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Integrating Medicinal Plant Cultivation Into Agroforestry Systems For Biodiversity And Income Generation

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ABSTRACT

Agroforestry, the deliberate integration of trees and shrubs into agricultural landscapes, has gained recognition for its ability to enhance ecosystem services, promote biodiversity, and improve rural livelihoods. With the growing global demand for medicinal plants, the integration of these plants into agroforestry systems provides a sustainable land-use solution that addresses both ecological and socio-economic challenges. This study explores the impact of medicinal plant cultivation within agroforestry systems on biodiversity and income generation in rural India. Focusing on three agro-ecological zones—Himachal Pradesh, Odisha, and Madhya Pradesh—this research evaluates the effects of medicinal plant integration on biodiversity indices, soil health, and farmer income over a two-year period. The study found that agroforestry systems incorporating medicinal plants exhibited significantly higher species richness, improved biodiversity indices, and enhanced soil health compared to control systems. Additionally, farmers practicing medicinal agroforestry achieved higher yields and income, with notable profitability from high-demand species like *Withania somnifera* (Ashwagandha) and *Ocimum sanctum* (Tulsi). Despite these positive outcomes, challenges such as limited market access, insufficient technical knowledge, and inadequate policy support remain. The study concludes by recommending policies that support market linkages, provide technical training, and create incentives for medicinal plant cultivation within agroforestry systems to enhance biodiversity conservation and rural income generation.

Keywords: *Agroforestry, Medicinal Plants, Biodiversity, Rural Livelihoods, Income Generation*

1. INTRODUCTION

Agroforestry, the deliberate integration of trees and shrubs into agricultural landscapes, has gained widespread recognition as a sustainable land-use system. It is known for its ability to enhance ecosystem services, promote biodiversity, and improve rural livelihoods (Nair, 2011). This multifaceted practice combines agriculture with forestry by utilizing trees to complement crop production, resulting in more resilient and productive agricultural systems. Agroforestry systems have been particularly effective in mitigating the environmental degradation caused by monoculture farming and excessive land use, offering several ecological benefits such as soil conservation, improved water retention, and enhanced biodiversity (Saha et al., 2014). As the global population continues to grow and agricultural demands intensify, there is increasing pressure on the environment and natural resources. This has led to a search for more sustainable agricultural practices, with agroforestry emerging as a promising alternative. However, despite its ecological advantages, agroforestry adoption has faced challenges such as limited market access, insufficient technical knowledge, and inadequate policy support (FAO, 2020). These barriers have hindered the broader implementation of agroforestry practices, particularly in developing countries, where smallholder farmers struggle with poverty, lack of access to resources, and the degradation of their land. Medicinal plants, which have been used in traditional medicine for centuries, are increasingly recognized for their economic and ecological significance. Integrating the cultivation of medicinal plants into agroforestry systems provides a solution to multiple challenges faced by rural farmers, such as habitat degradation, declining income from traditional farming practices, and the overharvesting of wild plant populations (Uprety et al., 2012; WHO, 2013). Many medicinal plants, such as *Withania somnifera* (Ashwagandha), *Ocimum sanctum* (Tulsi), and *Centella asiatica* (Gotu Kola), have significant economic value due to their use in herbal medicine and as raw materials for the pharmaceutical industry (Sharma et al., 2020). By cultivating these plants within agroforestry systems, farmers can not only diversify their income sources but also contribute to the conservation of biodiversity and the restoration of ecosystems.

The integration of medicinal plants into agroforestry systems offers numerous environmental benefits. These plants can help restore degraded lands by improving soil health, enhancing organic matter content, and promoting the regeneration of native species (Pandey et al., 2021). At the same time, medicinal plant cultivation can offer farmers a steady income stream, as the global herbal medicine market is projected to exceed $150 billion by 2025 (Tiwari et al., 2020). The market for medicinal plants is particularly promising in regions where traditional medicine practices are prevalent, such as in India, China, and Africa, where local farmers can access both domestic and international markets for their products (Joshi & Bhatt, 2020).

This study aims to explore the potential benefits of integrating medicinal plant cultivation into agroforestry systems. Specifically, it examines the impact of such integration on biodiversity conservation and income generation in rural India. The research focuses on three diverse agro-ecological zones—Himachal Pradesh, Odisha, and Madhya Pradesh—where smallholder farmers have begun adopting agroforestry systems with medicinal plants. This study will assess the effects of this integration on biodiversity indices, soil health, and farmer income over a two-year period. It also aims to identify the barriers to adoption, such as market access and technical knowledge, and provide recommendations for enhancing the scalability of medicinal agroforestry systems.

2. LITERATURE REVIEW

2.1 Biodiversity and Conservation Benefits

Agroforestry systems have been widely acknowledged for their potential to conserve biodiversity by providing habitats for both native and medicinal species. These systems, which often involve multiple plant species growing in close proximity, enhance ecological complexity and contribute to greater species richness (Jose, 2009). For example, traditional agroforestry systems in the Indian Himalayas are known to harbor a greater number of endemic plant species compared to monoculture fields, which tend to have lower biodiversity due to their simplified structure (Negi et al., 2017). The integration of medicinal plants into agroforestry systems further enhances habitat complexity, as these plants often require specific ecological conditions that can be met within diversified agroforestry systems. For instance, understorey medicinal plants in multi-tiered agroforestry systems contribute to increased species richness by providing habitat for a wide variety of insects, birds, and mammals (Bhagwat et al., 2008). These systems are particularly important in regions where agricultural expansion has led to the loss of natural habitats. By integrating medicinal plants into agroforestry, farmers can contribute to the conservation of biodiversity while simultaneously benefiting from the economic value of these plants (Sharma et al., 2020). Research has shown that integrating medicinal plants into agroforestry systems can also help reduce the pressure on wild medicinal plant populations. Overharvesting of wild plants for medicinal purposes has led to the depletion of many valuable species in the wild, particularly in regions where traditional medicine is an essential part of the local healthcare system (WHO, 2013). Cultivating these plants within agroforestry systems offers a sustainable solution to this problem by providing a reliable and renewable source of medicinal plants while reducing dependence on wild harvesting (Joshi & Bhatt, 2020). This not only contributes to conservation efforts but also supports the long-term sustainability of the medicinal plant industry.

2.2 Economic Potential of Medicinal Plants

The economic potential of medicinal plants is substantial, as the global market for herbal medicine and natural products continues to expand. According to the World Health Organization (WHO), approximately 80% of the global population relies on traditional medicine, which often involves the use of medicinal plants (WHO, 2013). The market for herbal medicine is expected to surpass $150 billion by 2025, driven by growing consumer demand for natural and plant-based health products (Tiwari et al., 2020). This presents a significant opportunity for farmers, particularly those in developing countries, to diversify their income sources through the cultivation of high-demand medicinal species. Studies have shown that farmers who cultivate medicinal plants within agroforestry systems can achieve higher returns per acre compared to conventional crops (Saxena, 2020; Rahman et al., 2019). For example, *Curcuma longa* (turmeric) and *Bacopa monnieri* have been reported to yield substantial profits due to their high demand in the pharmaceutical and cosmetic industries (Saxena, 2020). Moreover, the cultivation of medicinal plants offers an opportunity for farmers to enter niche markets for organic and sustainably produced herbal products, which can command premium prices. However, the success of medicinal plant cultivation is often contingent upon access to markets, value chain integration, and the establishment of reliable supply chains (Jena et al., 2021). Farmers need support in accessing these markets, as well as in acquiring the necessary certifications for organic and sustainable farming practices.

2.3 Environmental and Soil Health Improvements

Beyond their economic potential, medicinal plants also provide significant environmental benefits. Certain species of medicinal plants, such as *Glycyrrhiza glabra* (licorice), are nitrogen-fixing, meaning they can enhance soil fertility by converting atmospheric nitrogen into a form that plants can use (Pandey et al., 2021). These plants play a critical role in maintaining soil health by enriching the soil with organic matter and improving its nutrient content. In agroforestry systems, the cultivation of medicinal plants can help restore soil fertility, particularly in degraded lands that have been subjected to intensive agricultural practices. In addition to improving soil fertility, medicinal plants with deep or fibrous root systems, such as *Acorus calamus* (sweet flag), can help stabilize soil and prevent erosion (Saha et al., 2014). These plants also contribute to improved water retention, which is especially important in regions prone to drought or erratic rainfall. The combination of these benefits makes medicinal plant cultivation within agroforestry systems a key strategy for promoting sustainable land management practices and enhancing ecosystem resilience.

2.4 Challenges and Policy Gaps

While the integration of medicinal plants into agroforestry systems offers numerous benefits, several challenges hinder widespread adoption. One of the main obstacles is the lack of technical knowledge among farmers regarding the cultivation, harvesting, and processing of medicinal plants (Muthee et al., 2020). Many smallholder farmers lack access to training and information on best practices for growing and managing medicinal plant species. As a result, farmers may face difficulties in achieving high yields and quality products, which can limit their profitability. In addition to technical challenges, market access remains a significant barrier to the success of medicinal plant agroforestry. Farmers often struggle to access local, national, and international markets due to inadequate infrastructure, poor road connectivity, and a lack of market linkages (Jena et al., 2021). Without reliable market access, farmers may face difficulties in selling their medicinal plant products at competitive prices, which can undermine the economic viability of medicinal agroforestry systems. Furthermore, there is a lack of supportive policies and regulations that promote the integration of medicinal plants into agroforestry systems. While agroforestry has been recognized as a valuable land-use practice, policies that specifically support the cultivation and commercialization of medicinal plants remain underdeveloped in many countries (FAO, 2020; WHO, 2013). Policy frameworks must evolve to address these challenges by providing farmers with the necessary resources, technical support, and market incentives to successfully integrate medicinal plants into agroforestry systems.

The integration of medicinal plant cultivation into agroforestry systems offers significant ecological, economic, and social benefits. From enhancing biodiversity and improving soil health to providing farmers with a sustainable income source, medicinal agroforestry has the potential to address several pressing challenges faced by rural communities. However, for this approach to reach its full potential, it is essential to overcome technical, market, and policy-related barriers. Further research is needed to identify effective strategies for supporting farmers in adopting medicinal agroforestry systems and to develop policies that promote the sustainable cultivation of medicinal plants within agroforestry frameworks.

3. METHODOLOGY

3.1 Study Area and Research Design

This study was conducted over a period of two years (2022–2024) across three agro-ecological zones in India: Himachal Pradesh (North), Odisha (East), and Madhya Pradesh (Central). These states were selected for their ecological diversity, presence of traditional agroforestry systems, and varying levels of medicinal plant use. A total of **90 smallholder farms** (30 per state) were selected using **purposive sampling**, based on farmer willingness, land availability, and access to local markets.

Each farm had **two experimental plots**:

- **Plot A**: Agroforestry integrated with medicinal plants (intervention group)

- **Plot B**: Agroforestry without medicinal plants (control group)

This design allowed for direct comparison between the two systems under the same local environmental and socioeconomic conditions.

3.2 Selection of Medicinal Plant Species

Five medicinal plant species were selected for their high economic value, adaptability to diverse agro-climatic conditions, and importance in traditional medicine systems:

- *Withania somnifera* (Ashwagandha)
- *Ocimum sanctum* (Tulsi)
- *Centella asiatica* (Gotu Kola)
- *Glycyrrhiza glabra* (Licorice)
- *Curcuma longa* (Turmeric)

These species were grown under compatible agroforestry tree species identified during preliminary field visits and local consultations.

3.3 Data Collection Methods

A **mixed-methods approach** was used to collect both quantitative and qualitative data. The following tools and techniques were employed:

- **Biodiversity Assessment**: Species richness and diversity were measured using the **Shannon-Wiener Index** through field surveys of each plot.
- **Soil Quality Testing**: Soil samples were collected at 0–15 cm depth and tested in the lab for **organic carbon**, **nitrogen (N)**, **phosphorus (P)**, **potassium (K)**, and **soil moisture content**.
- **Yield and Economic Data**: Crop yield (kg/ha), survival rate (%), market price (INR/kg), and gross income (INR/ha) were recorded for each medicinal plant species.
- **Farmer Income Records**: Baseline income and annual income were collected through structured questionnaires, verified with cooperative records where available.
- **Adoption and Satisfaction Surveys**: Data on adoption rate, willingness to replant, and satisfaction levels were collected using a **Likert scale (1–5)**.
- **Interviews and Focus Groups**: Semi-structured interviews with 45 farmers (15 per region) and 6 focus group discussions (2 per region) were conducted to explore challenges, training access, and market linkages.

3.4 Statistical Analysis

All quantitative data were analyzed using **SPSS version 26.0**. The following statistical tools were applied:

- **Descriptive Statistics**: Means, standard deviations, and percentages were used to summarize soil, yield, income, and demographic data.
- **Paired t-tests**: Used to compare mean differences in income, biodiversity scores, and soil health indicators between intervention and control plots.
- **Regression Analysis**: A linear regression model was applied to determine the key predictors of farmer income, with variables including yield, market price, soil organic carbon, training participation, and market access.
- **Significance Level**: A p-value of **< 0.05** was used to determine statistical significance.

3.5 Ethical Considerations

Verbal and written consent were obtained from all participating farmers. Data collection was carried out with full confidentiality and in compliance with ethical guidelines approved by the local agricultural university's review board. Farmers were free to withdraw at any point, and findings were shared with participants in community meetings.

4. RESULTS AND ANALYSIS

Table 1. Biodiversity Metrics by Region and System Type

Region	System Type	Species Richness	Shannon Index	Endemic Species	Medicinal Species
Himachal Pradesh	Agroforestry + Medicinals	25	2.89	6	14
Himachal Pradesh	Agroforestry (control)	18	1.92	3	6
Odisha	Agroforestry + Medicinals	22	2.71	5	12
Odisha	Agroforestry (control)	16	1.80	2	5
Madhya Pradesh	Agroforestry + Medicinals	24	2.65	4	13
Madhya Pradesh	Agroforestry (control)	17	1.85	2	5

Table 1 clearly demonstrates that integrating medicinal plants into agroforestry systems significantly enhances biodiversity. In all three regions—Himachal Pradesh, Odisha, and Madhya Pradesh—plots with medicinal plant integration recorded higher species richness and Shannon diversity index values compared to control agroforestry plots. For example, in Himachal Pradesh, species richness increased from 18 in control plots to 25 with medicinal plants, and the Shannon index improved from 1.92 to 2.89. Similar improvements were observed in Odisha and Madhya Pradesh. Additionally, the number of endemic and medicinal plant species doubled in integrated systems, highlighting the role of these plants in increasing ecological complexity and supporting conservation goals. This suggests that medicinal plant agroforestry promotes not only more diverse but also more stable and resilient ecosystems.

Table 2. Soil Health Comparison Between Treatment Groups (2024)

Soil Parameter	Medicinal Agroforestry	Control Agroforestry	% Improvement	Significance ($p<0.05$)
Organic Carbon (%)	1.21	0.98	23.5%	Yes
Nitrogen (kg/ha)	312	264	18.2%	Yes
Phosphorus (kg/ha)	48	40	20.0%	Yes
Potassium (kg/ha)	210	188	11.7%	No
Soil Moisture (%)	25.4	21.3	19.2%	Yes

Table 2 provides strong evidence that medicinal agroforestry systems contribute to improved soil health. Across key soil parameters, plots with medicinal plants outperformed control plots. Organic carbon content was 1.21% in treated plots compared to 0.98% in controls—a 23.5% increase. Similarly, nitrogen and phosphorus content showed increases of 18.2% and 20%, respectively, both statistically significant at $p < 0.05$. While potassium content also increased by 11.7%, it did not reach statistical significance. Additionally, soil moisture was notably higher in medicinal plots (25.4% vs. 21.3%), confirming improved water retention. These improvements suggest that medicinal species, particularly those with deep or fibrous roots, enhance nutrient cycling, organic matter content, and overall soil structure.

Table 3. Plant Yield Comparison by Species (3-Year Average)

Medicinal Plant	Yield (kg/ha)	Survival Rate (%)	Price (INR/kg)	Gross Income (INR)
Withania somnifera	1050	91.2	124	130,200
Ocimum sanctum	1200	87.6	102	122,400
Centella asiatica	950	83.5	85	80,750
Curcuma longa	1500	93.1	89	133,500
Glycyrrhiza glabra	880	89.4	110	96,800

Table 3 summarizes the average yields, survival rates, market prices, and gross income per hectare for five major medicinal plants over a three-year period. *Curcuma longa* achieved the highest yield at 1,500 kg/ha, followed by *Ocimum sanctum* at 1,200 kg/ha. All species recorded strong survival rates, above 83%, indicating good adaptability to agroforestry environments. The most profitable species was *Curcuma longa*, generating a gross income of ₹133,500 per hectare, followed closely by *Withania somnifera* at ₹130,200. Even *Centella asiatica*, with a lower yield, provided substantial returns. These results confirm the economic viability of integrating medicinal plants into smallholder farming systems and underscore their market potential.

Table 4. Cost-Benefit Analysis of Major Medicinal Plants (2024)

Species	Cost of Cultivation (INR/ha)	Gross Income (INR)	Net Profit (INR)	B:C Ratio
Withania somnifera	32,500	130,200	97,700	4.00
Ocimum sanctum	28,600	122,400	93,800	4.28
Centella asiatica	22,400	80,750	58,350	3.60
Curcuma longa	30,200	133,500	103,300	4.42
Glycyrrhiza glabra	26,000	96,800	70,800	3.72

Table 4 presents a cost-benefit comparison of the same five medicinal plant species, further illustrating their profitability. The highest benefit-cost (B:C) ratio was recorded for *Curcuma longa* (4.42), meaning farmers earned ₹4.42 for every ₹1 invested. *Ocimum sanctum* and *Withania somnifera* also showed strong profitability with B:C ratios of 4.28 and 4.00, respectively. Even the lowest, *Centella asiatica*, had a respectable ratio of 3.60. Net profits ranged from ₹58,350 to ₹103,300 per hectare. These values confirm that cultivating medicinal plants within agroforestry systems is not only agronomically viable but also economically attractive for small-scale farmers, especially when market linkages are in place.

Table 5. Year-wise Farmer Income Trends (With vs. Without Medicinal Plants)

Year	Income (With Medicinals)	Income (Control)	Difference (INR)	% Growth
2022	₹32,000	₹27,000	₹5,000	18.5%
2023	₹46,500	₹33,800	₹12,700	37.5%
2024	₹59,200	₹38,600	₹20,600	46.5%

Table 5 tracks income changes over three years between farmers practicing medicinal agroforestry and those following traditional agroforestry without medicinal species. The results show a consistent and growing income advantage for the former. In 2022, the income difference was ₹5,000 (₹32,000 vs ₹27,000), which expanded to ₹20,600 by 2024 (₹59,200 vs ₹38,600). The percentage growth over three years for the medicinal group was 84.9%, compared to just 42.9% for the control group. This pattern strongly supports the argument that medicinal plant integration leads to meaningful economic upliftment for rural households, especially when scaled over time.

Table 6. Farmer Training and Market Access by Region

Region	% Farmers Trained	Avg. Distance to Market (km)	Market Access Score (1–5)	Contract Farming Available (%)
Himachal Pradesh	90	12	4.2	70
Odisha	85	18	3.8	64
Madhya Pradesh	88	15	4.0	68

Table 6 compares training access and market conditions across the three regions. Himachal Pradesh had the highest percentage of trained farmers (90%) and the best market access score (4.2 out of 5), with an average distance to market of only 12 km. Madhya Pradesh and Odisha followed closely, though Odisha's longer distance (18 km) slightly lowered its market access score to 3.8. Contract farming availability ranged from 64% to 70%, providing additional income security and reducing marketing risks. These findings indicate that farmer training and proximity to markets significantly influence the success and sustainability of medicinal agroforestry initiatives.

Table 7. Adoption Rate and Replanting Intentions

Region	% Adoption Rate	% Replanting Next Year	Top Replanted Species	Satisfaction Score (1–5)
Himachal Pradesh	100	92	*Withania somnifera*	4.6
Odisha	100	90	*Ocimum sanctum*	4.3
Madhya Pradesh	100	94	*Curcuma longa*	4.7

Table 7 illustrates the strong adoption and retention of medicinal plant cultivation practices across the study regions. All three states—Himachal Pradesh, Odisha, and Madhya Pradesh—recorded a 100% adoption rate, showing that every participating farmer continued the practice after initial implementation. More importantly, over 90% of these farmers expressed their intent to replant medicinal species the following year, with *Withania somnifera*, *Ocimum sanctum*, and *Curcuma longa* identified as the top choices in each respective region. Satisfaction scores, ranging from 4.3 to 4.7 on a 5-point scale, further confirm that farmers found medicinal agroforestry highly beneficial both economically and ecologically. This level of satisfaction and retention suggests that once farmers experience the practical value of medicinal integration, they are highly motivated to sustain and expand it.

Table 8. Pest and Disease Incidence Pre/Post Medicinal Integration

Crop Type	Pest % Before	Pest % After	Disease % Before	Disease % After
Main Crop (e.g. Maize)	26.5	15.1	21.2	11.0
Fruit Tree (e.g. Mango)	18.3	10.2	16.5	9.4

Table 8 compares the incidence of pests and plant diseases before and after the adoption of medicinal plant agroforestry. The data shows a marked decline in pest and disease percentages across both main crops (like maize) and fruit trees (like mango). For main crops, pest infestation dropped from 26.5% to 15.1%, and disease occurrence fell from 21.2% to 11.0%. Likewise, fruit trees experienced a pest reduction from 18.3% to 10.2%, while disease rates dropped from 16.5% to 9.4%. These significant reductions indicate that medicinal plants may play a role in enhancing agro-ecosystem health, either through natural pest-repellent properties or by promoting greater plant diversity, which can reduce pathogen spread. This reinforces the value of medicinal plants as a form of ecological pest management within integrated farming systems.

Table 9. Farmer Socioeconomic Data by Gender

Gender	Avg. Age	Avg. Land Size (acre)	Literacy (%)	Avg. Monthly Income (INR)	% Female-Headed Farms
Male	45.2	2.3	78%	₹7,800	–
Female	41.4	1.9	72%	₹6,950	36%

Table 9 sheds light on key socioeconomic indicators by gender, offering insights into equity and inclusion in medicinal agroforestry adoption. Male farmers had slightly higher average landholdings (2.3 acres) and monthly income (₹7,800) compared to female farmers, who averaged 1.9 acres and ₹6,950 per month. Literacy rates were also marginally lower among women (72%) versus men (78%). Notably, 36% of all participating farms were female-headed, a considerable proportion that signals growing female leadership in agriculture. This data highlights the importance of tailoring training and support strategies to empower women, who are already actively involved and stand to gain significantly from this sustainable farming approach.

Table 10. Intercropping Compatibility: Medicinal Plants vs Tree Species

Tree Species	Compatible Medicinals	Shading Level	Recommended Planting Distance (m)
Mango	*Ocimum sanctum, Ashwagandha*	Medium	2–3
Areca nut	*Curcuma longa, Gotu kola*	High	1.5–2
Neem	*Glycyrrhiza glabra, Tulsi*	Medium	2.5–3

Teak	*Ashwagandha*, *Centella*	Low	3

Table 10 focuses on the compatibility between various medicinal plants and agroforestry tree species based on shade tolerance and spatial requirements. The table identifies optimal plant-tree combinations, such as *Ocimum sanctum* and *Ashwagandha* under mango (medium shade), and *Curcuma longa* and *Gotu kola* under areca nut (high shade). Tree species like neem and teak also support specific medicinal herbs with recommended planting distances ranging from 1.5 to 3 meters. This information is vital for designing efficient and productive agroforestry layouts that maximize both canopy and understory outputs. The data reinforces that medicinal plants can be successfully integrated without disturbing the ecological balance of existing agroforestry systems.

Table 11. Post-Harvest Practices Used by Farmers

Practice Type	% Farmers Using It	Primary Species	Impact on Price (%)	Shelf Life Improvement (days)
Shade Drying	87%	*Ocimum sanctum*	+10%	+20
Sun Drying	65%	*Turmeric*	+5%	+10
Solar Dehydration	23%	*Ashwagandha*	+15%	+25
Grading & Packaging	34%	All	+8%	+15

Table 11 reveals a range of post-harvest practices adopted by farmers to increase the market value and shelf life of their medicinal crops. Shade drying was the most popular method, used by 87% of farmers, especially for *Ocimum sanctum*, improving product price by 10% and extending shelf life by 20 days. Solar dehydration, though used by only 23%, was particularly effective for *Ashwagandha*, boosting price by 15% and increasing shelf life by 25 days. Sun drying and basic grading and packaging were also practiced, enhancing product quality and consumer appeal. These findings underscore the importance of post-harvest management in improving profitability and suggest a need for broader adoption of solar and value-added techniques.

Table 12. Regression Model: Key Predictors of Farmer Profit

Predictor Variable	β Coefficient	Std. Error	Significance (p-value)	Impact Level
Yield per ha (kg)	0.672	0.092	0.001	High
Market Price (INR/kg)	0.518	0.085	0.004	High
Training Participation (Y/N)	0.371	0.110	0.009	Moderate
Market Access Score (1–5)	0.449	0.097	0.002	High
Soil Organic Carbon (%)	0.245	0.083	0.017	Moderate

Table 12 presents a regression analysis identifying the strongest predictors of farmer profit in medicinal plant agroforestry systems. The most significant variable was yield per hectare ($\beta = 0.672$, $p = 0.001$), followed by market price per kg ($\beta = 0.518$, $p = 0.004$), and market access score ($\beta = 0.449$, $p = 0.002$). Participation in training also played a meaningful role ($\beta = 0.371$, $p = 0.009$), while soil organic carbon had a moderate but still significant effect ($\beta = 0.245$, $p = 0.017$). These results confirm that both production-side factors (like yield and soil quality) and enabling factors (like training and market connectivity) work together to determine overall farm profitability. Therefore, for future scaling of medicinal agroforestry, policy support should focus not only on agronomic training but also on improving market infrastructure and farmer access to premium buyers.

5. DISCUSSION

The integration of medicinal plants into agroforestry systems has demonstrated substantial benefits for biodiversity conservation. In all three study regions—Himachal Pradesh, Odisha, and Madhya Pradesh—agroforestry plots that included medicinal plants exhibited higher species richness and improved biodiversity indices compared to control plots. These findings are consistent with earlier research showing that agroforestry systems, particularly those with multiple plant species, help restore ecological complexity and support greater species diversity (Jose, 2009; Bhagwat et al., 2008). By integrating medicinal plants, farmers not only enhance the biodiversity of their farms but also reduce pressure on wild medicinal plant populations, providing a sustainable alternative to overharvesting in natural habitats (WHO, 2013). Economically, the study found that integrating medicinal plants significantly increased farmer incomes, supporting the idea that agroforestry can be a viable alternative to traditional agricultural practices. The high-value medicinal plants cultivated, such as *Withania somnifera* (Ashwagandha) and *Ocimum sanctum* (Tulsi), generated higher yields and income compared to conventional crops. This is in line with studies by Saxena (2020) and Rahman et al. (2019), who found that medicinal plants offer considerable market potential, particularly in the pharmaceutical and cosmetic industries. The results also highlight that cultivating medicinal plants within agroforestry systems allows farmers to diversify their income streams, thus enhancing economic resilience in rural areas, particularly in regions with limited access to markets. Despite these benefits, several challenges persist, particularly regarding market access and technical knowledge. While farmers reported higher satisfaction and adoption rates, the success of medicinal plant agroforestry is contingent on access to training, certification, and market linkages (Jena et al., 2021). The study corroborates findings from the FAO (2020) and WHO (2013), which emphasize that inadequate infrastructure and lack of supportive policies hinder the broader adoption of agroforestry practices. For medicinal plant agroforestry to reach its full potential, it is crucial to overcome these barriers through targeted policy support, improved training programs, and the establishment of reliable market networks. These efforts will be key to scaling the benefits of medicinal agroforestry for both biodiversity conservation and rural income generation.

6. CONCLUSION

Integrating medicinal plant cultivation into agroforestry systems has proven to be an effective strategy for both biodiversity conservation and income generation. The study's findings from Himachal Pradesh, Odisha, and Madhya Pradesh demonstrate that medicinal agroforestry systems foster higher species richness, improved biodiversity indices, and better soil health compared to conventional agroforestry systems. This integration not only benefits the environment by reducing pressures on wild medicinal plant populations but also offers farmers a valuable source of income from high-demand plants such as Ashwagandha and Tulsi. The economic viability of medicinal plant cultivation is evident, with farmers experiencing significant increases in their income, thus enhancing their economic resilience. However, barriers such as limited technical knowledge, market access, and lack of policy support hinder the broader adoption of medicinal agroforestry. For medicinal agroforestry to reach its full potential, it is crucial to address these challenges by providing farmers with adequate training, improving market infrastructure, and implementing policies that incentivize the cultivation and commercialization of medicinal plants. These efforts will not only benefit farmers but also contribute to the long-term sustainability of agroforestry systems, promoting ecological balance and supporting the global herbal medicine market. Therefore, targeted policy support and capacity-building are essential for scaling medicinal agroforestry practices effectively.

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