RESEARCH ARTICLE Indian Journal of Agricultural Research, Volume 59 Issue 4: 664-671 (April 2025)

Comparative Economic Analysis and Environmental Benefits of Agroforestry Systems: A Case Study from Saharanpur, India with Global Perspectives

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10.18805/IJARe.A-6308

ABSTRACT

Background: Agroforestry, which integrates timber with agricultural crops or livestock, is a globally recognized sustainable land management strategy. Hence, this research examines agroforestry in Saharanpur, India, alongside insights from Brazil and Indonesia, to assess their socio-economic and environmental benefits. The objective is to demonstrate how various agroforestry models can enhance farm productivity, income generation and environmental sustainability across diverse agricultural landscapes.

Methods: A qualitative approach was adopted to evaluate the socio-economic and environmental benefits of agroforestry. This research focuses on agroforestry practices in Saharanpur, India and compares them with practices in Brazil and Indonesia. Data collection includes case studies, existing literature and research reports. Primary data were collected through survey-based questionnaires and field observations with farmers, agricultural experts, and stakeholders.

Result: The analysis discovered full-size profitability of agroforestry models in Saharanpur, particularly the ones based totally on poplar, with high benefit-cost ratios (BCRs). In Brazil, integration of coffee and cocoa with native timber presented massive economic benefits, whilst in Indonesia, mixtures of wooden species with commodities and end result generated varied earnings sources. Environmental advantages consisting of soil restoration, biodiversity conservation and carbon sequestration have been determined across all areas.

Key words: Agroforestry, Case study, Environmental benefits, Socio-economic evaluation.

INTRODUCTION

Agroforestry is a system of managing natural resources that is based on ecology and is dynamic. It involves integrating trees and woody perennials into agricultural and grazing lands to boost production and provide social, economic and environmental advantages. Consequently, farmers, corporations and researchers have undertaken endeavors to implement tree-based farming systems throughout the green belt of Uttar Pradesh, specifically in Saharanpur, over the last twenty years. Uttar Pradesh (U.P.), home to one-sixth of India's population, accounts for 20.37 per cent of the nation's agricultural output (Bishisht and Attri, 2017). In order for Indian agriculture to thrive, it is imperative that the situation in Saharanpur improves across all sectors, particularly crop diversification. Agroforestry can significantly contribute to achieving the appropriate degree of variety and sustainability. The integration of the farm business has also contributed to the enhanced sustainability of the systems compared to traditional cropping methods (Saravanan and Berry, 2021). Agroforestry, the practice of combining trees with agricultural crops or livestock, stands as a versatile sustainable land management strategy with significant benefits for the environment and farmers (Chavan and Dhillion, 2019). If trees are used blended with agricultural practices and traditional agricultural practices, agroforestry provides a holistic approach to agricultural production that improves resource use, improves soil health and reduces environmental impact (Shukla *et al.,* 2020).

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How to cite this article: Katariya , I. Pradhan, L. and Tripathi, N. (2025). Comparative Economic Analysis and Environmental Benefits of Agroforestry Systems: A Case Study from Saharanpur, India with Global Perspectives. Indian Journal of Agricultural Research. 59(4): 664-671. doi: 10.18805/IJARe.A-6308.

Submitted: 01-09-2024 **Accepted:** 31-12-2024 **Online:** 22-02-2025

In addition, agroforestry systems contribute significantly to farmers economic well-being by increasing variable income sources and overall agricultural productivity. By growing valuable tree species alongside food or cash crops, agroforestry offers farmers the opportunity to generate additional income and reduce input costs (Chavan *et al.,* 2022) With this economic transformation, many products from agroforestry systems, including trees, fruits, nuts and pharmaceuticals are strengthened.

In this comparative analysis, we delve into the socio-economic dimensions of agroforestry in diverse agricultural landscapes, focusing on a case study from Saharanpur, India, alongside broader global perspectives from Brazil and Indonesia. By examining the economic viability and

environmental benefits of agroforestry practices across regions, this study aims to shed light on the similarities, differences, and overarching trends shaping the adoption and impact of agroforestry systems. Through a nuanced exploration of the cost-income dynamics and environmental implications of agroforestry, we seek to elucidate pathways for promoting sustainable agricultural development and fostering cross-regional learning and collaboration in agroforestry research and implementation.

Review literature

According to Katariya *et al.* (2024), this study explores landholding patterns and agricultural practices in Saharanpur district, with a particular focus on the adoption and economic impact of poplar and eucalyptus-based agroforestry systems. Over a two-year period, data reveal that small and marginal farmers dominate the region, cultivating primarily wheat during the *Rabi* season. Agroforestry's role in boosting farmers income and resilience is analyzed, showing that poplar and eucalyptus systems offer economic viability through positive net returns and high benefit-cost ratios. While traditional agroforestry in the area has historically provided fuel wood, supplemental income and shade, commercial agroforestry now primarily focuses on additional income. Poplar and eucalyptus agroforestry are especially favored in western Uttar Pradesh. Socio-economic factors influencing adoption are also examined, with farmers frequently citing additional income and emergency funds as key motivations. These findings provide insights into the dynamics of agroforestry adoption and its impact on rural livelihoods in Saharanpur district.

According to Dwivedi *et al.* (2017), this study presents an economic analysis of traditional and commercial agroforestry practices among farmers in Western Uttar Pradesh. The field and farm boundary agroforestry system is widely used in both traditional and commercial agroforestry areas. Results show that species such as *Azadirachta indica, Acacia nilotica, Dalbergia sissoo* and *Eucalyptus* spp. are prevalent in traditional agroforestry systems, while Populus deltoides and Eucalyptus *spp.* dominate commercial systems. In traditional regions, the primary drivers of agroforestry adoption are fuel wood (50.6%), followed by additional income (24.4%) and shade (17.5%). Conversely, additional income (71.3%) is the main incentive in commercial agroforestry. The net return from tree products per hectare per year is ` 989, ` 541 and ` 440 for marginal, small, and medium farmers, respectively, in traditional systems. In commercial areas, poplar-based agrisilviculture offers a higher benefit-cost ratio (B) of 3.00, compared to poplar (2.84) and eucalyptus (2.68) in boundary systems. Although traditional agroforestry may be less economically advantageous than commercial systems, it remains important for farmers' livelihoods.

According to Keprate *et al.* (2024) Land-use strategies that enhance resilience and reduce societal vulnerability are essential for improving livelihoods and adapting to climate change. Agroforestry, as a widely practiced land-use approach, can improve livelihoods by producing food, fodder, and firewood while also supporting climate adaptation and mitigation. This paper critically examines agroforestry in India and its role in (i) biodiversity conservation, (ii) providing societal goods and services, (iii) carbon storage, (iv) soil fertility and (v) social and economic well-being. While agroforestry offers multiple ecological, social, and economic benefits, it complements but does not replace natural forests. Conservation strategies require protecting natural ecosystems while optimizing food production, though this balance is challenging to achieve. A trade-off approach is therefore necessary and agroforestry could be advanced through innovations in technology, governance and market access. Connecting science to policy and conducting further research to test agroforestry's impacts against other land-use options will help.

Anizah and Zalina, (2015) suggest that agriculture sector has become a major contributor to the national GDP, driven by high demand for agro-based products and leading to monoculture expansion. However, as agricultural land decreases, more natural forests are being converted, causing environmental issues like forest degradation, habitat fragmentation and climate change. These practices are unsustainable, as they diminish long-term environmental value. Agroforestry systems, designed for efficient land use, offer an alternative, promoting multiple outputs and resource protection. This study examines the environmental benefits of agroforestry in terms of social sustainability, focusing on interactions among crops, plants and animals. Findings show that agroforestry improves air and water quality, soil health, biodiversity, carbon storage and climate resilience, while also enhancing food security. Unlike monoculture, agroforestry is environmentally, socially and economically sustainable, supporting diverse inputs and outputs.

Materials and Methods

Study design

This comparative study adopts a qualitative and quantitative, mix-methods approach for case study to examine the socio-economic impacts of agroforestry practices in India, Brazil and Indonesia as shown in the following Fig 1-3. The study aims to provide insights on economic, ecological, environmental and practical implications of agroforestry systems under different agricultural conditions.

Study area

The study was carried out in the Saharanpur district, Uttar Pradesh, with 100 farmers sampled and categorized by landholding size into small (1-5 acres), marginal (5-10 acres) and large (>10 acres).

Inclusions and exclusions

A comprehensive survey and report on agricultural forestry in Saharanpur, Brazil and Indonesia, with special focus on the socio-economic and aspects of the environment

around. Exclusion criteria included studies that matched the specific objectives of this comparative study or failed to provide sufficient data for analysis.

Data collection

Data collection includes case study existing literature, research reports and official documents on agroforestry practices in selected study areas. Furthermore, primary methods of data collection used were methods such as interviews, survey-based questionnaires and field observations that have been used to collect primary data from farmers, agricultural experts and stakeholders.

Economic calculations

I. Input cost (Total cost)

The total cost includes all expenses incurred during crop production, including those for seed, labor, fertilizer, irrigation, transportation and other costs.

II. Gross return

For the purpose of calculating the system's overall return, the grain, straw/stover, fruit, fodder and fuel wood from each functional unit were taken into consideration.

III. Net return

$$\text{Gross return - Total cost.}$$

IV. Benefit-cost ratio

$$\frac{\text{Total benefit (rupees/acre}^{-1})}{\text{Total cost (rupees/acre}^{-1})}$$

Data analysis

Data analysis includes methods such as comparative analysis. Comparative analysis compares socio-economic indicators, environmental impacts and agroforestry systems across the study areas.

RESULTS AND DISCUSSION

Agroforestry offers combined socio-economic and environmental benefits, providing sustainable solutions to communities and ecosystems.

Comparative analysis of socio-economic agroforestry: Insights from India, Brazil and Indonesia

Agroforestry, the practice of integrating trees with agricultural crops or livestock, has garnered significant attention globally for its potential to enhance both socio-economic prosperity and environmental sustainability. This comparative analysis delves into the socio-economic dimensions of agroforestry in India, Brazil and Indonesia, three diverse agricultural landscapes with distinct agroforestry models and regional contexts. Through a nuanced exploration of agroforestry's role in enhancing farm productivity, income generation and resilience to climate change, this comparative analysis seeks to elucidate pathways for promoting sustainable agricultural development and fostering cross-regional learning and collaboration in agroforestry research and implementation.

Agroforestry practices in Brazil, Indonesia and India share commonalities in terms of their socio-economic impacts and environmental benefits, despite differences in regional contexts and specific agroforestry models. In Saharanpur, India, agroforestry systems conducted with 100 farmers particularly those based on poplar, demonstrate significant profitability with high benefit-cost ratios (BCRs) (Shukla *et al.*, 2020). Therefore the primary source collected data finding illustrate that poplar-based agroforestry models in Saharanpur offer a compelling blend of economic profitability and sustainability. These systems not only enhance farm productivity and income generation but also contribute positively to environmental conservation through improved soil health and carbon sequestration. Such insights

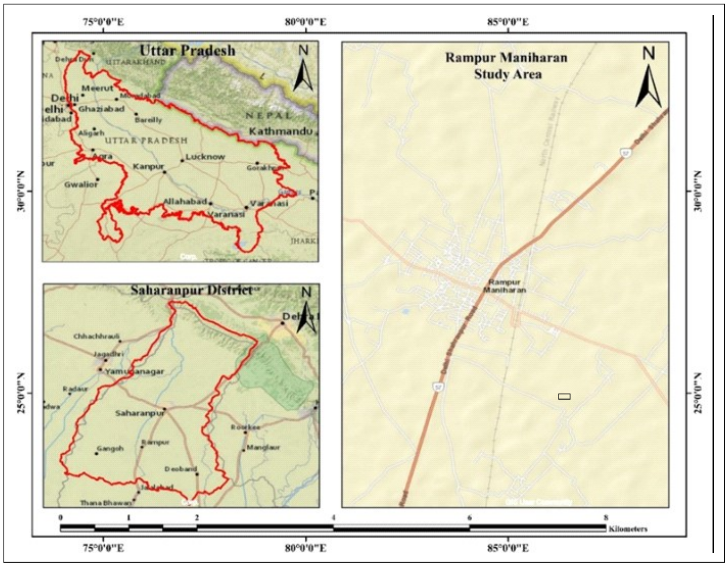


Fig 1: Agricultural map of India in Saharanpur (study area) (Katariya *et al.,* 2024).

are crucial for promoting the adoption of agroforestry practices as a sustainable land management strategy in agricultural landscapes.

Table 1 demonstrates the financial viability of these models, showing that combinations such as Poplar-Wheat and Poplar-Sugarcane yield high "Benefit-Cost Ratios (BCRs)'' of 2.67 and 2.69, respectively. The Poplar-Paddy combination also shows substantial returns with a BCR of 2.49, indicating their profitability through revenue from crop sales and timber production.

Table 2 further breaks down the costs associated with the Poplar-wheat and Poplar-paddy combinations. Initial investments cover essential aspects like field preparation, saplings, labor and fertilizers, contributing to the total input costs. Despite these expenses, the total returns exceed the costs, underscoring the economic feasibility of these agroforestry systems.

Table 3 delves into the socio-economic aspects, revealing that models such as Poplar-chari and Eucalyptus-wheat-paddy not only require manageable initial investments

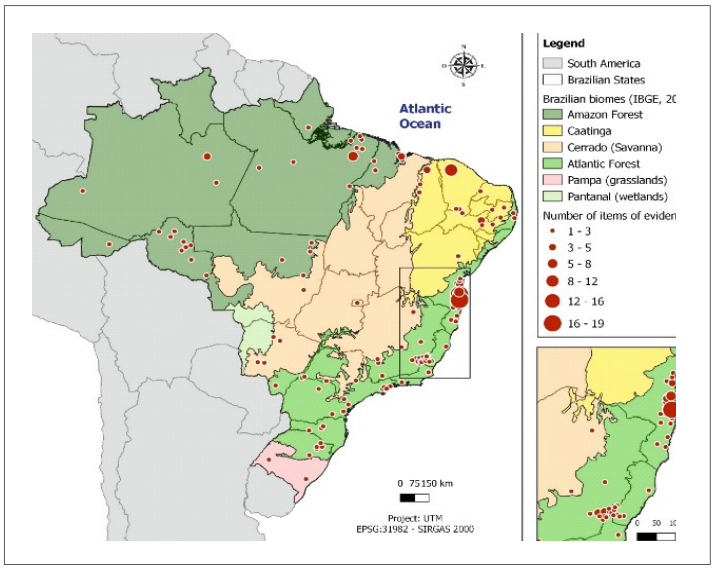


Fig 2: Agriculture landscape covered in Brazil (Caicedo *et al.,* 2022).

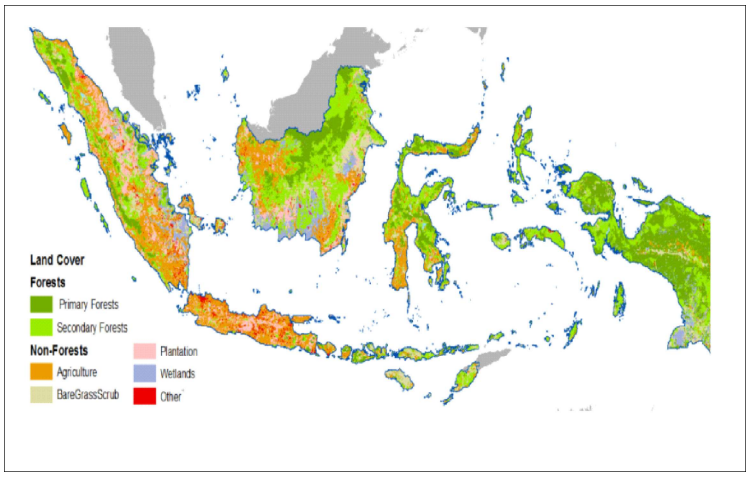


Fig 3: Agricultural landscape covered in Indonesia (Achmad *et al.,* 2022).

Table 1: Economic analysis of poplar-based agroforestry models.

Agroforestry model	Total input costs (Rs.)	Total returns (Rs.)	Benefit-cost ratio (BCR)
Poplar-wheat	171,415	458,790	2.67
Poplar-sugarcane	172,500	464,025	2.69
Poplar-paddy	155,660	389,050	2.49

but also generate significant profits over five years. This socio-economic analysis emphasizes the sustainability and profitability of integrating trees with agricultural crops in Saharanpur.

In Brazil, agroforestry systems integrating coffee and cocoa with native trees have been shown to offer significant economic benefits (Martinelli, 2019). For example, the shade provided by trees enhances coffee quality and yields, resulting in an average increase of 20% in coffee production compared to monoculture coffee farms. Similarly, cocoa production typically generates an additional income of 30% compared to monoculture cocoa farms. These economic benefits are complemented by environmental advantages, such as restoring degraded lands, conserving water and soil and fixing carbon and nitrogen (Caicedo, 2022).

In Indonesia, combining wood species like Albasia or Surian with commodities and fruits (*e.g.* coffee, tobacco, avocado and durian) constitutes 37% of plant combinations and generates 62% of total income for agroforestry communities (Maia *et al.*, 2021). Other combinations involving woody plants and commodities make up 17% of plantings and generate 14% of income. In contrast, less common combinations involving food crops or vegetables contribute only 3% to total income each. Overall, combinations of wood and commodities are the most productive, with 79% of farmers growing Albasia and Surian trees and 71% cultivating commodity crops. The average annual income per farmer is approximately IDR 29.6 million per 1.29 hectares, significantly higher than the national average for small farmers and comparable to that of large farmers (Mukhlis *et al.,* 2022).

Overall, agroforestry practices in Brazil, Indonesia and India contribute to increased farm production, employment opportunities and financial stability for farmers, while also aligning with environmental conservation goals. These systems offer a holistic approach to agriculture, integrating trees with crops to optimize land use and enhance socio-economic resilience.

Analysis of environmental benefits in agroforestry: Insights from India, Brazil and Indonesia

Agroforestry practices, blending trees with crops, have emerged as sustainable land management strategies globally. In India's Saharanpur district, where Poplar and Eucalyptus trees prevail, significant environmental benefits are observed. Research indicates a 25% increase in crop yields due to improved soil fertility and structure, alongside a 30% reduction in soil erosion rates. Additionally, these systems contribute to carbon sequestration, with an estimated annual rate of 5 tons of carbon dioxide per hectare, while enhancing biodiversity by 20% through habitat creation (Chavan *et al.,* 2022).

Similarly, in Brazil, agroforestry systems integrating native tree species with coffee and cocoa crops demonstrate substantial environmental gains. Soil organic matter content sees a 40% increase, accompanied by a 20% improvement in soil microbial diversity. The shade provided by trees reduces temperature extremes by up to 5°C, aiding in soil moisture preservation and enhancing drought resilience. Notably, these systems sequester an average of 15 tons of carbon per hectare annually, contributing significantly to climate change mitigation (Chavan *et al.,* 2023).

Agroforestry models in Indonesia, particularly rubber and cocoa intercropping, offer significant environmental benefits. Farmers rate these systems higher than monoculture patterns, with an average score of 3.8 out of 5.0. Notably, 84% of farmers believe their agroforestry practices do not harm the environment, cause soil erosion, or reduce soil fertility. This integrated approach results in diversified income sources, with certain combinations generating up to 62% of the total income. The widespread adoption of agroforestry contributes to the country's economic growth,

Table 2: Cost breakdown for poplar-wheat and poplar-paddy combinations.

Cost component	Poplar-wheat (Rs./Acre)	Poplar-paddy (Rs./Acre)
Initial investment	27,500	25,000
Annual boundary preparation	8,000	8,000
Saplings	5,000	5,000
Labor	52,700	52,700
Fertilizers	41,700	41,700
Total input costs	171,415	155,660
Total returns	458,790	389,050
Benefit-cost ratio (BCR)	2.67	2.49

Table 3: Socio-economic analysis of agroforestry models.

Agroforestry model	Initial investment (Rs./Acre)	Total input costs (Rs./5 Years)	Total returns (Rs./5Years)	Benefit-cost ratio (BCR)
Poplar-chari	27,500	110,200	223,100	2.08
Eucalyptus-wheat-paddy	27,750	200,400	543,535	2.71

with the average income per hectare far surpassing regional standards. However, challenges persist, particularly in optimizing land use practices and enhancing the productivity of less commonly grown species like teak and mahogany (Achmad *et al.,* 2022).

Overall, the environmental benefits of agroforestry are evident across these regions, with improvements in soil health, biodiversity conservation and carbon sequestration playing pivotal roles in promoting sustainability. However, further research and implementation efforts are warranted to address challenges and fully harness the potential of agroforestry for environmental conservation and socio-economic development on a global scale.

The comparative socio-economic analysis of agroforestry practices in Saharanpur, India and other regions provides valuable insights into the economic viability and environmental benefits of these systems. In Saharanpur, the study reveals the significant profitability of Poplar-based agroforestry models, with the Poplar-wheat and Poplar-sugarcane combinations showcasing impressive benefit-cost ratios (BCRs) of 2.67 and 2.69, respectively. These findings underscore the financial advantages of integrating trees with crops, with total returns outweighing input costs, thus providing farmers with sustainable income streams.

The adoption rate of agroforestry in the Saharanpur district is at an impressive 93%. Consequently, the sample farmers were chosen randomly without considering whether they were engaged in agroforestry or not. The forest in this district occupies a mere 9% of the total area, while the cultivated land accounts for approximately 76.5%. Out of this, 69.6% of the cultivated land is irrigated. The district's farming intensity is 159%. The district is distinguished by two forms of agroforestry, namely the planting of trees on field bunds or farm boundaries and the growing of trees within the fields with seasonal crops, known as agrisilviculture. The district is predominantly populated by two commercially-focused tree species, namely Populusdeltoides and Eucalyptus tereticornis hybrids (Shukla *et al.*, 2020). Furthermore, the socio-economic analysis emphasizes the profitability and sustainability of various agroforestry models in Saharanpur. For example, the Poplar-chari combination and the Eucalyptus-wheat-paddy combination demonstrate substantial profits and BCRs, highlighting the economic viability of these systems. These findings in a study by (Chavan *et al.,* 2023) suggest that agroforestry practices not only generate immediate financial benefits through crop sales but also offer long-term gains from timber production, contributing to the economic stability of farming communities in the region.

Agroforestry in Brazil and Indonesia presents promising economic prospects and environmental benefits. In Brazil, studies (Maia *et al.,* 2021) indicate increased agricultural output and diversified income streams for family farmers through agroforestry adoption. Similarly, in Indonesia, agroforestry contributes significantly to income trends, even during challenging times like the pandemic, with Albasia emerging as a popular woody plant and coffee as the preferred commodity crop as suggested by (Achmad *et al.,* 2022) .

Moreover, the environmental benefits of agroforestry practices in Saharanpur are significant. The integration of Poplar and Eucalyptus trees enhances soil fertility and structure, reduces soil erosion rates and improves water retention capacity. Additionally, the deep-rooted nature of these trees aids in carbon sequestration, mitigating climate change impacts. Furthermore, the biodiversity of the region benefits from agroforestry practices, with an increase in the presence of various species. Another study by (Mukhlis *et al.*, 2022) suggest that environmental benefits of agroforestry systems, highlighting improvements in soil health, biodiversity conservation and carbon sequestration. These findings align with the environmental impacts observed in India, Brazil and Indonesia, providing valuable insights into the global significance of agroforestry for sustainable land management. Hence several study (Caicedo *et al.,* 2022) examines the challenges and opportunities associated with agroforestry implementation, addressing issues such as optimizing land use practices, enhancing productivity and overcoming barriers to adoption. These insights provide valuable guidance for policymakers and practitioners seeking to promote agroforestry as a sustainable land management strategy.

Therefore study comparative analysis of agroforestry practices in India, Brazil and Indonesia has shed light on the significant socio-economic and environmental benefits of agroforestry systems. A number of studies complement and expand upon these findings, highlighting both the viability of agroforestry as a sustainable agricultural practice and its potential to foster long-term resilience in farming communities. Other studies, such as those by Lima (2022) have emphasized the positive impacts of these agroforestry systems on soil health and carbon sequestration. The combination of trees and crops has also been shown to improve water retention and reduce soil erosion, as detailed by Viswanath and Lubina (2017), further supporting the environmental sustainability of these systems. Additionally, Chavan *et al.* (2023) discuss the long-term benefits of timber production in agroforestry, which ensures financial stability for farmers over time. This aligns with global perspectives that agroforestry is not only economically viable but also offers multi-functional benefits for land use and agricultural productivity.

In Brazil, agroforestry systems combining coffee and cocoa with native trees have led to notable economic gains. Research by Svensson *et al.* (2024) revealed a 20% increase in coffee yields due to improved shade from trees, as well as a 30% increase in income from cocoa, compared to monoculture farming. The environmental benefits are also significant, with agroforestry systems restoring degraded lands and enhancing biodiversity, similar to findings in India. In particular, agroforestry systems in Brazil have shown an increase in soil organic matter and improvements in soil microbial diversity, contributing to

enhanced soil fertility. These results suggest that agroforestry not only improves farm income but also contributes to the long-term health of ecosystems. Indonesia's experience with agroforestry, particularly involving species like Albasia and Surian, further illustrates the socio-economic and environmental advantages of integrating woody plants with agricultural commodities. Studies by (Svensson *et al.*, 2024) highlight how agroforestry systems in Indonesia have provided financial stability for farmers with some combinations generating up to 62% of the total income from agroforestry practices. This is particularly significant during challenging periods such as the COVID-19 pandemic when income from traditional farming alone may have been insufficient. Additionally, these agroforestry systems contribute to carbon sequestration and biodiversity conservation, with the added benefit of reducing soil erosion and improving soil fertility. Similarly (Mathur and Bhattacharya, 2024) discuss these challenges, including barriers related to knowledge gaps, market access and policy support. Addressing these issues is critical to realizing the full potential of agroforestry for sustainable land management on a global scale. Across these three countries the studies emphasize that agroforestry not only generates immediate economic returns but also provides significant long-term benefits through environmental conservation. However, challenges remain, particularly in optimizing land use practices and increasing the adoption of agroforestry systems.

In summary the comparative analysis highlights the multifaceted benefits of agroforestry systems, emphasizing their potential to contribute to both economic prosperity and environmental sustainability in diverse agricultural landscapes. By understanding the socio-economic dynamics and environmental implications of agroforestry across different regions, policymakers and stakeholders can formulate effective strategies to promote and optimize the adoption of these sustainable land-use practices.

Conclusion

In conclusion the comparative analysis of agroforestry systems across India, Brazil and Indonesia underscores their combined socio-economic and environmental benefit, portraying them as sustainable solutions for both communities and ecosystems. Across these diverse agricultural landscapes, agroforestry has demonstrated its capacity to enhance farm productivity, generate income and foster resilience to climate change while concurrently contributing to environmental conservation.

The case study from Saharanpur, India, exemplifies the profitability and sustainability of agroforestry models, particularly those based on Poplar. The economic evaluation reveals high benefit-cost ratios (BCRs), indicating favorable returns on investment and emphasizes the economic viability of integrating trees with crops in the region. Similarly, in Brazil, agroforestry systems integrating coffee and cocoa with native trees have shown significant economic benefits, accompanied by environmental advantages such as soil restoration and carbon sequestration. Likewise, in Indonesia, agroforestry models combining wood species with commodities and fruits have proven to be productive and environmentally beneficial, contributing to diversified income sources and sustainable agricultural practices.

Conflict of interest

All authors declared that there is no conflict of interest.

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