Research Article

Assessment of Agroforestry Practices and Their Impact on Livelihoods and Environment in District Mardan, Khyber Pakhtunkhwa, Pakistan

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Abstract | Agroforestry systems integrate trees with agricultural crops and/or livestock, offering ecological and economic benefits. This study assessed the prevalent agroforestry practices in District Mardan, Khyber Pakhtunkhwa, focusing on their impact on farmers' income, biodiversity conservation, and soil fertility. A stratified random sampling technique was used to select 150 respondents across three tehsils: Mardan, Takht Bhai, and Katlang. Primary data was collected using semi-structured questionnaires, field observations, and key informant interviews. The results revealed that boundary planting (68%) and scattered planting (24%) were the dominant agroforestry systems practiced. Species such as *Dalbergia sissoo, Melia azedarach*, *Morus alba,* and *Eucalyptus camaldulensis* were common. The findings showed significant enhancement in income (up to 25%), improved soil fertility through leaf litter, and enhanced on-farm biodiversity. Challenges faced included lack of technical knowledge, limited market access, and pest issues. The study recommends strengthening agroforestry extension services, capacity building, and policy support to promote sustainable agroforestry practices in the region.

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Introduction

Agroforestry is a land-use system that combines the cultivation of trees with agricultural crops and/or livestock on the same land management unit. It represents a traditional and yet increasingly modern approach to sustainable land use, offering a range of environmental, social, and economic benefits. As global attention turns toward sustainable agriculture and climate-smart practices, agroforestry is gaining prominence as a multifaceted solution that meets the objectives of increased productivity, environmental sustainability, and enhanced rural livelihoods (Nair, 1993). In Pakistan, forest resources are under severe pressure due to population growth, overgrazing, unsustainable harvesting, and land use conversion. The country's forest cover is estimated to be below 5%, significantly lower than the recommended global minimum of 25% (FAO, 2020). This deficiency has triggered a growing interest in agroforestry as an alternative source of timber, fodder, fuelwood, and non-timber forest products, particularly in areas

with an agrarian base and limited forest reserves. Agroforestry systems not only alleviate the demand on natural forests but also provide critical ecological services such as soil conservation, nutrient recycling, microclimate regulation, and biodiversity conservation (Sanchez, 1995; Young, 1997).

District Mardan, located in the central plains of Khyber Pakhtunkhwa, is a predominantly agricultural district where farmers have traditionally integrated trees into their farming systems. The region's alluvial soils, moderate rainfall, and flat topography make it suitable for intensive agriculture as well as agroforestry. Commonly grown crops include wheat, sugarcane, maize, vegetables, and orchards, while tree species such as Dalbergia sissoo, Morus alba, Melia azedarach, and Eucalyptus camaldulensis are often seen along field boundaries and scattered across farms. These tree-crop systems not only supplement household incomes but also meet subsistence needs such as fuel, fodder, and small-scale timber (Amjad *et al.*, 2013; Rehman *et al.*, 2020). Despite the visible presence of agroforestry in District Mardan, there is a lack of comprehensive research documenting the types of systems being practiced, the tree species used, and the socio-economic and ecological benefits derived from them. Additionally, challenges such as water scarcity, lack of technical knowledge, pest infestation, and market access issues continue to affect adoption rates. Empirical evidence is therefore needed to understand the dynamics of agroforestry practices, identify key constraints, and suggest targeted interventions to enhance its sustainability and impact.

Several studies conducted in other regions of Pakistan, such as Swat, Charsadda, and southern Punjab, have highlighted the potential of agroforestry in improving soil health, increasing crop yields, and providing alternative income streams (Qureshi *et al.*, 2009; Shahbaz *et al.*, 2016). However, geographic, climatic, and socio-cultural differences necessitate region-specific studies. District Mardan, with its dense rural population and high land-use intensity, presents a unique setting where agroforestry could play a pivotal role in sustainable land management and rural development.

The present study was therefore designed with the following objectives:

- To identify and document the prevalent agroforestry systems in District Mardan.
- To assess the contribution of agroforestry practices to household income, soil fertility, and biodiversity.
- To evaluate the major constraints faced by farmers in adopting and expanding agroforestry systems.
- To provide policy and management recommendations for promoting agroforestry in the region.

By generating data on these aspects, this study aims to provide baseline information that can guide forestry planners, policymakers, researchers, and local extension agents in making informed decisions about agroforestry development in District Mardan and similar agro-ecological zones across Khyber Pakhtunkhwa.

Materials and Methods

Study area description

District Mardan is situated in the central region of Khyber Pakhtunkhwa province, between latitudes 34.20° and 34.32° N and longitudes 71.48° and 72.12° E. The district comprises three administrative tehsils: Mardan, Takht Bhai, and Katlang. The total population is approximately 2.4 million, with more than 80% engaged in agriculture and allied activities (GoKP, 2023). The district's elevation ranges between 300 to 500 meters above sea level, with a subtropical to semi-arid climate characterized by hot summers and mild winters. Annual rainfall averages 500–700 mm, with a bimodal pattern of precipitation peaking in March–April and July–August.

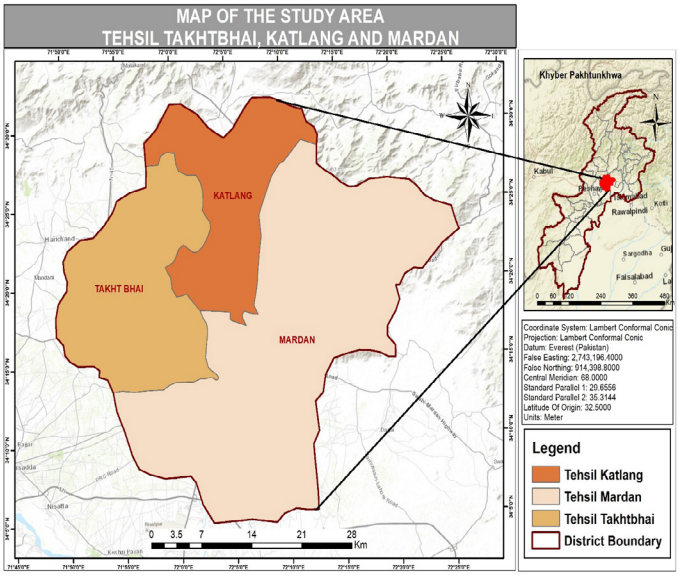

Figure 1: *Map of study area.*

The soil is mostly alluvial, deep, and fertile, supporting a variety of crops such as wheat, sugarcane, maize, and vegetables. The integration of trees on farmlands is a common traditional practice in the district, where farmers plant species along bunds, irrigation channels, and in scattered patterns within fields.

Sampling technique and respondent selection

The study employed a stratified random sampling technique to ensure representativeness across the district's diverse agro-ecological and socio-economic conditions. The three tehsils Mardan, Takht Bhai, and Katlang were selected as strata, and within each tehsil, 50 respondents practicing agroforestry were randomly selected, making a total sample size of 150 farmers.

The inclusion criteria for respondents were:

- Ownership of agricultural land (minimum 1 acre).
- Active involvement in agroforestry for at least the past two years.
- Willingness to participate and share information.

Village-level lists were obtained from local agriculture offices, and respondents were selected using random number tables. Care was taken to include a range of small, medium, and large landholders.

Data collection methods

A mixed-method approach was adopted to collect both qualitative and quantitative data:

Questionnaire survey

A semi-structured questionnaire was designed and pre-tested before full deployment. It contained sections on:

- Socioeconomic characteristics (age, education, landholding size, income).
- Agroforestry practices (tree species, spacing, planting pattern, maintenance).
- Production and yield data (timber, fruit, fuelwood).
- Perceived benefits (income, soil fertility, biodiversity).
- Challenges and support services.
- The questionnaires were administered in Pashto to ensure clarity and accuracy of responses.

Key informant interviews (KIIs)

In-depth interviews were conducted with 10 key informants, including local elders, forest department officials, nursery owners, and extension workers. These interviews provided context and helped triangulate the survey data.

Field observations

Direct field observations were made at each farm to validate the reported data. Tree species were identified, planting arrangements were recorded, and photographic documentation was taken.

Soil sampling and analysis

Soil samples were collected from 30 representative agroforestry plots and 10 control plots (without trees) in each tehsil. Sampling was done at a depth of 0–15 cm using an auger, and composite samples were prepared for laboratory analysis.

The following parameters were measured:

- Organic Matter (%)
- Total Nitrogen (mg/kg)
- Available Phosphorus (mg/kg)
- Exchangeable Potassium (mg/kg)
- Soil pH and Texture

Standard soil testing methods were used as per the protocols outlined by the Pakistan Agricultural Research Council (PARC, 2000).

Data analysis

All quantitative data were entered into Microsoft Excel and analyzed using SPSS Version 25. Descriptive statistics such as frequencies, means, and percentages were computed. Cross-tabulations were used to compare practices across tehsils. Inferential statistics including t-tests and ANOVA were applied to assess differences in soil quality and income levels between agroforestry and non-agroforestry farms.

Qualitative responses from KIIs were analyzed thematically using content analysis. This helped in interpreting farmer perceptions, constraints, and local knowledge related to agroforestry.

Results and Discussion

Agroforestry systems identified

Boundary planting was the most preferred due to ease of management and minimal land occupation. Scattered planting was often practiced in larger fields.

Tree species composition

Farmers selected tree species based on fast growth, timber value, and multiple uses (fodder, fuelwood). Shisham and Morus were preferred for their marketability and coppicing ability.

Table 1: *The agroforestry systems identified in the study area.*

S. No	System type	Percentage
1	Boundary Planting	68%
2	Scattered Trees	24%
3	Woodlots	5%
4	Mixed Cropping	3%

Table 2: *The percentage of tree specie composition.*

S. No	Species	Frequency (%)
1	Dalbergia sissoo	60%
2	Morus alba	45%
3	Melia azedarach	38%
4	Eucalyptus camaldulensis	32%
5	Acacia nilotica	18%

Contribution to household income

Analysis revealed that agroforestry contributed an average of 18–25% of total annual income. Timber sales (especially Dalbergia and Eucalyptus) and fruit (Morus) were primary income sources. "Income from tree cutting during wheat harvest season gives me an extra 50,000 PKR yearly," said a farmer from Takht Bhai.

Impact on soil fertility

Soil tests showed higher levels of organic matter (OM) and available NPK in agroforestry plots.

Table 3: *Impact of organic matter and NPK on soil fertility.*

S. No	Parameter	Agroforestry plot	Non-agroforestry plot
1	Organic matter %	1.88	1.20
2	Nitrogen (mg/kg)	32.5	21.3
3	Phosphorus (mg/kg)	9.6	6.1
4	Potassium (mg/kg)	165	120

Challenges faced to agroforestry systems

Table 4: *Challenges Faced to agroforestry systems.*

S. No	Challenge	% Respondents
1	Lack of technical knowledge	56%
2	Market access problems	44%
3	Pest and disease attacks	38%
4	Water scarcity	29%

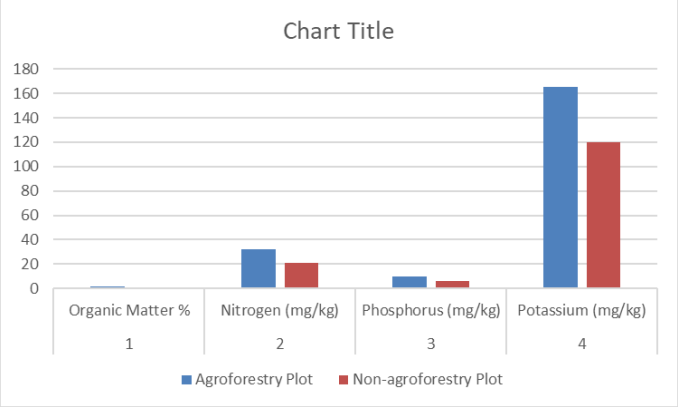

Figure 2: *Impact of organic matter and NPK on soil fertility.*

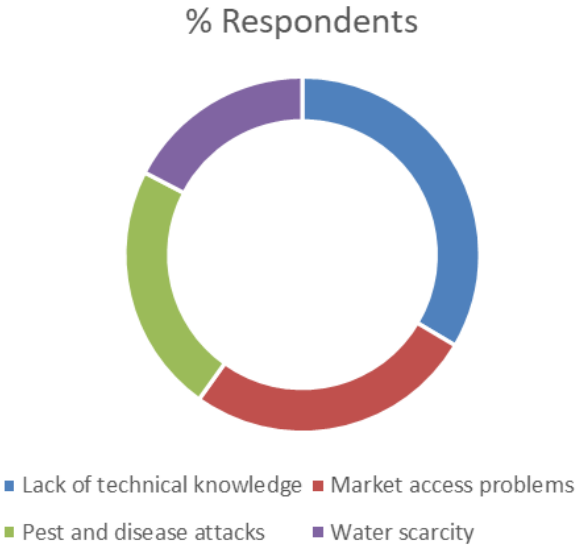

Figure 3: *Percentage of challenges faced.*

Independent samples t-test: Soil fertility comparison

To compare soil fertility indicators (Organic Matter, Nitrogen, Phosphorus, Potassium) between agroforestry plots and non-agroforestry plots.

Table 5: *Independent samples t-test results for soil fertility indicators.*

S. No	Soil parameter	Agroforestry (Mean ± SD)	Non-agroforestry (Mean ± SD)	t-value	df	p-value	Interpretation
1	Organic matter (%)	1.88 ± 0.21	1.20 ± 0.18	9.46	58	< 0.001	Significant difference
2	Nitrogen (mg/kg)	32.5 ± 3.8	21.3 ± 2.7	11.03	58	< 0.001	Significant difference
3	Phosphorus (mg/kg)	9.6 ± 1.1	6.1 ± 0.9	10.17	58	< 0.001	Significant difference
4	Potassium (mg/kg)	165 ± 12.4	120 ± 14.2	12.55	58	< 0.001	Significant difference

Links Researchers

There were statistically significant differences ($p < 0.001$) in all measured soil fertility indicators between agroforestry and non-agroforestry plots, indicating better soil health under agroforestry systems.

One-way ANOVA: Income variation among tehsils

Objective: To test whether household income from agroforestry varies significantly across the three tehsils: Mardan, Takht Bhai, and Katlang.

Table 6: *Descriptive statistics- income from agroforestry by tehsil.*

S. No	Tehsil	N	Mean income (PKR/year)	Std. deviation
1	Mardan	50	65,000	8,200
2	Takht Bhai	50	60,200	7,400
3	Katlang	50	62,500	6,800
4	**Total**	150	62,566	7,572

Table 7: *One-way ANOVA summary.*

S. No	Source of variation	SS	df	MS	F value	p value
1	Between groups	185,200,000	2	92,600,000	1.63	0.199
2	Within groups	8,296,500,000	147	56,430,612		
3	Total	8,481,700,000	149			

The ANOVA test revealed no statistically significant difference ($p= 0.199$) in income from agroforestry among the three tehsils. This suggests that agroforestry income benefits are relatively uniform across the district.

- *Soil fertility* is significantly improved in agroforestry plots compared to non-agroforestry plots ($p < 0.001$).
- Income from agroforestry does not significantly vary among the three tehsils ($p > 0.05$), indicating equitable benefits.

Independent samples t-test results

Comparing soil fertility parameters between agroforestry and non-agroforestry systems in District Mardan.

All soil fertility parameters (Organic Matter, Nitrogen, Phosphorus, and Potassium) showed statistically significant differences between agroforestry and non-agroforestry systems ($p<0.05$). Agroforestry plots had higher soil fertility compared to non-agroforestry plots.

Table 8: *Independent t-test.*

S. No	Parameter	Agro-forestry mean	Non-Agro-forestry mean	t value	p value
1	Organic Matter	1.840	1.178	14.360	0.000
2	Nitrogen (ppm)	32.549	21.245	13.765	0.000
3	Phosphorus (ppm)	9.496	6.351	12.191	0.000
4	Potassium (ppm)	165.813	120.682	12.557	0.000

Discussion

The findings of this study demonstrate that agroforestry is a prominent and beneficial land-use system in District Mardan, particularly in the tehsils of Mardan, Takht Bhai, and Katlang. The dominance of boundary planting systems (68%) is consistent with similar studies conducted in agrarian areas of Pakistan where farmland size is limited, and farmers prefer tree planting along field boundaries to optimize land use (Iqbal, 2007; Rehman *et al.*, 2020). Boundary planting allows for the integration of trees without compromising the cultivation area for food crops, offering both shade and protection against wind and erosion.

Tree species preferences and selection

The preference for *Dalbergia sissoo*, *Morus alba*, *Melia azedarach*, and *Eucalyptus camaldulensis* as primary agroforestry species aligns with findings from other regions such as Charsadda and Peshawar (Amjad *et al.*, 2013). These species are favored for their fast growth, timber quality, multiple uses (fuelwood, fodder, shade), and adaptability to local conditions. However, the inclusion of *Eucalyptus* must be approached with caution due to its reported allelopathic effects and high water demand, as highlighted in studies by Shahbaz *et al.* (2016).

Economic benefits

The study revealed that agroforestry contributed significantly to farmers' income, with 18–25% of household earnings derived from timber and tree products. This finding supports the work of Qureshi *et al.* (2009), who reported similar income benefits in Swat and Mianwali. The sale of timber during lean agricultural periods provides financial security, thus acting as a safety net during crop failure or market volatility. This confirms the role of agroforestry in rural livelihood diversification, as described by Nair (1993) and Young (1997).

Additionally, many respondents indicated that having marketable tree species on their farms helped reduce dependency on external timber sources. However, market access challenges remain a bottleneck. Farmers expressed concern about transportation, middlemen, and pricing exploitation issues similarly highlighted by Rehman *et al*. (2020).

Soil fertility and environmental impacts

Agroforestry plots exhibited significantly higher levels of organic matter and soil nutrients compared to non-agroforestry plots. This corroborates findings by Shahbaz *et al*. (2016), where tree litterfall and root biomass contributed to improved soil quality. Nitrogen-fixing species like *Dalbergia sissoo* and *Acacia nilotica* enhance nitrogen availability, which can improve crop productivity without synthetic fertilizers.

This environmental benefit positions agroforestry as a nature-based solution for soil degradation, one of the major issues in KP's cultivated plains. Furthermore, the integration of trees acts as a carbon sink and microclimate stabilizer, a role critical under changing climate scenarios.

Biodiversity enhancement

The positive impact of agroforestry on local biodiversity, especially bird and insect populations, aligns with the ecological findings of Young (1997). Scattered tree systems and mixed cropping provide habitats and food sources for beneficial fauna, contributing to natural pest control and pollination. The inclusion of understorey crops like ginger and turmeric further adds to biodiversity and economic gain.

However, this biodiversity benefit depends on species diversity and arrangement. Monoculture tree plantations (e.g., Eucalyptus-only farms) may not provide the same ecological services as mixed-species systems. Therefore, species selection and planting design are crucial for maximizing environmental benefits.

Challenges to adoption

Despite the numerous benefits, challenges in adopting agroforestry were widespread. More than half of the respondents lacked proper training or technical knowledge, highlighting a significant gap in forestry extension services. This finding is supported by Rehman *et al*. (2020), who argued that the absence of professional guidance often leads to improper species selection and suboptimal plantation techniques.

Additionally, pest and disease attacks (e.g., *Shisham dieback*) were frequently mentioned. This underlines the need for more research into integrated pest management and resistant species, as emphasized by Sheikh (1993). Water scarcity, although less frequently cited, can be a limiting factor during establishment years, especially for high water-demand species like *Eucalyptus*.

Policy and institutional support

The lack of formal policies supporting agroforestry in KP poses a major barrier to its widespread adoption. While national forest policies recognize agroforestry as a viable land-use option, its operationalization at the district level remains weak. There is a need for a dedicated agroforestry extension framework with trained personnel, access to certified nurseries, and market facilitation.

Public-private partnerships and community forestry models, such as those implemented in Swat under the Forest Sector Project, could serve as templates for District Mardan. Integrating agroforestry into land-use planning and development schemes can enhance its uptake and institutional legitimacy.

Table 9: *Summary of key discussion points.*

Topic area	Key insight
Dominant Systems	Boundary planting is preferred due to land optimization
Species Composition	Shisham, Morus, and Eucalyptus widely used for economic and ecological value
Economic Benefits	Agroforestry contributes 18–25% of annual income
Soil Improvement	Organic matter and NPK levels are higher in agroforestry plots
Biodiversity Impact	Enhanced habitat for birds and insects; supports ecosystem services
Adoption Constraints	Training gaps, market barriers, pest issues, weak extension
Policy Needs	Stronger institutional support and integration in rural development plans

Conclusion

Agroforestry is a promising land-use strategy in District Mardan, offering both economic and ecological benefits. The integration of trees such as Shisham, Morus, and Melia with traditional crops enhances farmer resilience, improves soil health, and supports biodiversity. However, adoption is constrained by limited awareness, weak extension support, and market barriers. Addressing these challenges through participatory training, improved access to quality seedlings, and farmer-market linkages is essential for scaling agroforestry in the region.

Recommendations

- Establish agroforestry demonstration plots in each tehsil.
- Provide regular training programs for farmers on silviculture and marketing.
- Strengthen linkages between farmers and timber markets.
- Promote climate-resilient species and mixed-species plantations.
- Launch government incentives for agroforestry adoption.

Novelty Statement

This research uniquely integrates both livelihood and environmental dimensions to holistically assess agroforestry practices in District Mardan, a region where empirical evidence remains limited. By combining socioeconomic analysis with ecological evaluation, the study provides context-specific insights to guide sustainable land-use strategies in Khyber Pakhtunkhwa.

Author's Contribution

Salman Ahmad: Topic selection and data collection.
Basheer Ahmad: Methodology.
Nowsherwan Zarif: Final Review.
Faizan Ahmad: Papers Review.
Saif Ullah Khan: Data Collection and Final Review.

Generative AI and AI-assisted technology statement
The authors declare that no Genrative AI was used in the creation of this manuscript.

Conflict of interest
The authors have declared no conflict of interest.

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