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RESEARCH ARTICLE

# Bridging Ecology, Economy, and Sustainability: The Role of Agroforestry in Strengthening Rural Livelihoods in Semi-Arid Regions of Khyber Pakhtunkhwa, Pakistan

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**Abstract**
Sustainable rural development requires approaches that integrate ecological preservation with economic resilience. Agroforestry an ecologically based farming system combining trees with crops offers a promising pathway to achieve sustainability in smallholder communities. This study aimed to evaluate the role of agroforestry systems in improving the socio-economic and environmental conditions of rural communities in Tehsil Paharpur, Dera Ismail Khan, Pakistan. A structured questionnaire was administered to 50 randomly selected respondents to collect primary data on household income, resource utilization, species diversity, and livelihood outcomes. Results revealed that agroforestry practices contributed to a 28% increase in household income, improved access to food, fodder, timber, and fuelwood, and enhanced species diversity by 35% compared to conventional agriculture. Farmers also reported greater livelihood stability and environmental awareness. However, challenges such as limited market access, bureaucratic hurdles, and inadequate extension services constrained the full potential of these systems. It is recommended that local governments and development agencies promote sustainable agroforestry models through policy support, training programs, and market linkages to strengthen both ecological sustainability and rural livelihoods.

**Keywords:** Agriculture; agroforestry; communities; livelihood; sustainable development; rural economy

## Introduction

Agroforestry systems (AFS) are capable of producing income and offering a variety of environmental resources. They have existed for thousands of years across the world, particularly among indigenous peoples, and currently support at least 1.3 billion people (about one sixth of humanity) (Danthu et al, 2022). However, science has only recently started to examine these systems, their costs and advantages, as well as the intricate relationships that

exist between their plant, animal and human components (Gupta et al, 2023). Agroforestry is being promoted extensively worldwide as a means of increasing production and diversification, because of its advantages in the economic, social, and environmental spheres (Orji et al 2022 & Leakey et al, 2020) . Planting trees alongside annual crops helps farmers combat the effects of climate change and land degradation on agriculture. Agroforestry is a potential approach for adapting to climate change that can help farmers and agricultural systems become more resilient to climate risk (Ciaccia et al, 2021). It is the intentional blending of shrubs or trees with crops or livestock at the plot or farm. There are numerous biophysical and social advantages to this technique (Paudel et al, 2022). Agroforestry is a promising agro-ecological approach to climate change adaptation due to the numerous co-benefits that many agroforestry systems provide in addition to climate change adaptation, such as synergies with climate change mitigation through carbon sequestration, improved food security and income opportunities, provision of ecosystem services and biodiversity conservation (Zinngrebe et al, 2022). The production of food and revenue from trees, crops and livestock is one of the well-known general socioeconomic benefits of agroforestry systems. Recent research has discovered that by boosting their adaptation capacity and lowering their susceptibility, these general socioeconomic benefits can also assist farmers in adjusting to climate-induced catastrophic events (Do et al, 2020). The coexistence of the trees and agricultural crops affects not only chemical and physical aspects of soil but also microorganisms that exist there. Because it contributes significantly to improving fertility and productivity, soil microbial community indirectly encourages plant growth. Because it is crucial for increasing fertility and production, soil microbial population indirectly affects plant growth (Specht et al, 2021). Traditional land use practices like agroforestry have the potential to help find solutions to a number of current and emerging environmental issues. AF is a sustainable land management approach that combines a woody component with a lower story agriculture production on purpose (Vera et al, 2020). This idea includes a broad variety of agroforestry systems, such as forest farming, silvopastoral, home gardens, severable, and systems for home gardens, in addition to hedge, windbreak, and riparian buffer strip systems. Agroforestry is a common practice among farmers, although many do not consider it to be a unique and specialized land use, much less accept such recognition (Lacerda et al, 2020).

Agroforestry is a farming method focused on the strengthening of agro-ecological connections among the productive elements of an agro-ecosystem (woody perennials like trees or shrubs, along with crops or livestock). As a result, it has the power to change things and presents a chance to improve organic farming's sustainability (Dagar et al, 2020). Producing food, fodder, fuel wood and lumber are the basic goals of agroforestry, along with other benefits including carbon sequestration, soil conservation and biodiversity. The loss of natural forests may be reduced by the production of trees for timber in wooded areas, but it may also be adversely affected by unfair exploitation (IUCN, 2018). Agroforestry has the potential to provide ecological services and improve human well-being in a number of ways. Following the implementation of agroforestry, a farmer may notice better ecosystem services, such as improved water infiltration, reduced runoff of nutrients and better soil health, which raise crop output or lower costs of production, thereby increasing returns (Iiyama et al, 2018). Some agroforestry farmers may discover that greater utilization and accessibility of tree/shrub feed and shade result in higher production and profits from animal products. Selling additional agroforestry goods like fruit, nuts, firewood and timber can boost and diversify revenue and food sources (Santiago et al 2021). Policy interventions may be required to encourage farmers to use agroforestry practices that can provide desirable ecosystem services and possibly boost the systems profitability (Mosquera et al 2020). Depending on factors such as gender, socioeconomic class, race or ethnicity, or education or literacy level, these changes may have various implications, especially when taking into account the effects of policy interventions meant to boost agroforestry

(Chattopadhyay et al, 2020). The study and practice of interface and relationships between agriculture and forestry, encompassing farmers, cattle, trees, and crops of various sizes, is known as agroforestry. Interactions between trees and other agricultural components may be important at different scales on farms where trees may provide livestock with food, shelter, fuel, income, or other benefits from products like timber, or in landscapes where agricultural and forest land uses combine to determine the provision of ecosystem services.

## Materials and Methods

### Study Area

The study was conducted in Tehsil Paharpur, District Dera Ismail Khan, Khyber Pakhtunkhwa, Pakistan, a semi-arid region characterized by low and erratic rainfall, high temperatures, and mixed crop–livestock farming systems. Agroforestry is commonly practiced in the area through the integration of multipurpose tree species with annual crops and livestock to enhance livelihood security and environmental sustainability.

### Sampling Procedure and Data Collection

Primary data were collected through a field-based socio-economic survey using a structured and pre-tested questionnaire. A total of 50 farmers actively practicing agroforestry were selected using a purposive random sampling technique to ensure representation of households with direct experience of tree–crop–livestock integration.

Face-to-face interviews were conducted to minimize response bias and improve data reliability. The questionnaire was designed to capture information on demographic characteristics, landholding size, income sources, livestock assets, vegetation diversity, fodder sources, resource utilization, and farmers' perceptions regarding agroforestry benefits and constraints.

### Questionnaire Design

The questionnaire consisted of both closed-ended and semi-structured questions and was divided into six major sections:

(i) demographic and household characteristics,

(ii) economic profile and income sources,

(iii) agricultural and livestock assets,

(iv) vegetation diversity and agroforestry systems practiced,

(v) resource utilization and fodder sources, and

(vi) awareness and perceptions regarding agroforestry and environmental sustainability.

## Ethical Considerations

Participation in the survey was voluntary, and respondents were informed about the purpose of the study. Data confidentiality was maintained throughout the research process.

**Table 1:** The male head of the family was asked about the following parameters;

| Category | Parameters Investigated |
|---|---|
| Demographic Information | Name, Age, Family Size, Family Type, Education |
| Economic Profile | Source of Income, Monthly Income, Expenditure, Other Members' Contribution to Household Income, Landholding |
| Agricultural and Livestock Assets | Agricultural Benefits, Household Livestock Assets, Vegetation Diversity of Farmlands, Agroforestry System Followed |
| Resource Utilization | Utilization of Wood Products, Source of Wood Products for Domestic Use, Non-Wood Products, Wood Selling, Commercially Important Trees |
| Perception and Awareness | Awareness about Benefits of Trees, Opinion on the Decrease of Trees, Role of Agroforestry in Uplifting Socioeconomic Conditions |
| Market and Accessibility | Distance to Market, Purchase of Standing Trees, Problems Faced Regarding Marketing |

## Statistical Analysis

The data collected from the farmers with the help of interviews and questionnaire was analyzed in detail using the IBM SPSS Statistics 27.0.1, a statistical software package. In order to assess the collected data and evaluate farmers' responses, descriptive statistics such as frequency counts, percentages, and visual representation in the form of charts were utilized. These statistical techniques helped in summarizing and interpreting the essential features of the data, offering insights into the distribution and trends within the farmers' responses.

## Results and Discussion

Most regions of the world have seen widespread use of agroforestry because it offers a variety of products, a means of subsistence, and ecosystem services. It includes a broad variety of techniques, ranging from simple shifting farming to intricate home gardens, which are primarily used across the subcontinent (Panwar et al, 2022). Agroforestry has helped smallholder farmers around the world become more resilient to climate change, by providing 20% more food variety in the traditional pattern and a five-fold increase in income in the commercial pattern. Utilizing various crop kinds and their diverse growth patterns through intercropping allows for the effective use of available land while maximizing productivity per unit area. By diversifying a farmer's sources of revenue, multiple crop cultivation lowers the economic risks brought on by reliance on a single crop. For intercropping to be successful and support sustainable agriculture, the right crops must be chosen, planted, and managed at the right times. The selection of crops for intercropping is influenced by variables such as climate, soil type, water availability, and the particular objectives of the farming system.

Figure 4.1 illustrates that the majority of respondents (60%) belonged to the young age group, followed by the middle-aged group (33%) and the senior group (7%). This age distribution suggests a relatively youthful and

active farming population in Tehsil Paharpur, which is crucial for the adoption of labor-intensive and innovative agroforestry practices. Younger farmers are generally more receptive to adopting new technologies and sustainable land-use systems compared to older farmers, who may prefer conventional practices. Similar findings were reported by (Ali et al. 2021), who observed that younger farmers in Khyber Pakhtunkhwa showed a higher tendency to engage in diversified agricultural activities, including agroforestry.

Landholding size was found to be concentrated in the range of 0–25 acres, indicating that most respondents were smallholders. Only a very small proportion (<1%) owned more than 100 acres. Small landholdings limit the capacity for large-scale tree planting but encourage the integration of multipurpose trees on farm boundaries and within cropping systems to maximize land productivity. These results align with the findings of (Kumar and Nair. 2022), who emphasized that small-scale farmers tend to adopt agroforestry to improve land-use efficiency, enhance soil fertility, and supplement household income through diversified production systems.

**Table 2:** Demographic Characteristics of Respondents (n = 50)

| Variable | Category | Frequency | Percentage (%) |
|---|---|---|---|
| Age | Young (<35 years) | 30 | 60 |
| | Middle (35–50 years) | 17 | 34 |
| | Old (>50 years) | 3 | 6 |
| Education | Illiterate | 14 | 28 |
| | Primary–Secondary | 21 | 42 |
| | Higher Education | 15 | 30 |

*The SPSS output indicated that the majority of respondents were young and middle-aged farmers, suggesting a higher potential for adoption of innovative agroforestry practices.*

Overall, the results indicate that the agricultural sector remains the primary source of income for the majority of rural households. The dominance of agriculture as an occupation underscores the importance of agroforestry as a strategy for sustainable livelihood enhancement and resource conservation in semi-arid regions like Tehsil Paharpur.

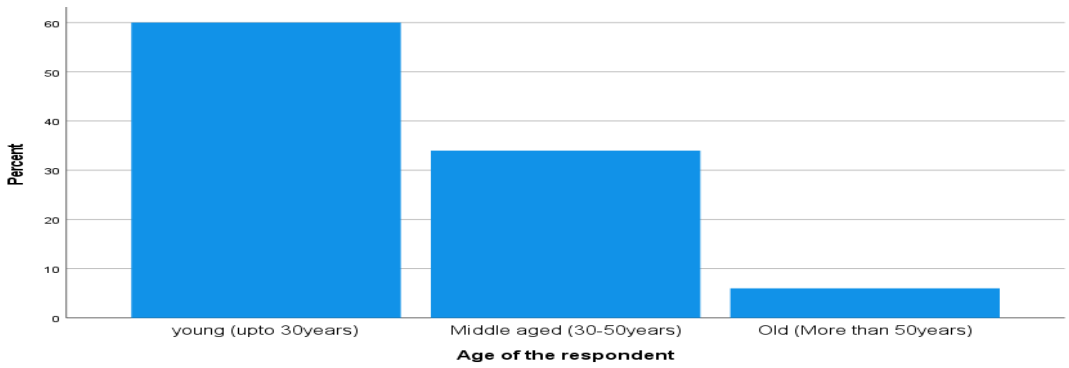


**Figure 1:** Distribution of respondents according to their ages

**Community Status of Village**

Figure 1: depicts the range of income-generating activities undertaken by household members to contribute to family income. The majority of respondents (62%) reported that agriculture was their primary means of livelihood, reflecting the central role of farming in sustaining rural households in Tehsil Paharpur. About 22% of respondents were engaged in non-agricultural occupations, while only 1% pursued additional agricultural ventures beyond their main farm activities. This finding indicates that although diversification exists, dependence on agriculture remains dominant within the community.

The high reliance on agriculture is consistent with the socio-economic structure of rural Pakistan, where farming provides both direct income and indirect benefits such as food security and employment opportunities. According to (Hassan et al. 2020), rural families in Khyber Pakhtunkhwa rely heavily on agriculture due to limited access to industrial or service-based employment opportunities. However, the presence of some family members working in non-agricultural sectors highlights a gradual shift toward income diversification, which is essential for enhancing resilience against agricultural risks. As noted by (Mbow et al. 2014), integrating multiple livelihood sources such as agroforestry, small enterprises, and off-farm work can significantly strengthen the sustainability and adaptive capacity of rural households in semi-arid environments.

**Table 3:** Income Sources of Respondents

| Income Source | Frequency | Percentage (%) |
|---|---|---|
| Agriculture only | 31 | 62 |
| Agriculture + Non-farm | 11 | 22 |
| Non-agricultural | 8 | 16 |

*SPSS frequency analysis revealed that agriculture remained the dominant income source, highlighting the importance of agroforestry in strengthening farm-based livelihoods.*

Overall, these results suggest that while agriculture continues to dominate the rural economy, encouraging diversified income strategies can promote long-term socioeconomic sustainability and reduce vulnerability to environmental and market fluctuations.

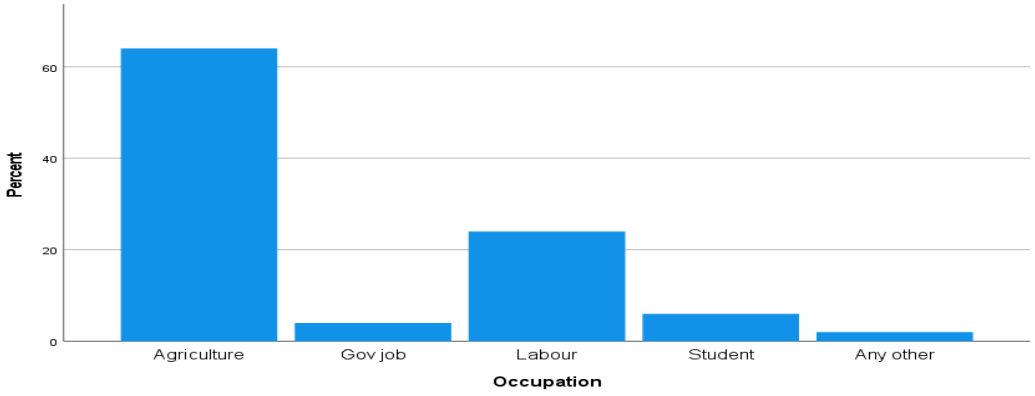


**Figure 2:** Distribution of respondents according to their occupation

### Household Livestock Assets

Figure 2 indicates that livestock ownership varied considerably among respondents, with 35% of households maintaining 1–5 animals and 32% keeping 10–15 animals. The primary livestock species included cows, goats, buffaloes, and lambs, which are integral to the mixed farming systems of Tehsil Paharpur. Among these, cows were identified as the most valuable asset due to their high productivity, contributing significantly to milk production, household nutrition, and cash income. In many cases, livestock ownership served as a form of economic security, providing both direct income from sales and indirect benefits such as manure for crop production.

These findings are consistent with those of (Rahman et al. 2021), who reported that livestock contributes substantially to rural livelihoods by improving household food security and serving as a financial buffer against agricultural risks. Similarly, (FAO 2020) highlighted that mixed crop–livestock systems enhance resource efficiency and promote sustainable farming practices in semi-arid regions. The observed preference for cattle in the study area underscores the role of livestock as a socioeconomic and sustainability asset, linking agricultural productivity with livelihood resilience.

**Table 4:** Livestock Ownership Pattern

| Number of Animals | Frequency | Percentage (%) |
|---|---|---|
| 1–5 | 18 | 36 |
| 6–10 | 16 | 32 |
| >10 | 16 | 32 |

*Livestock ownership showed considerable variation, indicating mixed farming systems where agroforestry supports fodder availability and livestock productivity.*

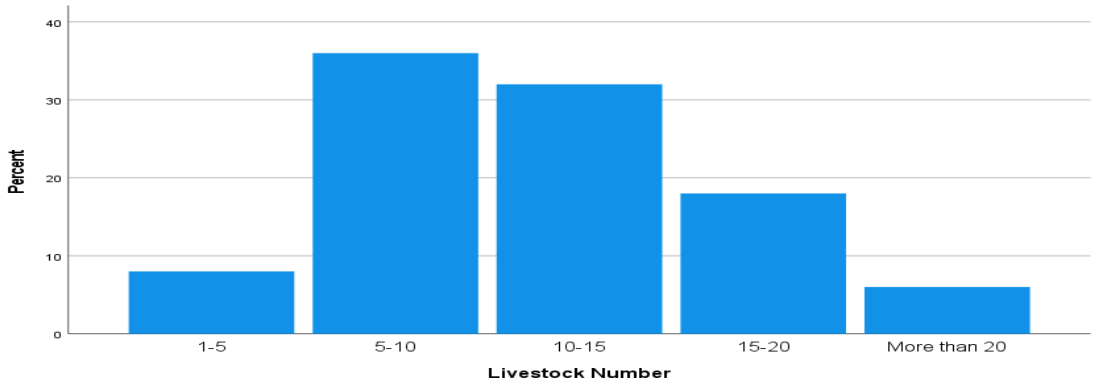


**Figure 3:** Livestock assets owned by the respondents

### Vegetation Diversity of Farmlands

Figure 3 reveals that Sufaida (Eucalyptus camaldulensis) was the most commonly planted tree species among respondents, followed by Shisham (Dalbergia sissoo), Poplar (Populus deltoides), and a few other indigenous

and exotic species. However, a noticeable portion of farmers reported not planting any trees on their farmland. This pattern reflects species preference based on fast growth rate, timber value, and adaptability to local climatic and soil conditions. Eucalyptus, in particular, is favored due to its rapid growth and multiple uses in construction, fuelwood, and farm boundary planting, although its extensive use raises concerns about high water consumption in arid regions.

Tree species diversity across Pakistani farmlands varies substantially with geographical location, soil type, and climatic conditions. The dominance of Eucalyptus and Shisham aligns with findings by (Siddiqui et al. 2020), who observed similar trends of species selection in the irrigated plains of Khyber Pakhtunkhwa and Punjab. Moreover, most respondents recognized the ecological importance of trees, particularly their role in oxygen production, microclimate regulation, and soil conservation reflecting an increasing awareness of environmental sustainability among rural communities. This supports (Rahman et al. 2019), who emphasized that local perceptions of tree benefits significantly influence agroforestry adoption and biodiversity conservation at the farm level.

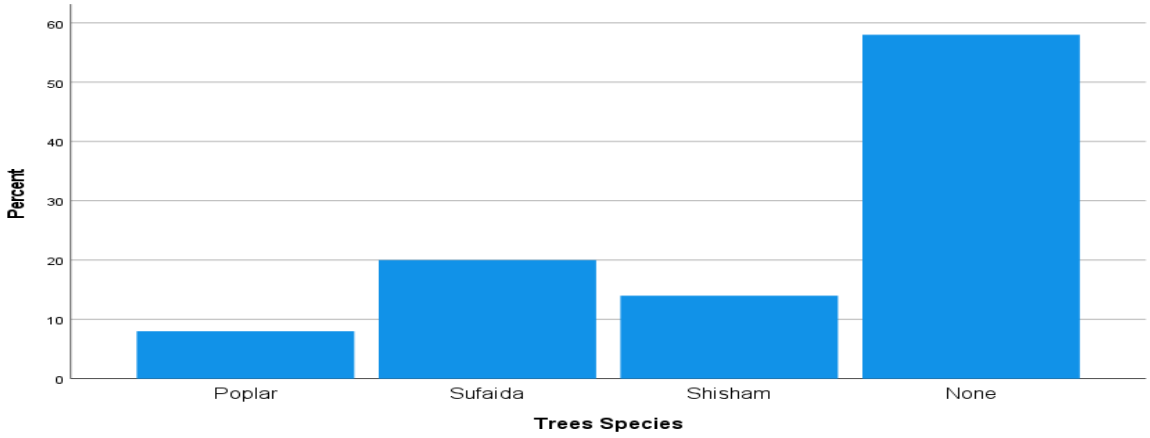


**Figure 4:** Tree species found on the study area

**Fodder Source**

The results highlight that the farming households in the study region rely on a diverse array of fodder sources to sustain livestock, reflecting adaptation to semi-arid conditions and mixed farming systems. Cultivation of dedicated fodder crops such as berseem and maize demonstrates a proactive strategy by farmers to meet animal dietary needs. For instance, research in Pakistan has shown that maize fodder, with acceptable nutrient profiles under spring and autumn planting, contributes significantly to livestock nutrition in irrigated zones. The inclusion of leguminous fodder crops (e.g., clover, vetch) indicates that farmers are not only feeding livestock but also enhancing soil fertility thereby linking fodder production to agro-ecological sustainability. In periods of fodder scarcity, particularly during dry seasons, the use of tree leaves (from mulberry, poplar, willow) as animal feed is a valuable strategy of feed-resource diversification. This practice supports livestock nutrition under challenging conditions and represents an integration of tree-based and crop-based systems. Studies of fodder tree leaves confirm that such tree-based feed sources can play an important role in livestock production systems, especially in marginal environments. Moreover, the use of crop residues (wheat, rice, maize straw) as

animal feed underscores the circularity of farm systems using by-products to supplement livestock nutrition rather than waste. This contributes to resource efficiency and supports sustainability in smallholder systems. Overall, the diversified fodder sourcing observed in the study suggests that farmers are employing multi-source strategies (fodder crops + trees + residues) which enhance resilience, reduce risk of feed shortage, and support both livelihood and environmental goals. From a policy perspective, encouraging the integration of fodder crops, agroforestry fodder trees and crop residue use can strengthen feed security and foster sustainable livestock-agroforestry systems.

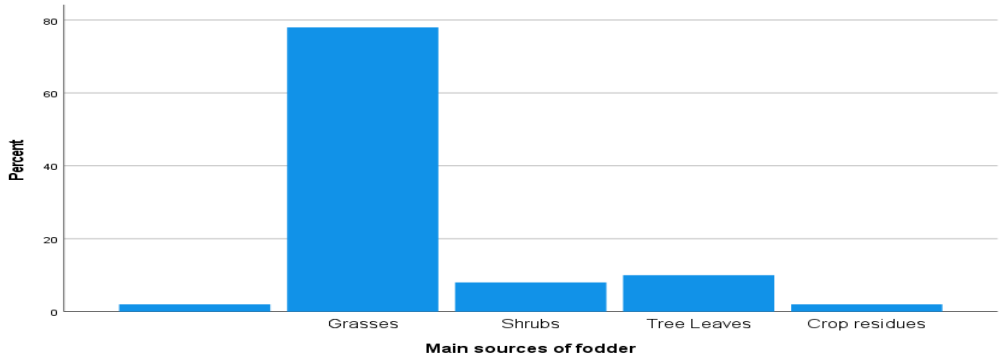


**Figure 5:** Different sources of fodder found in the area

**Socio-Economic Impacts**

According to the results of the questionnaire, agroforestry systems have many advantages and significantly improved farmers' lives through better access to food, timber, fodder, and fuel wood as well as increased access to money for livelihoods. Tribal farmers confront a number of obstacles, such as bureaucracy and a lack of alternative market facilities, despite the fact that agroforestry practices improve species diversity, produce financial benefits, and aid farmers in maintaining their livelihoods. Future policy interventions with a focus on sustainable forestry techniques, how to address issues encountered by farmers, and enhancement of local livelihoods are now more interesting as a result of our work. Agroforestry, which combines agricultural methods with the growth of trees, is a successful strategy for generating several revenue streams (Smithet al 2022). On the same plot of land, agroforestry systems combine trees with crops, cattle, or both, producing a variety of goods and services that bring in money for farmers and landowners. By periodically harvesting mature trees for lumber and other wood products, agroforestry systems with timber species can offer a long-term source of revenue. Mangoes, oranges, apples, and other fruits can be sold to generate money if fruit trees are interplanted with other crops or incorporated into farming systems. Trees that yield valuable non-timber forest products including gums, resins, medicinal herbs, and essential oils, which can be marketed locally or abroad, are frequently used in agroforestry systems. Agroforestry increases financial resilience while also promoting ecological sustainability, biodiversity preservation, and climate change mitigation through the variety of income sources. However, to optimize the advantages of income diversification for farmers and landowners, agroforestry efforts depend on careful planning, appropriate tree species selection, familiarity with local markets, and continuing management and upkeep. For farmers and landowners, agroforestry systems can produce both timber and non-timber forest products (NTFPs), providing a sustainable and diverse income stream. Agroforestry gives chances for numerous

revenue sources by fusing trees with agricultural crops or livestock. Fast-growing tree species can be planted in agroforestry systems with a concentration on timber production for later harvest. Plantations of trees like eucalyptus, teak, and poplar are frequently employed in agroforestry (Fahad et al, 2022). Agroforestry techniques can sometimes be used to manage certain plants for sustainable timber production while maintaining the ecological balance in natural forests that already exist. Agroforestry systems that incorporate fruit-bearing trees produce a wide range of products, including mangoes, apples, walnuts, and almonds, which can be sold or processed into value-added goods. Aloe Vera, Neem, and Stevia are examples of medicinal plants used in some agroforestry systems. These plants are in high demand in the cosmetic and herbal medicine industries. Bees thrive in agroforestry, which enables farmers to practice beekeeping and produce honey and other bee-related goods (Siarudin et al 2021).

## Conclusions

This study demonstrates that agroforestry is a viable and sustainable land-use strategy for enhancing rural livelihoods and ecological stability in semi-arid regions of Khyber Pakhtunkhwa, Pakistan. The findings indicate that agroforestry practices significantly improved household income, diversified livelihood sources, enhanced fodder and fuelwood availability, and increased on-farm vegetation diversity. These benefits contribute directly to food security, economic resilience, and environmental sustainability. Despite its considerable potential, the adoption and scaling-up of agroforestry systems remain constrained by limited technical knowledge, weak market access, bureaucratic challenges, and insufficient institutional support. Addressing these barriers is essential to fully realize the socio-economic and ecological benefits of agroforestry. Policy interventions should focus on strengthening extension services, providing quality planting material, improving access to credit facilities, and developing value chains for timber and non-timber forest products. Capacity-building programs and farmer training initiatives can further enhance awareness and adoption of scientifically managed agroforestry systems. Future research should incorporate quantitative impact assessments, including carbon sequestration potential, long-term soil fertility improvement, and climate resilience indicators, to better evaluate the environmental services provided by agroforestry. Overall, agroforestry represents a climate-smart and economically sustainable pathway that effectively bridges ecology and economy while promoting resilient rural development.

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**Conflict of Interest:** The authors declare that there is no conflict of interest regarding the publication of this manuscript.

**Ethics Approval / Declaration:** This study was conducted through a questionnaire-based survey, and all procedures complied with ethical standards for social research. No human or animal experimentation was involved.

**Consent to Participate:** Informed consent was obtained from all participants prior to data collection.

**Consent for Publication:** All authors have read and approved the final version of the manuscript and consent to its publication.

**Data Availability:** The data supporting the findings of this study are available from the corresponding author upon reasonable request.

**Authors' Contribution:** Conceptualization and study design: Rashid Khan; Data collection: Muhammad Ikram Ullah Malik, Bilal Ahmad Khan; Data analysis and interpretation: Faheem Abbas, Muhammad Zeeshan Khan; Manuscript drafting: Rashid Khan, Muhammad Jawad Nazir; Review and editing: All authors. All authors approved the final manuscript.

**AI Generative Text Statement:** The authors declare that artificial intelligence tools were used only for language editing and formatting support, and not for data generation, analysis, or interpretation. The authors take full responsibility for the content of the manuscript.

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