizers of organic origin such as compost manure, green manure, and bone meal and places emphasis on techniques such as crop rotation and companion planting.

Figure 2.2. Organic farming experimental plot at ICAR-IIFSR, Modipuram

Natural Farming

Natural farming is a chemical-free and low-input farming system based on minimal disturbance of soil and self-sustaining ecosystems. Natural farming systems largely rely on biomass recycling, biological rejuvenation of natural nutrient cycles, and on-farm plant and livestock-based inputs, and are found to be one of the alternative production systems to address the priorities outlined in the Food and Agriculture Organization's (FAO) report, "The State of Food & Agriculture" (FAO, 2021). This practice aims to emulate natural ecosystems and reduce human intervention.

Figure 2.3. Natural farming experimental plot at ICAR-IIFSR, Modipuram

These farming methods offer several key benefits:

- These practices encourage biodiversity by avoiding chemical pesticides, promoting soil health, and supporting diverse species of plants, insects, and microorganisms.
- These methods enhance soil structure and fertility through composting, crop rotation, and natural fertilizers, fostering long-term soil productivity and preventing erosion.
- Organic farming reduces water contamination from chemical runoff and uses water-efficient practices like mulching and drip irrigation to minimize water waste.
- By avoiding synthetic fertilizers, organic farming cuts down nitrous oxide emissions, a major greenhouse gas, thus helping mitigate climate change.
- Organic methods protect pollinators like bees and butterflies by avoiding harmful pesticides, which enhances pollination services essential for food production.
- NPF practices builds ecosystem resilience, supporting long-term productivity while reducing dependency on external inputs, ensuring food security and sustainable yield for future generations (Figure 2.4).

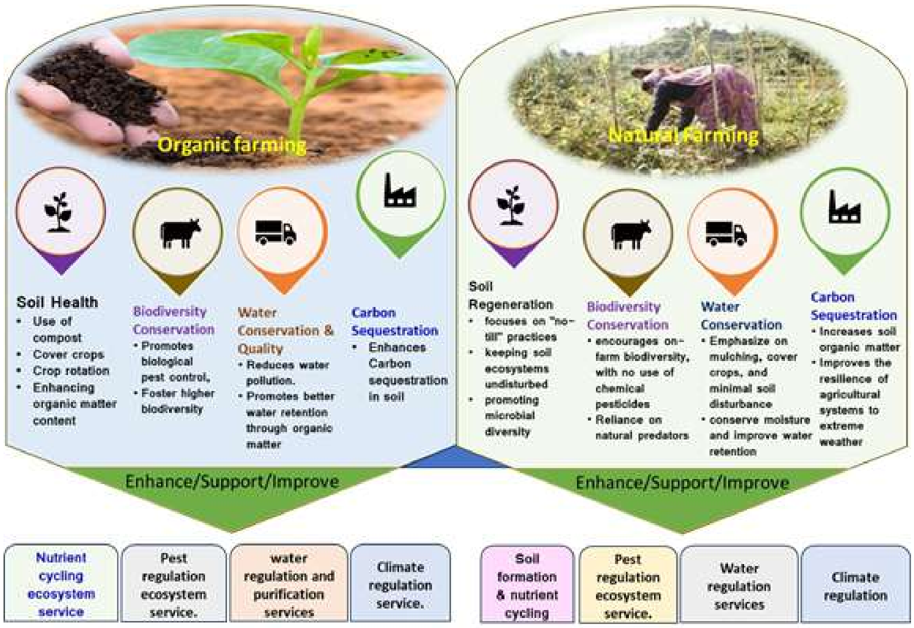


Figure 2.4. Role of NPF practices in eco-agri-food systems and improved ecosystem services.

2.3: Scholar's opinion

As we have learned that the Ecosystem Services refer to the benefits humans derive from natural ecosystems, such as water regulation, soil fertility, biodiversity conservation, and carbon sequestration. While conventional farming has been associated with high yields, it often leads to significant environmental degradation due to synthetic input usage. On the other hand, organic and natural farming practices are argued to enhance ecosystem services through sustainable resource use and no chemical inputs. These practices contribute to soil health, biodiversity conservation, climate regulation, water management, and more. In the Indian context, these practices help to achieve a balance between productivity and sustainability, particularly in addressing issues like soil erosion, water scarcity, biodiversity loss, and climate change. Various studies highlight the advantages of established agronomic practices like multiple cropping/intercropping, mulching, and green manuring to boost organic matter, enhance water retention, and promote microbial activity, all vital for maintaining healthy ecosystems and enhance ecosystem services (Ravisankar et al., 2021; Panwar et al., 2022; Ansari et al., 2023).

A meta-analysis by Lori et al. (2017) found that organic farming systems on an average had 41% higher SOM compared to conventional systems, which results in improved soil water retention and reduced erosion. According to Pimentel et al. (2005), conventional agriculture contributes to soil erosion rates that are 10-20 times higher than soil formation rates, leading to long-term soil health deterioration. Another study by Seiz et al., (2019) indicated that organic farming methods could reduce soil erosion by over 30% compared to conventional tillage. Panwar et al., 2022, reported in multi locational long term (13 years) experiment that the enforcement of organic inputs in organic system significantly improved ($p<0.05$) the microbial biomass carbon, soil organic carbon, available nitrogen, available phosphorous and available potassium by 40.6%, 33.3%, 16.4%, 37.8%, and 20.3% over inorganic crop management. Bengtsson et al., 2005, found that the reduced use of chemical increase in biodiversity which in turn contributes to ecosystem stability and resilience, improving services such as pollination and natural pest control. Study by Tuomisto et al., 2012 has shown that organic systems can reduce nitrate leaching up to 50%, thereby improving water quality and aquatic ecosystem health. Gattinger et al., (2012) justified that NPF practices enhance soil carbon sequestration by avoiding disturbance and increasing organic matter, which helps mitigate climate change and improve nutrient and water retention for long-term agricultural sustainability. The use of natural inputs like bio-fertilizers and mulches in natural farming supports a thriving soil microbial community (Figure 2.3) and biodiversity. These microbes play a crucial role in nutrient cycling and maintaining soil health, thereby enhancing ecosystem services related to nutrient availability (Kassam et al., 2011).

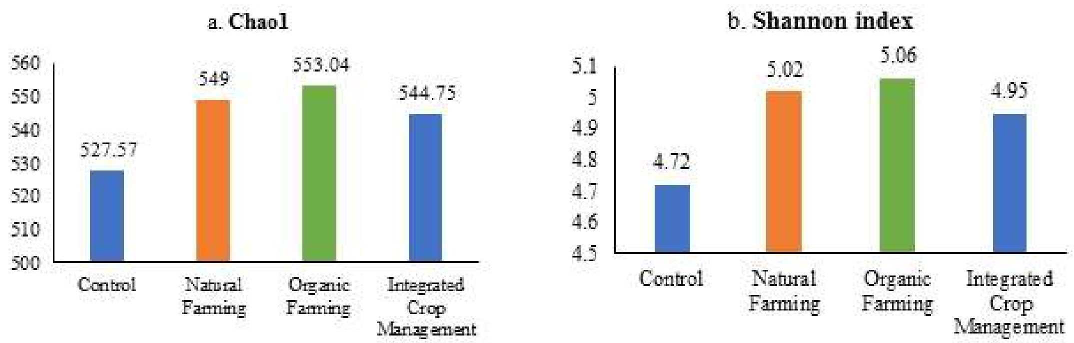


Figure 2.5. Microbial diversity index Chao1 (a) and Shannon index (b) under different management practices in soybean + maize -wheat + chickpea cropping system (AI-NPOF, ICAR-IIFSR)

Synthetic fertilizers and pesticides used in conventional farming can leach into water bodies, causing eutrophication and harming aquatic ecosystems. In contrast, organic and natural farming practices that minimize or avoid these chemicals can reduce the risk of pollution and contribute to healthier ecosystems (Tilman et al., 2002). Studies have shown that integrated organic farming systems are more resilient and sustainable (Layek et al., 2023). This resilience is partly due to improved soil structure and higher biodiversity, which enhance the ecosystem's ability to withstand disturbances (Reganold & Wachter, 2016). By enhancing ecosystem services such as soil health, water quality, and biodiversity, organic and natural farming contribute to achieving several SDGs, including zero hunger, clean water and sanitation, and climate action (FAO, 2018).

Figure 2.1 Integrated organic farming system model, AI-NPOF, Meghalaya

2.4 Government Initiatives and Ecosystem-Based Approaches

Indian agriculture sector and food-industries has a crucial role in the economy and presently this sector is facing a lot of challenges due to excessive use of harmful toxic chemical inputs in the field, which can only be tackled by policy making, providing capacity building and training opportunities to flourish a sustainable agriculture system, and to support the various natural ecosystem services and regulatory processes. As, the Indian government has recognized the importance of integrating ecosystem services into agriculture. Initiatives such as the National Mission for Sustainable Agriculture (NMSA), Paramparagat Krishi Vikas Yojana (PKVY), Mission Organic Value Chain Development for North Eastern Region (MOVCD-NER), Rashtriya Krishi Vikas Yojana (RKVY), and schemes like Soil Health Card Scheme, Voluntary Carbon Market (VCM), and Global Carbon Credit (GCC) to promote sustainable practices like organic farming, agroforestry, and water conservation. These programs aim to reduce the environmental impact of agriculture while maintaining productivity.

TEEB FRAMEWORK

The TEEB (The Economics of Ecosystems and Biodiversity) is a global initiative focused on "making nature's values visible", under the United Nations Environment Programme (UNEP) assessing the costs of the 'loss of biodiversity' and the associated decline in ecosystem services at all the levels worldwide. The objective of this initiative is to protect biodiversity, valuing the invisible services of agriculture and contribute to more sustainable agriculture and food sector. It promotes the assessment of ecosystem services by combining economic analysis with environmental and social perspectives. The framework helps policymakers, businesses, and communities understand the economic costs of biodiversity loss and ecosystem degradation, thereby encouraging sustainable practices. The TEEB evaluation Framework is a structured approach to understanding, valuing, and managing ecosystem services. It provides a systematic process for assessing how ecosystems contribute to human well-being and how different policies and decisions impact these contributions (Figure 3.1).

It starts with recognizing the ecosystem services, such as food production, climate regulation, cultural value, and more. Demonstrating the value of these services involves quantifying their economic, social, and environmental worth, often in monetary terms, to highlight their significance. Capturing the value means incorporating these valuations into public policies, corporate decision-making, and local planning processes. Finally, assessing the impacts of policy options ensures that the chosen strategies optimize the benefits for both ecosystems and human well-being, guiding sustainable development.

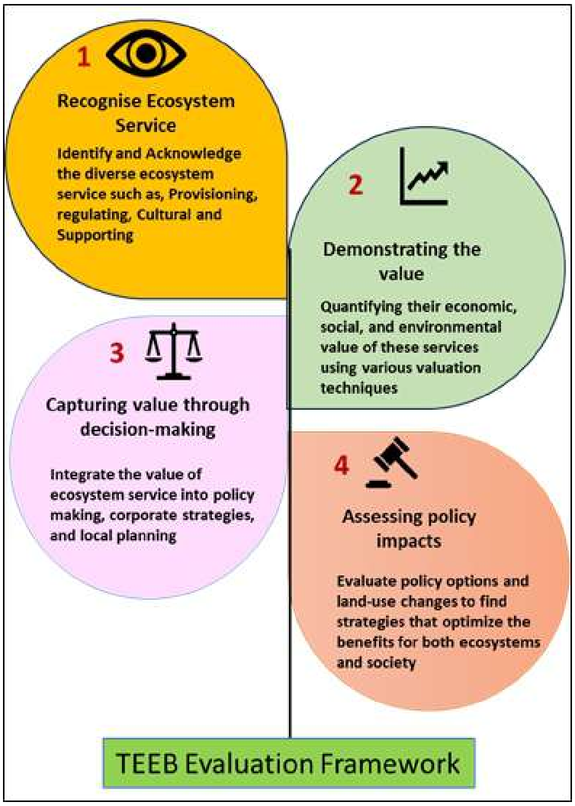


Figure 3.1. Structure and objective of TEEB evaluation framework

The TEEB, Promoting Sustainable Agriculture and Food Sector' (TEEB Agri Food initiatives) aim to protect the ecosystem and valuing the invisible services of agriculture in partner countries (Brazil, China, India, Indonesia, Malaysia, Mexico, and Thailand), testing of agricultural interventions, policies and schemes, which have already been applied by the government, that claim to stimulate positive livelihood and biodiversity benefits, and assess their hidden or unaccounted outcomes on natural, produced, social, and human capitals (UNEP, 2024).

The framework has proven beneficial in the Indian agricultural context by emphasizing the economic value of ecosystem services, thereby promoting sustainable agricultural practices and biodiversity conservation.

3.1 Four Capitals in Agriculture Ecosystem Services

TEEB defines the "Four Capitals" in the context of agricultural ecosystem services as essential stocks of resources that support and sustain the production of ecosystem services.

In the context of agriculture and ecosystem services, the concept of the four capitals refers to the different types of resources or assets that support the sustainability and productivity of ecosystems and agriculture. These four types of capital are natural, human, social, and human. They form the foundation for ecosystem services, and their interaction plays a crucial role in maintaining a balanced agricultural system.

1. **Natural Capital:** Refers to the natural resources and processes that ecosystems provide, such as soil fertility, water, biodiversity, and ecosystem functions like pollination and nutrient cycling. It forms the foundation of agricultural productivity.
2. **Produced Capital:** Produced capital consists of physical assets generated by applying human productive activities to natural capital and capable of providing a flow of goods or services.
3. **Human Capital:** Human capital refers to the productive capacities of an individual, both inherited and acquired through education and training. It involves the skills, knowledge, labor, and health of people involved in agriculture. Human capital influences the ability to manage ecosystems sustainably and utilize natural resources effectively.
4. **Social Capital:** Social capital refers to the relationships, networks, institutions, and social norms that facilitate collaboration and cooperation in agricultural communities. It includes the governance structures, trust, and social cohesion that help manage shared resources.

The main objective of this evaluation framework is to mainstream the values of biodiversity and ecosystem services into decision-making at all levels (Figure 3.2).

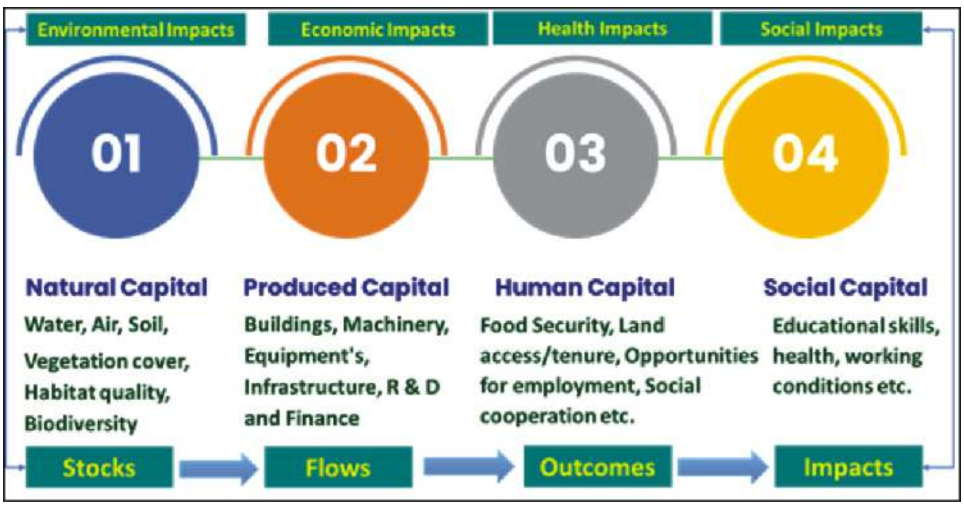


Figure 3.2. Capitals, their flow and impact as per TEEB evaluation framework.

2.3 Relevance in Indian Agriculture

Evaluation framework is highly relevant to Indian agriculture as it emphasizes the economic value of ecosystem services, promoting sustainable farming practices that enhance biodiversity and natural resources. By quantifying benefits such as soil health, water retention, and carbon sequestration, framework encourages the integration of traditional and eco-friendly farming methods like organic and agroforestry practices. This framework supports policy reforms aimed at incentivizing sustainable agriculture, improving rural livelihoods, and fostering climate resilience, making it crucial for addressing challenges such as land degradation, water scarcity, and biodiversity loss in India's agricultural sector (Figure 3.3).

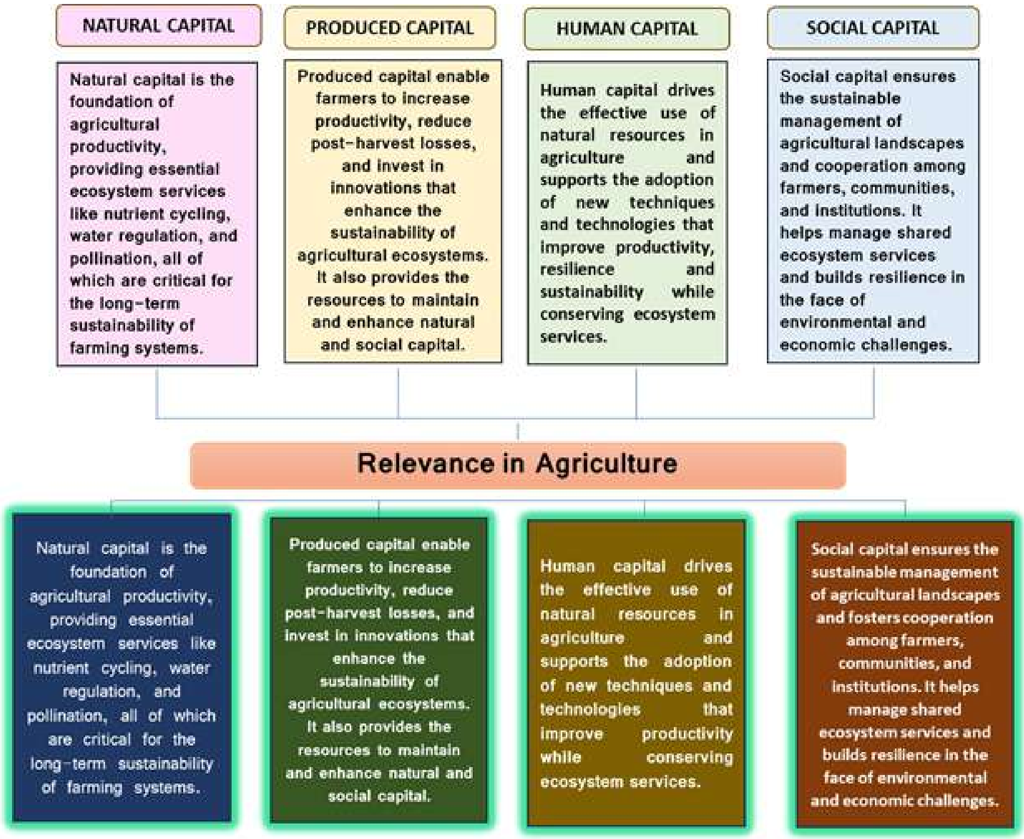


Figure 3.3. Relevance of four capitals in Indian Agriculture

NATURAL CAPITAL

Natural capital in an agricultural ecosystem refers to the resources and benefits provided by nature that contribute to farming. This includes soil, water, air, biodiversity, and ecosystems that contribute to the sustainability and productivity of farming. These natural assets support various ecosystem services such as nutrient cycling, pest control, water purification, pollination, and carbon sequestration, which are vital for crop growth and livestock health (Smith, 2021). NPF practices contribute to the preservation and enhancement of natural capital by employing practices that minimize soil disturbance, avoid synthetic inputs, and promote biodiversity (Altieri, 2019). These approaches help maintain soil fertility, improve water retention, and support ecosystem resilience, thus sustaining the long-term productivity of agricultural systems (IFOAM, 2018). Sustainable management of natural capital is crucial to ensuring the provision of ecosystem services that support farm sustainability and resilience against environmental stress.

4.1 Indicators and Assessment of Natural Capital

Indicators of natural capital in agriculture usually revolve around soil health, biodiversity, and water quality. Organic and natural farming view natural capital as both an asset and a partner in creating sustainable, resilient agricultural systems. Indicators of Natural Capital in organic farming and natural farming systems includes the essential natural resources and ecosystem functions that support agricultural productivity and sustainability.

4.1.1 Soil Health

Organic matter content, soil fertility, and microbial activity are vital indicators. Higher organic matter and biological activity indicate better nutrient cycling and soil structure (Pimentel et al., 2005). Under NPF practices such as composting, mulching, and crop rotation are used to maintain or enhance soil fertility, structure, and biological activity (Altieri, 2019).

Indicators	Quantification/ Assessment Method	Tools/ Softwares
Soil organic matter	Laboratory tests measure the organic content in the soil, indicating fertility and biological activity.	Walkley and Black method, dry combustion or loss-on-ignition are most popular among various techniques. Portable soil test kits - on-site analysis
Microbial activity assays	Soil respiration tests (Quantify the amount of CO_2 released by soil microorganisms, indicating biological activity).	Phospholipid fatty acid (PLFA) analysis. Detailed protocols can be found in Quideau et al. (2016).
Nutrient analysis	Soil Sampling, Chemical Extraction Methods, Spectroscopy, Electrochemical Methods, Microwave-Assisted Digestion, X-Ray Fluorescence (XRF)	Olsen P (P extraction). Morgan's Solution (P, K extraction), Ammonium Acetate Extraction (exchangeable Ca, Mg, K), EC & pH meter, Optical sensing is also becoming popular technique used to measure soil macronutrients, micronutrients by using AAS (atomic absorption sepctrophotometer)

Sediment runoff/loss	Runoff Plots, Sediment Traps, Silt Fences, turbidity measurement	Universal Soil Loss Equation (USLE) and Revised Universal Soil Loss Equation (RUSLE), SWAT, HEC-HMS, CCHE2D or SRH-2D

4.1.2 Water Resources

Sustainable water management practices aim to improve water retention in soils, reduce runoff, and maintain water quality by minimizing synthetic inputs that could lead to contamination (IFOAM, 2018). Indicators such as reduced nutrient runoff, increased water infiltration, and improved water-holding capacity reflect sustainable water management (IFOAM, 2018).

Indicators	Quantification/ Assessment Method	Tools/ Softwares
Water infiltration tests	Field tests measure how quickly water penetrates the soil, indicating soil structure and water retention.	Single Ring Infiltrometer, Double-ring infiltrometers, Guelph Permeameter, Tension Infiltrometer
Nutrient runoff testing	Analyzing water samples for nitrogen and phosphorus concentrations to assess nutrient leaching risks.	SWAT, MODFLOW, Nutrient Management Planner (NMP), etc.
Moisture content measurement	Using sensors or probes to measure the water content in the soil	Soil Moisture Sensors e.g., Capacitance sensors (Affordable but can be inaccurate in high salinity soils). Time-domain reflectometry (TDR) sensors, Electromagnetic sensors. Suction based sensors (Tensiometers and gypsum blocks)
Water runoff modelling	Hydrological Models, Curve Number Method, SCS-CN Runoff Equation, Water Balance Approach, Field Measurements and statistical analysis.	InVEST (Integrated Valuation of Ecosystem Services and Trade-offs), Soil and Water Assessment Tool (SWAT), SWAT-CUP, MODFLOW, HEC-HMS

4.1.3 Biodiversity

NPF practices encourage diverse crop rotations, intercropping, and habitat conservation, which support beneficial organisms such as pollinators, soil microbes, and natural predators of pests (Pimentel et al., 2005). The presence and diversity of pollinators like bees are indicators of a healthy ecosystem that supports natural capital (Garibaldi et al., 2013).

Indicators	Quantification/ Assessment Method	Tools/ Softwares
Species inventories	Surveys and sampling to count the number of species (e.g., plants, insects, and soil organisms).	Quadrat sampling, Pitfall traps, sweep nets
Ecological indices	Indicators such as the Shannon or Simpson diversity index quantify the biodiversity in a given ecosystem	R Programming (Packages such as vegan and Biodiversity R), PAST (Paleontological Statistics), Microsoft Excel, Estimate S, Species Diversity, Richness (SDR), etc.

Habitat quality assessment	Evaluating the presence of natural habitats like hedgerows and cover crops that support biodiversity.	Remote sensing and GIS tools, InVEST, eDNA Metabarcoding Tools integrated with Geoinformatics tools.
Pollination Services assessment	Pollinator surveys, floral resource monitoring, correlation between pollinator activity and fruit set or seed production.	Observations and counts of pollinators. Assessing the relationship between pollinator activity and crop yield helps quantify the economic value of pollination services

Biodiversity measure at the level of species or populations are directed towards the attainment of an index of the number of species and their relative abundances within a given landscape. Biodiversity can be measured in different ways as given below

1. Scales: Diversity can measure at different scales eg. Alpha, Beta, Gamma, etc.
2. Species richness: is the number of different species in a habitat. E.g. More number of species have richer the habitat.
3. Species evenness: refer the uniformity of abundance between species in a community.
4. Diversity: A diversity index is a mathematical measure of species diversity in a community.
   a) Simpson's Diversity index

      $D = 1\text{-}[\Sigma(n/N)^2]$

      n = no. of individuals of a particular species

      N = total no. of individuals of all species

      Σ means 'sum of' (added together)

      Range of DI= 0 to 1 (The closer value to 1 indicate higher in diversity (richness and evenness)

   b) Shannon-Weiner diversity index

      $$H' = -\sum_{i=1}^{S} Pi \ln pi$$

      H' = Shannon-Wiener index of species

      Pi is the proportion (n/N) of individuals of one particular species found (n) divided by the total number of individuals found (N)

      ln is the natural log

      Σ is the sum of the calculations

      S is the number of species.

   c) Margalef's index

   d) Menhinick's index

4.1.4 Carbon Storage and sequestration

The ability of soils and vegetation to store carbon serves as an indicator of climate regulation potential. Practices like composting and cover cropping in in NPF practices boost carbon storage

(Lal, 2004). Indicators such as reduced nutrient runoff, increased water infiltration, and improved water-holding capacity reflect sustainable water management.

Indicators	Quantification/ Assessment Method	Tools/softwares
Carbon storage modeling	Laboratory analysis of soil samples for organic carbon content provides insights into carbon storage (accounting of carbon in different pools i.e. above C, Below C, soil organic C and dead C) (refer research article Ansari et al., 2024)	InVEST (Integrated Valuation of Ecosystem Services and Trade-offs) CENTURY model, The Rothamsted Carbon Model (RothC)
Remote sensing and modeling	Satellite imagery and computer models estimate above-ground biomass and soil carbon levels.	Carbon Sequestration Potential Index (CSPI), Random Forest (RF) regression model (for above-ground carbon storage in forests)
Long-term monitoring plots	Repeated sampling over time to track changes in carbon stocks due to different farming practices.	Field survey and laboratory analysis.

4.1.5 Air Quality

By reducing or eliminating the use of synthetic chemicals, these farming practices minimize emissions of pollutants, contributing to cleaner air.

Indicators	Quantification/ Assessment Method	Tools/softwares
Volatile Organic Compounds (VOCs) & Ground-level Ozone (O_3, Nitrogen oxides (NO_X), CO_2 Ammonia (NH_4) and Sulfur Dioxide (SO_2) & PM 2.5.	Air sampling and analysis, Remote Sensing techniques, Gas Chromatography (GC), Particulate Matter Sampling	Continuous Emission Monitoring Systems (CEMS), AERMOD, CALPUFF, Agilent ChemStation, OpenChrom
Biological Indicators	Observing sensitive plant species, lichen etc.	-
Health Indicators	Number of health complaints related to respiratory issues	-

4.2 Valuation of Natural Capital

Valuation of natural capital in OF and NF involves estimating the economic value of natural resources and ecosystem services that contribute to human well-being and agricultural productivity. It can be categorized into economic, social, and environmental dimensions, each reflecting different aspects of its contribution to agricultural systems like organic farming and natural farming. Combining economic, social, and environmental valuations provides a comprehensive understanding of natural capital's true value, informing sustainable management practices and policy-making in agriculture. Here's how each type of valuation is approached:

4.2.1. Economic Valuation

- Natural capital's direct contributions, such as increased crop yields due to improved soil fertility or savings on irrigation from better water retention, can be valued using market prices. For instance, the cost savings from reduced chemical fertilizer use in organic farming can be calculated
- Cost of artificial substitutes needed to replace ecosystem to estimate the use of chemical fertilizers to replace natural soil fertility.
- Measures the contribution of natural capital (e.g., soil quality, pollination services, increased yields of pollinator-dependent crops)
- Monetary value of Ecosystem Services using models like InVEST tool (carbon sequestration, nutrient cycling can be estimated based on their contribution to mitigating climate change or maintaining soil health). A visualization of modeling carbon sequestration and its economic evaluation of Mirazapur district (UP) using InVEST is given in figure 4.1.

4.2.2. Social Valuation

- Cultural and heritage value (preserve traditional knowledge or cultural heritage, use of indigenous crop varieties.
- Improved human health and well-being (lower exposure to chemical pesticides, pesticide free food, clean air, avoided costs on health treatments).

4.2.3. Environmental Valuation

- Climate mitigation (assessment of Carbon Sequestration value, carbon credits, long-term benefits of reducing greenhouse gas emissions).
- Biodiversity and Ecosystem Resilience (valuation of ecosystems' ability to support diverse species, reduced cost of ecosystem restoration,).
- Enhanced soil health (Improvement in soil structure (aggregate stability), increased organic matter, and better nutrient cycling, leading to sustainable crop production and reduced soil erosion).
- Pollution Mitigation (assessing the benefits of reduced soil, air, and water).
- Water Quality Improvement (Reduction in water pollution from agricultural runoff, protecting aquatic ecosystems).

4.3 Limitations and Gaps in Measuring Natural Capital

Despite the significance of natural capital in NF and OF systems, numerous limitations and gaps in its measurement continue to impede a precise representation of natural capital. These gaps highlight the need for improved methodologies and more comprehensive data to accurately assess natural capital in sustainable farming systems.

- Limited availability of long-term, high-quality data specific to OF and NF practices makes it difficult to establish accurate baselines and monitor changes over time.
- The multifunctional nature of natural capital in OF and NF (e.g., soil fertility, biodiversity, water retention) involves complex interactions that are challenging to isolate and measure accurately.

- Non-Market Valuation Challenges: Many benefits provided by OF and NF, such as biodiversity enhancement and cultural values, lack direct market values, making economic valuation difficult and subjective.
- complicating the standardization of valuation methods due to Spatial and Temporal Variability across different regions and seasons.
- lack the specificity to account for the unique characteristics of organic and natural farming practices under existing models.
- Despite valuation efforts, incorporating the results into practical policy-making and farm management remains limited.
- Monetizing natural capital raises ethical concerns, as it may not fully capture the intrinsic or cultural value of nature associated with OF and NF practices.

4.4 Scoping for Solutions

Addressing the limitations and gaps in measuring natural capital within OF and NF systems required a multi-faceted approach. This includes enhancing data collection methodologies, developing context-specific valuation models, and leveraging technology for accurate assessments. Additionally, fostering collaboration among stakeholders and integrating natural capital considerations into agricultural policies will be vital in promoting sustainable practices and ensuring the resilience of farming systems. By adopting these strategies, the true value of natural capital can be effectively captured and utilized.

Improving Data Collection and Monitoring: Invest in long-term and high-quality data collection. Establish regional and farm-level databases for natural capital indicators.

Integrating Multi-Disciplinary Approaches: Combine ecological, economic, and social science methods to better capture the multifunctionality of natural capital.

Enhancing Non-Market Valuation Techniques: Refine techniques for valuing non-market benefits (e.g., cultural values, biodiversity) by using advanced approaches like choice experiments, deliberative valuation, or participatory methods that engage stakeholders in the valuation process.

Spatial and Temporal Adaptation: Implementing spatially explicit and dynamic models that account for regional variations and seasonal changes in natural capital will enhance the scalability and transferability of valuation approaches across diverse locations.

Strengthening Policy Integration: Facilitate the integration of natural capital valuation results into agricultural policy-making and farm management strategies by including valuation indicators in agricultural performance metrics and sustainability assessments.

Addressing Ethical and Cultural Dimensions: Incorporating ethical considerations and cultural perspectives in natural capital valuation, through participatory approaches that engage local communities, ensures the respect for intrinsic and non-monetary values associated with natural resources.

Fostering collaboration among stakeholders: It encourage the sharing of knowledge, resources, and best practices. Engaging farmers, researchers, policymakers, and local communities ensures more comprehensive and effective valuation outcomes.

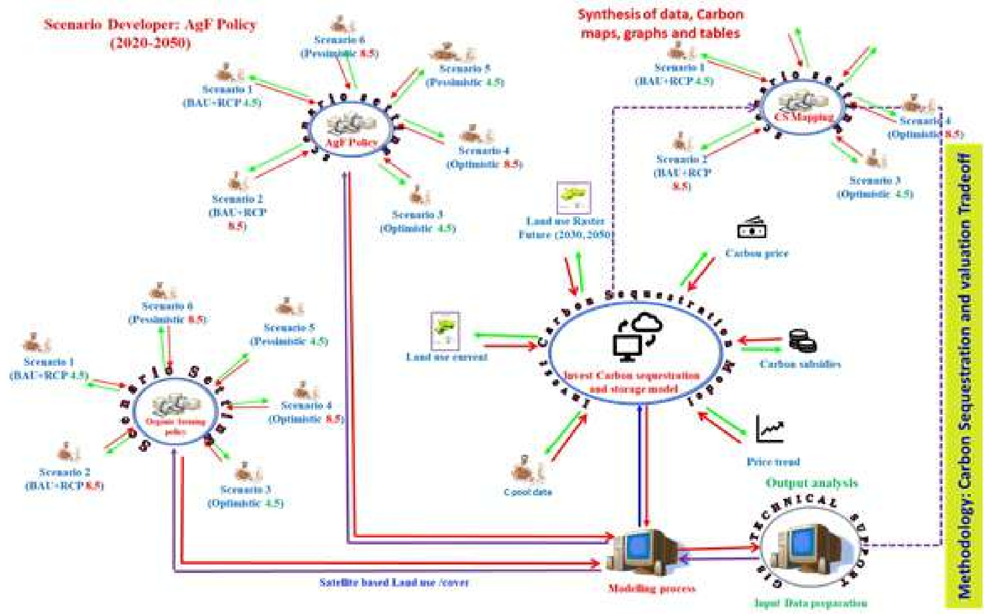
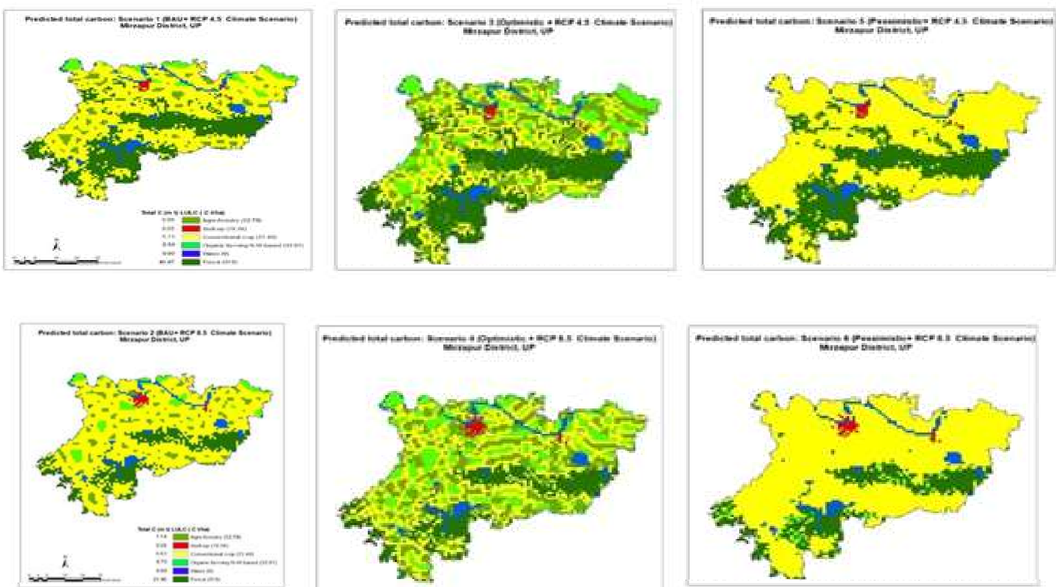


Fig. 4.1. Methodology for accounting of carbon sequestration and valuation tradeoff in organic and agroforestry systems (Ansari et al., 2024)



BaU scenario (RCP 4.5 and RCP 8.5) | Optimistic scenario (RCP 4.5 and RCP 8.5) | Pessimistic scenario (RCP 4.5 and RCP 8.5)

Figure 4.2. C sequestration Potential and its valuation under various land use and climatic scenario in Mirzapur district (UP). (Ansari et al., 2024)

PRODUCED CAPITAL

Produced capital in agriculture refers to the man-made assets and infrastructure used in agricultural production. It includes all man-made assets, such as buildings, factories, machinery, physical infrastructure (roads, water systems) as well as all financial assets. Human knowledge, often referred to as "intellectual capital," usually found embedded within produced capital, which includes technology, software, patents, brands, and other related assets. Unlike natural capital, which includes ecosystems and natural resources, produced capital is the result of human ingenuity and labor. It plays a significant role in economic development, especially when integrated with other forms of capital, such as human and natural capital, to sustain long-term growth.

5.1 Indicators for Quantification and Valuation of produced Capitals in Organic and Natural Farming

5.1.1 Infrastructure and Built Assets

Indicator	Quantification/ Assessment Method
Storage Facilities (Grain Silos, Cold Storage, Warehouses, etc.)	Asset Value Estimation, Depreciation Analysis, Cost-benefit (C-B analysis)
Transport infrastructure (Roads and Farm Access Routes)	Accessibility Index, Infrastructure Quality Surveys, Geospatial analysis, Transportation Cost Analysis, Cost-Benefit Analysis (CBA)
Energy Supply Systems (Electricity, Solar Panels, and Biogas)	Infrastructure Inventory, Energy Consumption Measurement, Energy Output Monitoring and cost saving, Carbon Emission Reduction Assessment
Composting Units, Manure Pits	Inventory Assessment (number, type, and capacity of composting units), Composting Efficiency Measurement, Output Quality Analysis, Impact on Soil Health and Crop Yield Nutrient Analysis (evaluate the potential fertilizer value)
Processing Facilities (Mills, Oil Presses, and Dairy Processing)	Inventory Assessment, Operational Efficiency Evaluation, Quality Assessment, Economic Impact Evaluation (C-B analysis, Value Addition Assessment)
Water Harvesting Structures (Check Dams, Ponds, Tanks, etc.)	Inventory and Capacity Assessment (Measure the number, type, and storage capacity). Water Availability and Usage Metrics. Impact analysis

Technology and Communication Infrastructure (Computers, GPS, Smartphones, drone, etc.)	Asset Value Estimation, Depreciation Analysis, Cost-benefit (C-B analysis) Impact Analysis (on Productivity and Efficiency)

5.1.2 Machinery and Equipment

Indicator	Quantification/ Assessment Method
Farm Machinery Usage (Tractors, plougs and Tillers, Seed Drills Planters, Combine etc.)	Asset Value Estimation, Depreciation Analysis, Cost-Benefit Analysis (CBA)
Organic Input Equipment (Compost Turners, Organic Fertilizer Makers), and Power Tools (Chainsaws, Trimmers, Power Tillers)	Inventory Assessment, Training and Adoption Rates, Asset Value Estimation, Depreciation Analysis,
Irrigation Facilities equipment's (Pumps, Drip Systems, Sprinklers, Canals)	Inventory Assessment (number, efficiency, working hour, fuel consumption etc.), Asset Value Estimation, Depreciation Analysis, Cost-Benefit Analysis (CBA)

5.1.3 Financial Capital & Technology

Indicator	Quantification/ Assessment Method
Investment levels	Financial Statements Analysis Return on Investment (ROI), Cost-Benefit Analysis (CBA), Risk Assessment and Portfolio Analysis
Availability of credit	Credit Scoring Models, Credit Distribution Analysis, Financial Surveys, Econometric Models
Insurance coverage	Coverage analysis (extent of insurance policies), Claim Settlement Rates, Assessing the cost of insurance premiums
Technology usage (Computers, GPS, Smartphones, Internet Access & drone use for smart farming)	Survey or census to estimate Technology Penetration Rate, Quantification of the extent of technology use in farm management Internet and Network Coverage Mapping, Impact Analysis (on Productivity and Efficiency)

5.2 Valuation of Produced Capital

Valuation of produced capital in NPF practices is essential for understanding the true contribution of these assets to sustainable agricultural development. It helps in quantifying the economic benefits, such as increased productivity and cost savings, while also considering social gains like improved livelihoods and environmental benefits such as reduced pollution and enhanced biodiversity. Accurate valuation informs investment decisions, policy formulation, and sustainable management practices, ensuring that agricultural systems optimize resource use while maintaining ecological balance (Boardman et al., 2017; Dasgupta, 2021). Valuation of produced capital involves quantifying its economic, social, and environmental contributions using various methods.

Economic Valuation: Economic valuation often uses market prices to estimate the value of produced capital. Approaches such as Net Present Value (NPV) and Cost-Benefit Analysis (CBA) are applied to assess investments in agricultural infrastructure or machinery (Boardman et al., 2017).

Social Valuation: This encompasses the broader social benefits associated with produced capital, such as job creation, food security, and improved living standards. Social Return on Investment (SROI) methods can quantify these impacts, providing a holistic view of agricultural investments (Nicholls et al., 2009). Assessing how much individuals are willing to pay for improvements in produced capital, also reflects its perceived social value (Nicholls et al., 2009).

Environmental Valuation: Produced capital may also be assessed for its environmental implications. For example, organic farming infrastructure that reduces pesticide use or promotes biodiversity has an added environmental value. Techniques like shadow pricing or ecosystem service valuation may be applied to capture these benefits (Costanza et al., 1997).

Combining these approaches provides a comprehensive valuation framework, integrating monetary and non-monetary factors to assess produced capital's overall impact.

5.3 Limitations and Gaps in Measuring Produced Capital

Despite the importance of measuring produced capital, several limitations exist:

1. **Data Limitations:** Inconsistent or incomplete data on the stock and quality of produced capital can hinder accurate measurement, particularly in rural or underdeveloped regions (Jorgenson & Griliches, 1967).
2. **Depreciation Estimation Challenges:** Estimating the depreciation rate accurately remains problematic, as it can vary significantly across different assets and environments (Poterba, 1997).
3. **Lack of Standardized Metrics:** There is often a lack of universally accepted metrics to measure the value and impact of natural and organic farming practices, making comparisons difficult.
4. **Technological Gaps:** Organic and natural farming may not always benefit from the latest technological advancements, which can affect the accuracy of produced capital measurements.
5. **Incorporating Non-Market Values:** While economic valuation can be straightforward, capturing the social and environmental benefits of produced capital in monetary terms remains challenging (Pearce, 1998).
6. **Market Access and Certification:** Limited market access and certification issues can hinder the financial assessment of organic and natural farming systems.
7. **Neglect of Intangible Assets:** Many measurement frameworks focus solely on tangible assets, often overlooking the role of intangible produced capital like software, patents, or specialized knowledge (Corrado et al., 2005).

5.4 Scope for Solutions

Addressing these limitations requires a combination of methodological improvements and policy interventions:

1. **Enhanced Data Collection:** Enhancing data collection methods and leveraging digital tools to gather comprehensive information on infrastructure, machinery, and technology in organic farming.
2. **Developing Standardized Metrics:** Creating universally accepted metrics for organic and natural farming to enable consistent and comparable assessments.
3. **Refined Depreciation Models:** Developing more sophisticated models that account for asset-specific and location-specific factors can improve depreciation estimates.
4. **Market Access and Certification:** Improving market access and simplifying certification processes for organic products to reflect their true economic value.
5. **Integration of Non-Market Valuation Techniques:** Employing advanced techniques such as Contingent Valuation or Choice Modeling can help capture the non-market benefits of produced capital.
6. **Inclusion of Intangible Assets in Measurement Frameworks:** Expanding measurement frameworks to incorporate intangible assets ensures a more comprehensive assessment of produced capital's role in economic and social development.

HUMAN CAPITAL

Human capital refers to the collective knowledge, skills, health, and abilities of individuals that contribute to productivity and economic growth (Becker, 1964). Human capital in OF and NF systems encompasses both technical knowledge and skills related to sustainable farming, as these systems heavily rely on farmers' knowledge of agroecological processes (Pretty et al., 2011). Further, the physical and mental well-being of farmers and workers is also essential as it is directly linked to labor productivity, as poor health reduces efficiency and threatens the long-term viability of farms (Horrigan et al., 2002). Investments in education, training, healthcare services, and social support systems are essential for building and maintaining strong human capital, which in turn fosters farm sustainability and resilience in the face of climate change and market volatility (Altieri & Nicholls, 2005).

6.1. Indicators and Assessment of Human Capital in OF and NF

6.1.1. Education and Training Levels in Sustainable Agriculture

Indicator	Quantification/ Assessment Method
Participation in agricultural training programs	Attendance records of formal training programs, Farmer's survey (information on frequency and participation in formal/ informal peer-to-peer learning networks)
Technical knowledge in sustainable farming (Expertise in organic soil management, water conservation, crop rotation, pest control, climate-smart agricultural practices, etc.)	Knowledge assessment surveys, Practical field tests, Self-reported surveys
Experience in crop and livestock management	No. of years of experience in managing diverse crops/ livestock, Structured interviews, Farm performance records
Capacity to manage farm financials	Farmers' financial literacy (budgeting, planning, and record-keeping), Self-assessment surveys, Evaluations of financial practices (managing cash flow, accessing credit, etc.)
Market access and pricing	No. of market linkages, Frequency of market participation, Knowledge of pricing strategies, Market-based production adjustment
Peer-to-peer knowledge exchange and networking	Participation frequency in local farmer groups, forums, or cooperatives, Adoption of new practices shared
Access to agricultural extension (Awareness of govt. programs and subsidies, crop insurance, etc.)	Frequency of contact with extension agents, Usefulness of the information received, Knowledge of govt. initiatives and subsidies

6.1.2. Health and Well-being of Farmers and Workers

Indicator	Quantification/ Assessment Method
Nutritional status	Household surveys for assessing dietary diversity, potential energy availability and dietary energy returns (Ansari et al., 2023) Data on food consumption, Assess to nutritious food, Body mass index (BMI)
Physical health	Health surveys focused on chronic illness prevalence, injury reports, and absenteeism, Data from local health services such as medical check-up records
Mental health and stress levels	Psychological well-being surveys or interviews, Self-reported stress levels, anxiety, or depression scales, Perceived Stress Scale (PSS), Beck Anxiety Inventory (BAI), Beck Depression Inventory BDI), etc., Happiness Index
Access to healthcare services	Proximity of healthcare facilities, Frequency of visits, Ease of access to medical services, Access to emergency health services
Occupational safety and health practices	Observations of safety practices on farms, Availability and use of protective gear, Safety training attendance records, Workplace injury reports
Rest and recovery periods	Self-reported surveys on working hours, no. of rest days, recovery period, etc., during high labor seasons
Insurance coverage	Percentage of farmers covered by health insurance, Type of insurance, Extent of coverage

6.1.3. Labor Productivity and the Ability to Adapt to Changing Agricultural Practices

Indicator	Quantification/ Assessment Method
Labor productivity	Crop yield per labor hour, Farm income per labor unit, Total output compared to input, Financial metrics for gauging productivity such as income generated per season, etc.
Adaptability to changing practices	Rate of adoption of new sustainable practices including climate-smart agriculture, organic certification, etc., Surveys or field data on the implementation of adaptive practices

6.2. Valuation of Human Capital

Valuation of human capital in OF and NF systems is essential for understanding its contribution to farm productivity, sustainability & resilience, and encompasses both direct and indirect benefits, including increased farm profitability, enhanced community resilience, and long-term environmental sustainability. The valuation process can be approached through several methods.

6.2.1. Economic Valuation

- Increased productivity and income (Assessing how education, training, and health improvements lead to higher crop yields and greater farm income; Can be measured through economic returns on training investments),
- Cost savings from reduced external inputs (Savings on these inputs, due to the expertise of farmers in managing natural resources more efficiently, can be valued in monetary terms by calculating the cost savings per hectare)

6.2.2. Social Valuation

- Enhanced community resilience and well-being (Lower healthcare costs, improved quality of life, and contribution to community resilience and social well-being),
- Intergenerational knowledge transfer (Role of mentorship, training programs, and peer-to-peer knowledge exchange in sustaining farming systems)

6.2.3. Environmental Valuation

- Reduction in environmental impact (Contribution to environmental sustainability, lower GHG emissions, improved water quality, and environmental benefits per hectare of land),
- Climate resilience (Valued in terms of carbon credits, carbon offset programs, and reduced environmental restoration costs)

6.3. Limitations and Gaps in Measuring Human Capital

Despite the importance of human capital in NPF practices, several limitations and gaps in its measurement persist hindering the accurate depiction of human capital's impact on farm productivity and sustainability:

- Lack of comprehensive data on smallholder farmers (particularly in developing countries),
- Difficulty in quantifying non-monetary aspects of human capital (qualitative methods that do not always align with conventional economic metrics),
- Underrepresentation of women and marginalized groups (Gender disparities in access to training, education, etc., often overlooks the contribution from women/ marginalized communities),
- Considerable variation in how human capital is measured across different regions and contexts,
- Limited focus on the long-term impact of training and education,
- Challenges in assessing health and well-being (Health data are often self-reported, making them subject to bias)

6.4. Scoping for Solutions

Addressing the limitations and gaps in measuring human capital within NPF practices requires a comprehensive approach. Solutions must focus on improving data collection, ensuring inclusivity, and using innovative tools and methods to capture the true value of human capital.

- Improving data collection on training, education, and health (Robust and standardized data collection methods; Expanding longitudinal studies),
- Incorporating qualitative assessments,
- Promoting inclusion of marginalized groups (creating training and education programs tailored to the specific needs of women and marginalized farmers),
- Standardizing human capital measurement across regions (establishing international benchmarks or guidelines that countries and regions can modify to their specific contexts while maintaining core indicators),
- Leveraging technology and innovation (Inclusion of remote sensing, AI-driven analytics, blockchain technology, etc., to track farmers' productivity, skills acquisition, and environmental impacts in real-time; Allowing for easy data sharing between farmers, researchers, and policymakers via digital platforms),
- Strengthening local institutions for capacity-building such as agricultural cooperatives, farmer's associations, self-reliant cooperatives, etc.

SOCIAL CAPITAL

Social capital refers to the networks, relationships, and shared values that enable individuals and communities to cooperate for mutual benefit (Putnam, 1995). It encompasses the collective resources available through community cooperation, social networks, and cultural heritage, which contribute to the well-being and productivity of farming systems (Woolcock and Narayan, 2000). The communal approach embedded in OF and NF systems fosters trust and collaboration building social capital through community-driven activities like farmer cooperatives, shared infrastructure, and group decision-making processes (Beck and Nesmith, 2001). Mutual support networks provide labor exchange, emergency assistance, and shared access to natural resources, helping farmers navigate challenges such as CC, market fluctuations, and resource shortages (Adger, 2003).

7.1. Indicators and Assessment of Social Capital in OF and NF:

7.1.1. Community Cooperation

Indicator	Quantification/ Assessment Method
Participation in Farmer Cooperatives and Associations	Membership percentage in cooperatives/ associations, Survey-based data collection, Cooperative membership records
Group-based Farming Activities	Frequency of participation in shared farming tasks (e.g., shared labor, equipment, etc.), Farmer surveys and interviews, Community activity records
Joint Investment in Infrastructure	Total monetary value/ time invested in communal infrastructure, Community records, Interviews with cooperative leaders
Participation in Community-led Development Projects	No. of farmers involved, Project participation records, Farmer surveys
Collective Decision-Making Processes	Frequency and inclusiveness of community decisions, Meeting attendance records, Interviews and surveys
Mutual Support Networks	No. of mutual assistance exchanges (e.g., labor, tools, etc.), Farmer self-reporting via surveys, Direct observations
Level of Trust Among Community Members	Trust scores based on farmer perceptions of fellow community members, Trust surveys using Likert-scale questions, Social Trust Scale (STS)
Participation in Community Savings and Loan Groups	Membership in savings/loan groups, Value of savings or loans accessed, Group records, Farmer surveys

Shared Access to Natural Resources	Frequency of use and management of shared resources, Survey data on resource use, Community resource management records
Frequency of Community Meetings and Farmer-to-Farmer Exchanges	No. of meetings, Exchanges per season, Attendance records, Surveys
Joint Marketing Initiatives	Volume of produce sold through joint marketing initiatives, Market records, Cooperative sales data
Conflict Resolution Mechanisms	No. of conflicts resolved, Survey data, Community records
Community-driven Research and Innovation	No. of community-led research projects, Research project reports, Interviews with participants
Civic Engagement and Advocacy for Agricultural Policies	No. of farmers involved in policy advocacy, Participation records from advocacy groups, Surveys

7.1.2. Social Network

Indicator	Quantification/ Assessment Method
Network Size	Number of social connections within and outside the farming community, Social network analysis (SNA)
Strength of Social Ties	Frequency and quality of interactions, Likert-scale surveys, SNA
Diversity of Social Networks	Range of social roles and diversity of connections (e.g., with NGOs, and government agencies) SNA, Survey data
Mutual Assistance and Reciprocity	No. of reciprocal exchanges (e.g., labor, tools, etc.), Farmer surveys, SNA
Influence and Leadership	No. of farmers recognized as community leaders, SNA, farmer surveys
Collaboration with External Stakeholders	No. and frequency of interactions with external entities, Survey data, Stakeholder engagement records

Participation rates of marginalized groups (e.g., women, minorities, etc.)	Survey data, Attendance records from community meetings
Conflict Resolution and Mediation within Social Networks	Number of conflicts resolved through the network, Survey data, Community records
Frequency of Social Gatherings	Number of social events or gatherings per season, Attendance records and surveys
Access to Resources through Networks	Frequency of resource sharing (e.g., seeds, tools, farm machinery, etc.), Farmer surveys, SNA

7.1.3. Cultural Heritage

Indicator	Quantification/ Assessment Method
Traditional Farming Practices	Percentage of farmers maintaining traditional practices, Survey data, Field observations
Cultural Festivals and Rituals Related to Agriculture	Number of agricultural festivals or rituals held per year, Community event records, Surveys
Intergenerational Knowledge Transfer	Percentage of farmers who engage in knowledge transfer activities with younger generations, Survey data, Interviews
Cultural Landscape Management	Area of cultural landscapes actively managed and preserved, GIS mapping, Field surveys
Culinary Traditions Linked to Agriculture	Frequency of traditional food preparation using local ingredients, Survey data, Interviews with farmers and community members
Cultural Artifacts and Structures Related to Farming	Number of cultural artifacts and structures preserved, Survey data, Field documentation
Rituals for Seed Saving and Planting Cycles	Frequency of participation in seed-saving rituals and planting cycles, Survey data, Field observations

7.2. Modes of Valuation

Valuing social capital in the context of OF and NF requires a multidimensional approach that captures both tangible and intangible benefits. The primary valuation methods focus on both qualitative and quantitative indices, incorporating community-driven assessments, economic proxies, and participatory methods.

7.2.1. Economic Valuation Method

Economic methods focus on assigning monetary value. In OF and NF systems, economic valuation may involve calculating the financial savings derived from cooperative efforts (Beck and Nesmith, 2001). Collective efforts on irrigation management, marketing, etc., can reduce costs significantly and can be quantified via Cost-Benefit Analysis. Similarly, contingent valuation may be used which surveys farmers based on their willingness to pay (WTP) or accept compensation for maintaining social capital-based arrangements such as community seed banks, shared farming tools, etc. (Lopez et al., 2010).

7.2.2. Social Network Analysis (SNA)

SNA is typically employed for assessing the strength and scope of social networks in NF and OF communities. By mapping relationships among farmers, cooperatives, and institutions, it helps identify key players, the density of networks, and the flow of resources and knowledge. This method also helps to measure trust and reciprocity within networks, which are critical for the success of OF/NF systems. Key matrices used in this approach are network density (No. of direct connections in a network relative to the total possible connections), centrality score (Identifies key actors within a network), and reciprocity rate (measures mutual exchanges within the network).

7.2.3. Participatory Rural Appraisal (PRA)

This approach allows the farmers to share and assess their social capital through group discussions, ranking exercises, and visual mapping. In the context of NF and OF, PRA allows farmers to identify communal resources and assess their shared values and collective practices (Chambers, 1994). The key matrices include community scoring on cooperation and trust levels, ranking of collective practices, etc.

7.2.4. Proxy-Based Valuation

Typically employed when direct valuation is challenging. E.g., the time spent in community activities, such as organic certification workshops, cooperative meetings, etc., can be used as a proxy for the strength of social capital. Additionally, the number of community-led projects may serve as an indicator of the community's investment in social networks and collective identity.

7.2.5. Cultural Valuation

In NF and OF, cultural valuation methods capture the importance of traditional farming practices, rituals, and intergenerational knowledge transfer. Narrative inquiry and ethnographic studies can be used to document the role of social capital in preserving cultural identity. For instance, festivals related to planting or harvesting seasons may not have a direct economic value but are crucial for fostering community solidarity and trust (Agrawal, 2001).

7.3. Gaps and Limitations

Despite its significance, the assessment of social capital in the context of NF and OF presents several challenges. These limitations can arise from methodological constraints, the complexity of social networks, and the difficulty in quantifying intangible benefits such as trust, cooperation, and cultural heritage. Key limitations are:

- Lack of standardized metrics (Assessing non-monetary elements of social capital—such as community trust and cultural practices—lacks universal metrics),

- Overemphasis on economic valuation (Often prioritizing economic proxies can undervalue the social and cultural dimensions of social capital overlooking essential non-tangible benefits),
- Difficulty in capturing long-term benefits (Trust and cooperation often build slowly over time, making it difficult to assess their full impact within short-term evaluation frameworks),
- Context-specific nature of social capital (Social capital is highly dependent on culture, governance, and social structures making it challenging to create a one-size-fits-all assessment framework),
- Invisibility of informal networks (Informal knowledge exchanges, barter systems, and reciprocity, remain invisible in formal assessments making it likely less to be captured in data collection),
- Limited access to participatory approaches (Applicability of the participatory methods is often limited due to resource constraints and the lack of capacity among facilitators),
- Gender and social inclusion gaps (Inadequate measurement of the gendered nature of social capital)

7.4. Potential Solutions

Overcoming challenges in assessing social capital in OF and NF systems requires improving metrics, fostering inclusivity, and enhancing participatory approaches. These include:

- Development of standardized social capital metrics and assessment toolkit (A set of context-specific indicators capturing both tangible and intangible benefits)
- Integration of social and cultural valuation into economic models (Expanding existing cost-benefit analyses to account for non-monetary benefits, such as the preservation of traditional farming practices or the strength of community networks via hybrid valuation models),
- Implement longitudinal studies in farming communities to track social capital over time, ensuring that long-term benefits are recognized and valued,
- Customize social capital assessment tools for each region or community, ensuring they align with local contexts,
- Expand the use of PRA and SNA to capture informal social capital, ensuring that hidden networks of cooperation and support are adequately valued,
- Promoting inclusivity in social capital assessments in the context of gender and minority inclusion

WAY FORWARD

The integration of ESS into agricultural systems has become increasingly vital for achieving long-term sustainability, especially in the face of CC impacts. OF and NF represent two pathways toward enhancing the provisioning, regulating, supporting, and cultural services that are offered by an ecosystem. This manual provides a comprehensive framework for quantifying and valuing these ecosystem services across NPF practices, emphasizing the need for reliable data, inclusive methodologies, and strong policy support. However, further efforts are required to refine these frameworks and address existing gaps. The following recommendations outline the way forward for advancing the quantification and valuation of ESS in the context of organic and natural farming.

8.1. Strengthening Data Collection and Standardization Efforts

A significant barrier to the effective quantification of ESS is the lack of standardized metrics and robust datasets, particularly in the context of OF and NF. The diversity of ecosystems, farming practices, and local contexts poses challenges in establishing uniform indicators for assessing natural, human, produced, and social capital. To overcome this limitation, there is an urgent need for enhanced data collection mechanisms that integrate scientific, local, and traditional knowledge systems. Global initiatives like the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) offer a starting point for the development of globally accepted indicators for ESS, which could be adapted to OF and NF systems (Díaz et al., 2018). In practical terms, farmer-driven data collection models, supported by mobile technologies and cloud-based platforms, could provide scalable solutions to monitor ecosystem services in real-time. Participatory approaches such as citizen science or community-based monitoring can empower farmers to contribute to the quantification of ESS, leading to more accurate and contextually relevant data. Building partnerships with research institutions and using open-access data platforms can facilitate broader adoption of these data collection efforts across various farming systems (Pretty, 2003).

8.2. Integrating Ecosystem Service Valuation into Policy and Decision-Making

The quantification and valuation of ESS must play a central role in shaping agricultural policies and decision-making processes. Policy frameworks such as TEEB provide a structured approach towards valuing ES (TEEB, 2010). These frameworks should be expanded to incorporate the specific dynamics of OF and NF. Integrating ESS valuation into public policy can create new financial incentives, such as payments for ecosystem services (PES), that reward farmers for sustainable practices and encourage ecosystem restoration efforts (FAO, 2011; NAAS, 2020). One such integration is the GCP of MOEFCC, GOI which aims to provide the PES in the form of 08 different 'Green Credits'. Further, the policies of the local and regional governments should be aligned with the UN SDGs and the country's NDCs. This shall ensure that the OF and NF would contribute to the broader objectives of climate resilience, biodiversity conservation, and food security (Shukla et al., 2019).

8.3. Promoting Inclusivity in Ecosystem Service Valuation

One of the critical gaps in current ESS valuation frameworks is the lack of inclusivity, particularly concerning the roles of marginalized communities and gender dynamics in OF and NF systems. Women, in particular, are often underrepresented in decision-making processes, despite their significant contributions to ecosystem management and knowledge sharing in smallholder farming systems (Meinzen-Dick et al., 2001). The future ESS valuation efforts must adopt a gender-sensitive approach along with the inclusion of indigenous and local communities who possess valuable knowledge of sustainable land management practices. A participatory valuation approach that involves stakeholders at all levels can create a more equitable and inclusive framework for ES assessment. Fostering inclusivity would assist in better reflection of diverse social, cultural, and environmental benefits provided by these systems.

8.4. Expanding Financial Mechanisms and Support for Ecosystem Service Enhancement

The financial sustainability of ESS enhancement in OF and NF requires innovative mechanisms that link environmental stewardship to tangible financial benefits. PES schemes, carbon credits, and green financing are potential avenues for incentivization (Jack et al., 2008). By linking farmers' contributions to carbon sequestration, biodiversity preservation, and water conservation to financial rewards, governments and private sector stakeholders can create new revenue streams that encourage sustainable agricultural practices. Expanding access to microfinance and impact investment funds specifically tailored for farmers engaged in ESS provision can also play a crucial role. These financial mechanisms should be accompanied by training programs and capacity-building efforts to ensure that farmers are equipped with ESS service enhancement.

8.5. Strengthening Research and Development for Ecosystem Service Innovation

Finally, the way forward for ESS quantification in OF and NF involves strengthening research and development to foster innovation in ecosystem service monitoring and sustainable farming practices. Interdisciplinary research collaborations, combining fields such as agroecology, economics, and social sciences, can provide new insights into the complex relationships between farming systems and ES. The development of innovative tools, such as remote sensing technologies, drones, and artificial intelligence, etc., can improve the precision and scalability of ESS monitoring in OF and NF systems (Kleemann et al., 2020). In addition, expanding research on the economic and social co-benefits of ecosystem service enhancement—such as improved rural livelihoods, food security, and climate resilience—will further support the case for integrating ESS into national and international agricultural strategies.

The quantification and valuation of ESS in natural and organic farming are essential for advancing sustainable agricultural practices, promoting biodiversity, and supporting resilient farming communities. By improving data collection, fostering inclusivity, linking financial mechanisms to ESS enhancement, and investing in research and innovation, stakeholders can unlock the full potential of OF and NF to deliver both environmental and socio-economic benefits. This manual serves as a guide for farmers, policymakers, and researchers to strengthen the role of ESS in shaping a sustainable future for agriculture.

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