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Agroforestry in Saharanpur District: A Socio-economic Study

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ABSTRACT

Background: This study investigates the landholding patterns and agricultural practices in Saharanpur district, focusing on the adoption and economic implications of agroforestry systems, particularly poplar and eucalyptus-based models. The data, collected over two years, reveal that small and marginal farmers dominate the agricultural landscape, with wheat being the primary crop during the *Rabi* season. The study examines the role of agroforestry in enhancing farmers' income and resilience, highlighting the economic viability of poplar and eucalyptus-based agroforestry models. Cost-benefit analyses of both systems indicate positive net returns and favorable benefit-cost ratios, underscoring their potential as sustainable agricultural practices. Traditional agroforestry regions were driven by fuel wood, additional income and shade, while commercial agroforestry regions were driven by the additional income.

Methods: The most common agroforestry system which is accepted by the farmers of western Uttar Pradesh is poplar and eucalyptus-based agroforestry. Additionally, socio-economic factors influencing the adoption of agroforestry are explored, with farmers citing additional income and emergency funds as primary motivators.

Result: The findings contribute to understanding the dynamics of agroforestry adoption and its implications for rural livelihoods in Saharanpur district.

Key words: Agroforestry, Farmers, Market survey, Socio-economic.

INTRODUCTION

Agroforestry has been practiced in India for so many years. It is a combination of tree species with agricultural crops. Agroforestry has attracted the interest of farmers because they get so many additional benefits after adopting agroforestry. India has a variety of agroforestry systems, including trees on farms, community forestry and local forest management (Katariyya *et al.,* 2023). This system involves the integration of trees into traditional farming practices. Trees are planted alongside or within crop fields to provide shade, improve soil fertility through leaf litter and nitrogen fixation and generate additional income through the sale of timber, fruits and other tree products. This system helps enhance biodiversity and supports sustainable agricultural practices (Dwivedi *et al*., 2016). In this approach, local communities collectively manage forested areas or plantations. The community benefits from the resources these forests provide, including fuelwood, fodder and non-timber forest products. Community forestry promotes sustainable land use, enhances local governance and empowers local populations by involving them in decision-making processes related to forest management (Katariyya *et al*., 2023). This system involves the management of forests by local institutions or village councils. It focuses on conserving forest resources while ensuring that local communities can sustainably harvest forest products. Local forest management aims to balance ecological preservation with the socioeconomic needs of the community, fostering a sustainable relationship between people and their natural environment (Verma *et al.,* 2017).

Science and development planners have developed a great interest in agroforestry due to its ability to provide a variety of products, provide insurance against risk caused by weather aberrations, control erosion hazards and ensure sustainable production of intercrops. In western Uttar Pradesh, agroforestry has been adopted by many farmers. By doing agroforestry farmers can get crops, fuel, timber, fibers and so many things from a single land at one time. Agroforestry must play a leading role in achieving sustainability and diversification (Verma and Singh, 2021) There are significant differences in agroforestry practice based on agro-climatic zones, socioeconomic conditions and tree species specific to a site. In addition, agroforestry systems offer proven strategies for carbon sequestration, soil enrichment, biodiversity conservation and air- and water-quality improvement, which benefits landowners as well as society at large (Sarkar *et al.,* 2020). In Saharanpur, Uttar Pradesh (the study area), poplar (Populus deltoides) based agroforestry is widely practiced. The farmers of district Saharanpur have a keen interest in agroforestry (Pradhan *et al.,* 2022). The current situation of agroforestry in district Saharanpur is that about 78% of farmers have adopted

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agroforestry. There are so many impacts of agroforestry on different components like ecological, environmental, climate change and most importantly social and economic status of farmers. This paper discussed the socio-economic impacts of agroforestry on those farmers who have adopted agroforestry. In the district Saharanpur, one of the common agroforestry systems is "Agrisilviculture" which means crops grown with trees. Farmers are growing poplar as an agroforestry crop on their fields, primarily for sale, on an increasing scale In the district, Saharanpur agroforestry is practiced on a large scale. Farmers are adopting agroforestry because it increases their income. In agroforestry, they get fuelwood, fibers, crops, etc. on the same land. In different climatic zones of India, different kinds of agroforestry systems are practiced. India's agroforestry systems perform various ecological, socioeconomic and economic functions, but they are only complementary - and not an alternative to natural ecosystems. In agroforestry, trees both on and off-farm are expected to support land management and sustainable land use while at the same time protecting the environment (Chavan *et al.*, 2021).

Agroforestry, the practice of integrating trees and shrubs into agricultural landscapes, is recognized for its potential to enhance biodiversity, improve soil health and boost agricultural productivity. In Saharanpur district, located in Uttar Pradesh, India, agroforestry practices are being increasingly adopted to address both environmental and socioeconomic challenges (Surya *et al.,* 2023). This study aims to explore the socio economic impacts of these practices in the region, building on existing research and understanding of agroforestry systems.

Previous studies have shown that agroforestry can significantly contribute to sustainable agriculture and rural development. For instance, Dhyani (2018) highlighted the role of agroforestry in tropical regions, emphasizing its potential for enhancing food security and income stability. In India, Verma *et al.* (2017) found that agroforestry systems improved soil quality and increased farmers' resilience to climate change. Specifically, in the context of Uttar Pradesh, demonstrated that agroforestry practices led to higher economic returns compared to traditional monoculture systems (Tripathi *et al.,* 2023).

Traditional agroforestry systems in Saharanpur include homegardens and agrosilvicultural systems. Homegardens are small-scale, family-managed plots that combine various crops, fruit trees and sometimes livestock, designed to meet household food and medicinal needs. These gardens provide a diverse range of products throughout the year. Agrosilvicultural systems involve growing agricultural crops and trees on the same plot of land, with common combinations including wheat or maize intercropped with poplar or eucalyptus trees.

Commercial agroforestry systems in the region feature poplar and eucalyptus plantations, which are widely adopted due to their fast growth and high market demand. Farmers integrate these trees with cash crops like sugarcane and wheat, optimizing land use and increasing profitability. Additionally, silvopastoral systems combine trees with livestock grazing areas, where trees provide shade and fodder for animals, while the livestock contribute manure, enhancing soil fertility.

Agroforestry systems in India also encompass trees on farms, community forestry and local forest management. The integration of trees into traditional farming practices involves planting trees alongside or within crop fields to provide shade, improve soil fertility through leaf litter and nitrogen fixation and generate additional income through the sale of timber, fruits and other tree products. This system enhances biodiversity and supports sustainable agricultural practices.

Community forestry involves local communities collectively managing forested areas or plantations, benefitting from resources such as fuelwood, fodder and non-timber forest products. This approach promotes sustainable land use, enhances local governance and empowers local populations by involving them in decision-making processes related to forest management.

Local forest management entails the management of forests by local institutions or village councils, focusing on conserving forest resources while ensuring sustainable harvesting of forest products by local communities. This system aims to balance ecological preservation with the socioeconomic needs of the community, fostering a sustainable relationship between people and their natural environment.

The study explores various agroforestry systems in the Saharanpur district of Uttar Pradesh, India, emphasizing the integration of trees with agricultural crops to enhance economic viability and sustainability. Traditional agroforestry systems, such as homegardens and agrosilvicultural systems, are prevalent. These systems involve the combination of crops, fruit trees and livestock, providing diverse and year-round benefits. Homegardens meet household food and medicinal needs, while agro-silvicultural systems involve intercropping trees like poplar or eucalyptus with crops such as wheat and maize. Agroforestry practices in India, such as trees on farms, community forestry and local forest management, reflect the integration of trees into traditional farming, collective management of forest resources and sustainable harvesting practices. These systems contribute to biodiversity, sustainable land use and enhanced local governance. The study underscores the importance of agroforestry in improving agricultural sustainability, economic viability and resilience to environmental stresses, offering valuable insights for farmers and policymakers in the region.

Study area

In western Uttar Pradesh, Saharanpur district is situated at the northern end of the upper Ganges-Yamuna Doab about 35 miles (56 km) west-northwest of Haridwar, Uttarakhand. There are approximately 0.34 million ha of land in the district, of which 0.15 million ha are devoted to agriculture. In district Saharanpur, wheat, paddy and

sugarcane are the main crops as shown in Fig 1. The main agroforestry system practiced in the district Saharanpur is Agri silviculture (tree + crops). Saharanpur district is situated in the northern part of Uttar Pradesh, lying between 29.57°N latitude and 77.70°E longitude. The district's altitude ranges from approximately 268 meters above sea level in the plains to slightly higher elevations towards the northwestern parts near the Shivalik hills. Saharanpur experiences a humid subtropical climate with three distinct seasons: summer, monsoon and winter.

Temperature

Maximum temperature: Summers can be quite hot with maximum temperatures reaching up to 45°C.

Minimum temperature: Winters are relatively cool with minimum temperatures dropping to around 4°C.

Precipitation

The district receives an average annual rainfall of about 1100 mm, predominantly during the monsoon season from June to September. The monsoon contributes to about 80% of the total annual precipitation.

MATERIALS AND METHODS

Sampling

In the district of Saharanpur, the adoption rate of agroforestry is very high. Farmers were selected randomly from the villages which are within the 100 km range of the district Saharanpur. Surveys and interviews were conducted with both agroforestry practitioners and those who do not practice agroforestry to compare their socioeconomic conditions. Data on crop yields, income levels and land use patterns were collected and analyzed to assess the impact of agroforestry practices. Ten villages were selected for the survey. From each village, 10 farmers were interviewed. The farmers were categorized based on landholding size. There were three categories of farmers-

1. Small (1-5 acre)
2. Marginal (5-10 acres)
3. Large (>10 acres)

Village selection

The villages were selected randomly from the district Saharanpur of Uttar Pradesh. A total of 10 villages were selected these 10 villages come under the tehsil named Rampur Maniharan. The selection of the 10 villages was solely based on randomness. This means that each village had an equal chance of being chosen without any bias or additional criteria influencing the decision. The process was designed to ensure that the sample is representative and unbiased, which is important for the integrity of the study or project in question.

Data collection

For primary data collection, besides a questionnaire survey focus group discussion was also held with the farmers who had adopted Agroforestry in their farmland. In this particular questionnaire, questions about farmers' demographic profiles and land or agricultural profile were included. Based on this questionnaire the interviews were conducted with farmers in selected villages.

1. Questionnaire design

A structured questionnaire was developed to collect both quantitative and qualitative data. The questionnaire included sections on demographic information, landholding patterns, types of crops grown, agroforestry practices, input costs, returns and socio-economic factors influencing the adoption of agroforestry.

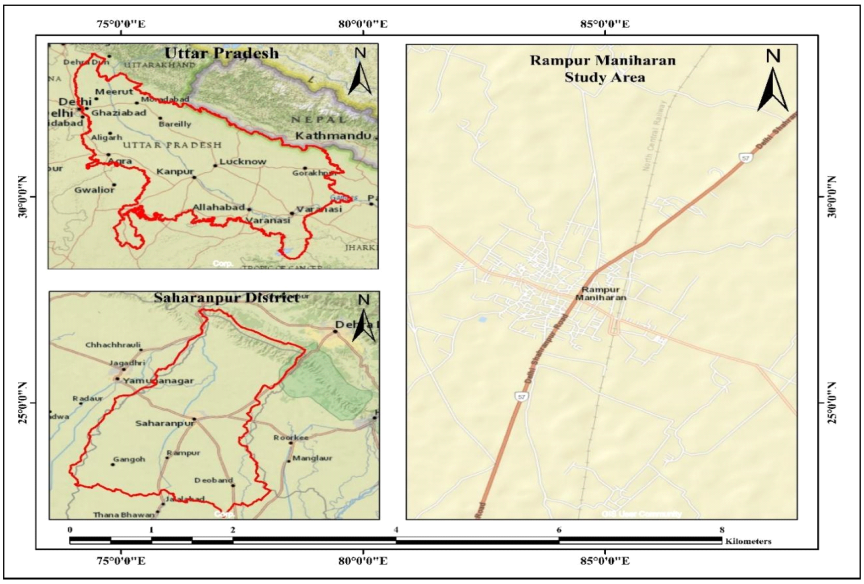


Fig 1: Study area map (Katariyya *et al.,* 2023).

Questions were a mix of open-ended and close-ended types to capture detailed information and to facilitate easy analysis.

2. Interviews

Face-to-face interviews were conducted with the sampled farmers to gather detailed insights into their agricultural practices, the challenges they face and the benefits they perceive from agroforestry.

3. Field observations

Direct observations were made during field visits to document the types of crops grown, the spacing and density of tree plantations and the interactions between crops and trees.

4. Focus group discussions

Focus group discussions (FGDs) were held with groups of farmers to discuss the broader impacts of agroforestry on their livelihoods and to cross-validate the data obtained from the questionnaires and interviews.

Ensuring reliability and validity

1. Pilot testing

The questionnaire was pilot-tested with a small group of farmers to identify and rectify any ambiguities or issues. Based on the feedback, necessary adjustments were made to ensure clarity and comprehensiveness.

2. Triangulation

Data triangulation was employed by using multiple data collection methods (questionnaires, interviews, field observations and FGDs) to cross-verify the information and enhance the reliability of the findings.

3. Training of enumerators

Enumerators were trained extensively on data collection procedures, the use of the questionnaire and ethical considerations to ensure consistency and accuracy in data collection.

4. Statistical analysis

Descriptive statistics, including means, standard deviations and percentages, were calculated to summarize the data. Basic inferential statistics were used to compare the economic returns from different agroforestry systems and to assess the significance of differences observed.

Data analysis

After completing the primary data collection through interviews with farmers the data were tabulated and analyzed. The respondents were categorized into different categories based on land size. Benefit-cost analysis and tabular analysis were mostly used to examine the study's data. The formulas of benefit-cost analysis:

$$\text{Net return} = \frac{\Sigma Bt}{(1+i)\,t} - \frac{\Sigma Ct}{(1+i)\,t} \quad \text{...Eq (1)}$$

Where

ΣBt = Total occurred benefits for a period of t years.

ΣCt= Total occurred cost for a period of t years.

i= Discount rate.

t= Time period.

$$\text{Annual average return} = \frac{\Sigma Bt}{(1+i)\,t} - \frac{\Sigma Ct}{(1+i)\,t} / T \quad \text{...Eq (2)}$$

Where,

ΣBt = Total occurred benefits for a period of t years.

ΣCt= Total occurred cost for a period of t years.

i= Discount rate.

t= Time period.

T= Year of crop rotation.

$$\text{Benefit-cost ratio} = \frac{\frac{\Sigma Bt}{(1+i)t}}{\frac{Ct}{(1+i)t}} \quad \text{....Eq (3)}$$

Where,

ΣBt = Total occurred benefits for a period of t years.

ΣCt= Total occurred cost for a period of t years.

i= Discount rate.

t= Time period.

RESULTS AND DISCUSSION

Agroforestry emerges as a promising avenue for enhancing farmers' income and resilience in Saharanpur district. The integration of trees with agricultural crops offers various ecological, economic and social benefits, ranging from soil fertility improvement to diversification of products. Poplar and eucalyptus-based agroforestry models, in particular, demonstrate economic viability, with positive net returns and favorable benefit-cost ratios. The findings suggest that investing in agroforestry can contribute to rural development and poverty alleviation by providing additional sources of income and promoting resource-efficient agricultural practices.

Socio-economic factors play a significant role in driving the adoption of agroforestry among farmers in Saharanpur district. The pursuit of additional income and emergency funds motivates farmers to integrate trees into their agricultural landscapes, while factors such as employment and fuelwood also influence adoption decisions. Understanding these factors is crucial for designing effective policy interventions and extension programs to promote sustainable agroforestry practices and support rural livelihoods.

Hence the study underscores the importance of agroforestry as a sustainable land use practice with significant potential to improve livelihoods, enhance

Table 1: Landholding pattern.

Farmer's category	Farmer's percentage	Landholding (average)In acre
Small (1-5 acre)	17 (17%)	2.53
Marginal (5-10 acres)	51 (51%)	5.71
Large (>10 acres)	32 (32%)	23.95

Source: Primary data collection.

ecosystem services and contribute to food security and environmental sustainability in Saharanpur district and similar agroecological contexts. Further research is warranted to explore the long-term socio-economic and environmental impacts of agroforestry adoption and identify strategies for scaling up and mainstreaming these practices in agricultural landscapes.

According to the results of the socioeconomic studies conducted in the villages of the Saharanpur district, it's evident that most of the farmers have marginal landholdings as shown in Table 1. Marginal landholdings, comprising approximately 51% of the surveyed farmers, are defined as landholdings ranging from 5 to 10 acres. This percentage suggests that a significant portion of the farmers in the region operate on smaller plots of land. In comparison, small landholdings, ranging from 1 to 5 acres, account for approximately 17% of the surveyed farmers, while large landholdings, exceeding 10 acres, make up the remaining 32%. This distribution reflects the predominance of smaller and medium-sized farms in the area. It's worth noting that despite their smaller size, these marginal and small landholdings play a crucial role in agricultural production. The most common crop combination observed in these villages is poplar with wheat or paddy. This information underscores the importance of understanding the landholding patterns and agricultural practices of farmers in the region, which can inform targeted interventions and support mechanisms to enhance agricultural productivity and livelihoods. The study findings shed light on the agricultural landscape and agroforestry practices in Saharanpur district, providing valuable insights into landholding patterns, crop cultivation and the economic potential of agroforestry systems. The predominance of small and marginal farmers underscores the importance of sustainable and income-generating agricultural practices to support rural livelihoods.

Table 2: Cost-benefit analysis of poplar-based AF in district Saharanpur.

Particulars	Amount (Rs.) per annum
Input cost of trees	6467
Input cost of crop	66780
Total input cost	73247
Return from trees	60000
Return from crops	150000
Total return	210000
Net return	136753
Annual average return	19536
Benefit-cost ratio	2.86

Table 3: Cost-benefit analysis of eucalyptus-based AF in district Saharanpur.

Particulars	Amount (Rs.) per annum
Input cost of trees	8790
Input cost of crop	66780
Total input cost	75570
Return from trees	50000
Return from crops	150000
Total return	200000
Net return	124430
Annual average return	17775
Benefit-cost ratio	2.64

Table 4: Factors affecting the adoption of agroforestry in the district Saharanpur.

Factors	No. of farmers	Percentage
Additional income	70	71.69%
Emergency money	18	16.98%
Employment	3	2.83%
Fuelwood	9	8.49%
Total	100	100%

Agriculture details

Agriculture is the primary economic activity in Saharanpur. Agricultural products will continue to be in high demand worldwide for the foreseeable future The main crop of the winter season in the district of Saharanpur is wheat. Winter crops are sown in October-November and harvested in March-April. Kharif crops are sown at the beginning of May-June and harvested in October. Small areas of farmland are devoted to Intermediate crops like lentils, vegetables and spices. Paddy is the main crop of the *Kharif* season. The agricultural sector occupies 75.61 per cent of the land (Rajput *et al.*, 2019).

Two years were spent conducting the study (2021-2022). The study was mainly for "wheat, paddy and Poplar tree". The main pattern of tree growing was boundary plantation. The plantation of trees on the boundary was done at about 1.5 m spacing. Generally, the harvesting time of poplar trees is 5 years. The survey was started in April 2021 summer (*Kharif* season) for paddy crops and October 2021(*rabi* season) for wheat crops. It was observed that the shade of poplar trees affects the crop. Boundary plantation is followed by more farmers because it gives less shade to the main crop. There are many impacts of shade on crops the major impact is the small size of grains.

Agroforestry in western Uttar Pradesh

An agricultural forest is one where trees are intentionally grown at the same time as agricultural crops for mutual benefit and service. These systems, which include a variety of techniques including contour farming, intercropping, established shelterbelts, riparian zones/ buffer strips, *etc*., are purposefully created and managed to optimize beneficial interactions between the tree and non-tree components (Indu Murthy *et al.,* 2016). Within the last few years, other parts of central and eastern UP have been attracted to remunerative agroforestry projects after the successful adoption and commercialization of poplar and eucalyptus-based agroforestry models in western UP (Verma *et al.,* 2017). In western Uttar Pradesh agroforestry is practiced on a large scale. In addition to being the most populous state, UP is

the largest contributor to the country's food grain stock. In comparison to other parts of the state, Western UP has more advanced methods of agriculture and agroforestry.

Agroforestry systems in this area have been extensively refined, facilitated by the presence of wood-based industries that encourage farmers to engage in tree-based agroforestry practices to fulfill their raw material requirements (Dwivedi *et al.,* 2016).

Farmers usually integrate eucalyptus, bamboo and poplar with agricultural crops in an Agri-silviculture system. Farmlands with agricultural crops have been cultivated with trees for additional income (Malagi *et al.,* 2023). Planters and farmers can take advantage of the high demand for wood as raw material and gain access to various wood-based industries. Farmers in the block and boundary plantations throughout the state highly encourage the use of poplar trees since they are fast-growing, deciduous trees that can be harvested within six to eight years.

According to Verma *et al.* (2017), the successful adoption and commercialization of poplar and eucalyptus-based agroforestry models have spurred interest in similar practices across central and eastern Uttar Pradesh. These models are particularly prevalent in western Uttar Pradesh, where advanced agricultural techniques are more commonly practiced compared to other parts of the state.

Yadav *et al.* (2018) describe agroforestry systems as intentionally designed to optimize beneficial interactions between trees and crops. In western Uttar Pradesh, popular systems include contour farming, intercropping and established shelterbelts. These methods have been shown to improve soil fertility, enhance biodiversity and provide multiple revenue streams for farmers.

Studies have highlighted the economic viability of agroforestry in this region. Handa *et al.* (2020) emphasize that integrating trees with crops can lead to higher returns per unit area due to the diverse range of products generated, such as timber, fruits and fodder. Furthermore, these practices contribute to soil conservation and water management, essential for sustainable agriculture (Indu *et al.,* 2016).

The role of poplar and eucalyptus trees in agroforestry systems has been particularly significant. Research has demonstrated that these fast-growing trees can be effectively combined with crops like sugarcane, wheat and paddy. This combination not only optimizes land use but also enhances the overall productivity and profitability of agricultural systems. The preference for boundary plantations is common among farmers, as it mitigates the shading effect on crops while still providing economic benefits from tree products.

In summary, previous studies underscore the successful implementation and economic benefits of agroforestry in western Uttar Pradesh. The integration of trees and crops has proven to be a sustainable agricultural practice that enhances productivity, conserves resources and provides multiple income opportunities for farmers in the region.

Poplar-based agroforestry

Farmers in the study area generally combine agricultural crops with poplar tree plantations. They have established poplar trees as the cornerstone of farmer-led, market-oriented agroforests in north India, finding that cultivating poplar alongside agricultural crops is manageable. During field visits, a combination of crops such as sugarcane, wheat, paddy and berseem fodder was observed alongside poplar trees. Farmers have demonstrated the effectiveness and feasibility of poplar-based agroforestry models (Chavan and Dhillon, 2019). They recognize that the density of the plantation is crucial for successful intercropping with poplars, opting for wider gaps to ensure adequate sunshine for crop growth and efficient soil preparation. Poplar-based agroforestry models align well with the region's economics, as evidenced by interventions aimed at enhancing economic sustainability. Farmers prefer boundary plantation models based on poplar, investing significantly in crops like sugarcane, wheat and paddy along boundaries. This integration of trees and crops has the potential to generate higher returns per unit area. For instance, a study on silvoarable agroforestry in Europe found that 0.9 hectares of wheat and 0.4 hectares of poplars planted in alternate strips produced the same amount of grain as one hectare of wheat alone (Zahoor *et al.*, 2020).

Table 2 demonstrate cost-benefit analysis of poplar-based agroforestry (AF) in Saharanpur district reveals crucial insights into the economic viability of this agricultural practice. The initial investment in poplar trees and crop cultivation forms the input costs of this agroforestry system. The expenditure for establishing and maintaining poplar trees amounts to Rs. 6467 per annum, while the cost incurred in cultivating crops stands at Rs. 66780 per annum. Consequently, the total input cost sums up to Rs. 73247. The returns from the poplar-based agroforestry system encompass proceeds from the sale of poplar trees and the harvest of crops. The revenue generated from poplar trees is Rs. 60000, complemented by Rs. 150000 from crop harvests, culminating in a total return of Rs. 210000.Upon deducting the total input cost from the total return, the net return emerges, representing the profit attained from the agroforestry endeavor. In this instance, the net return amounts to Rs. 136753. The annual average return, calculated by dividing the net return by the number of years, provides a nuanced understanding of the system's profitability over time. Here, the annual average return stands at Rs. 19536 per annum.The benefit-cost ratio, a pivotal metric for evaluating investment efficiency, is calculated by dividing the total return by the total input cost. With a benefit-cost ratio of 2.86, the analysis suggests that for every rupee invested, a return of approximately Rs. 2.86 is generated.

In summation, the comprehensive cost-benefit analysis underscores the favorable economic prospects associated with poplar-based agroforestry in Saharanpur district. With a positive net return and a robust benefit-cost

ratio, investing in this agricultural practice emerges as a promising avenue for farmers, promising substantial economic gains.

Eucalyptus-based agroforestry

Eucalyptus is also grown on the boundaries of farmers' fields with crops like; wheat, paddy and sugarcane. Goats, lambs and cattle do not enjoy eating *Eucalyptus globulus* trees. Because they are positioned in either an east-west or north-south orientation, they offer a notable advantage as border planting when planted with the suggested interrow spacing (Rajput *et al.,* 2019) . Near tube wells, work huts, farmer residences, cow barns, or in rows along farm routes, irrigation channels, along the field border, the boundary of fruit orchards, or in agricultural fields, eucalypts are typically planted distributed in singles or multiples (*Eucalypts-in-Agroforestry*, n.d.). In this setting, eucalyptus borders begin to yield a harvestable tree crop four to five years after being planted. The spacing, density, kind and character of the existing bund plantation, as well as their impacts on shade, including effects on morphology (internode length, leaf area and effects on flower initiation/fruit-set of related crops), all affect production (Raj *et al.,* 2014).

Eucalyptus-based agroforestry systems have been extensively studied for their economic viability and environmental benefits. Planting eucalyptus trees alongside or around agricultural crops offers advantages such as additional income, improved soil fertility and enhanced biodiversity.

Several studies highlight the economic benefits, noting that eucalyptus trees are preferred by farmers for their fast growth and high market demand for timber (Sharma *et al.*, 2016). Integrating eucalyptus with crops like wheat, paddy and sugarcane can significantly boost farm income by diversifying revenue sources.

Environmentally, eucalyptus trees improve soil health and structure. Singh *et al.* (2021) found that their deep root systems reduce soil erosion and increase water infiltration, enhancing soil moisture retention. Additionally, the leaf litter from eucalyptus trees adds organic matter to the soil, improving fertility over time (Singh *et al.,* 2015). Biodiversity also benefits from eucalyptus plantations, which create habitats for various plant and animal species, thus increasing overall biodiversity (Prasad, 2018). This is particularly important in areas where monocropping has reduced biodiversity.

Productivity studies indicate positive outcomes. Chaturvedi *et al.* (2016) observed that eucalyptus trees, when planted in strategic orientations, provide optimal shading without significantly impacting crop yields. This ensures crops receive adequate sunlight while benefiting from the protective presence of eucalyptus trees.

In summary, previous studies on eucalyptus-based agroforestry in western Uttar Pradesh demonstrate their multifaceted benefits, enhancing economic returns, environmental sustainability and biodiversity. The strategic integration of eucalyptus trees with crops offers a viable and sustainable farming approach, aligning well with the region's socio-economic and ecological needs.

The cost-benefit analysis of eucalyptus-based agroforestry (AF) in Saharanpur district, as depicted in Table 3, sheds light on the financial implications of this agricultural practice. The input costs associated with establishing and maintaining eucalyptus trees and cultivating crops form the foundation of the analysis. It's revealed that the input cost for trees amounts to Rs. 8790 per annum, while the input cost for crops remains consistent at Rs. 66780 per annum. Consequently, the total input cost is estimated at Rs. 75570. The returns generated from the eucalyptus-based AF system are sourced from the sale of eucalyptus trees and the yield of crops. Specifically, the return from eucalyptus trees is Rs. 50000, supplemented by Rs. 150000 from crop harvests, resulting in a total return of Rs. 200000. After accounting for the total input cost, the net return is calculated, representing the profit accrued from the eucalyptus-based AF endeavor. In this scenario, the net return stands at Rs. 124430.

The annual average return, calculated by dividing the net return by the number of years, offers insight into the average profitability of the system per annum. Here, the annual average return is determined to be Rs. 17775. The benefit-cost ratio, a key metric for assessing investment efficiency, is computed by dividing the total return by the total input cost. With a benefit-cost ratio of 2.64, the analysis suggests that for every rupee invested, a return of approximately Rs. 2.64 is realized.

Regarding the comparison between the net return from the poplar system and the eucalyptus-based AF, statistical significance testing would indeed provide a more rigorous analysis. Without statistical significance testing, it's challenging to definitively confirm that the net return from one system is better than the other.

Crop combination

In the various types of agroforestry, farmers had grown a mixture of agricultural crops and tree crops, as described earlier. A majority of the respondents admitted to growing wheat since it is the most common crop. It is followed by paddy and sugarcane crops. Food for farming families was the primary objective of growing these crops. The distance from the tree root has a substantial impact on grain crop production (Raj *et al.,* 2014). For additional income, these crops were also used as a source of export income. Alternatively, crop residues were used as cattle fodder or as dry fuel by them. In response to a question about extra quantities of crop residues and cereal grains, adopters stated that they were often purchased by local people. Agroforestry shows a high probability that in most cases farmers will invest in agroforestry over the long term because the nature and production of agricultural crops not only meet their food needs but also provide economic rewards (Chavan and Dhillon, 2019). *Mangifera indica* (mango), *Dalbergia sissoo*, *Azadirachta indica* (neem) and other species were also noticed in agroforestry on a few farmers' fields, primarily around the field edges. Jamun can be used alone or in combination with Poplar or Eucalyptus.

Effects of poplar trees on crops

The main effect of poplar trees is shading. Due to the shading effect crops don't get enough sunlight, it is observed that when the crops are under the shade of trees the grain yield is comparatively small. Farmers prefer boundary plantations then block plantations because of the shading effect. The shading effect of poplar trees in agroforestry systems has been a topic of interest in agricultural research. While poplar trees offer various benefits such as timber production and soil conservation, their shading effect can impact crop growth and yield.

Numerous studies have documented the negative impact of shading on crop productivity in agroforestry systems. For instance, research by (Singh *et al.*, 2015) highlights that shading from trees can reduce crop yields by limiting sunlight availability and altering microclimate conditions. Similarly, findings from a study by Kumar *et al.*, (2016) demonstrate that crops grown under the shade of trees exhibit reduced photosynthetic activity, leading to lower biomass production and grain yield.

The preference for boundary plantations over block plantations due to the shading effect has also been documented in the literature. Farmers often opt for boundary plantations where trees are planted along field boundaries to minimize shading on crops grown in the central portion of the field. This strategy allows for better sunlight penetration to the crops, resulting in improved growth and yield. In contrast, block plantations, where trees are densely planted within the field, can exacerbate shading and lead to greater yield reductions.

Moreover, studies have explored various management strategies to mitigate the shading effect of trees on crops in agroforestry systems. These strategies include selective pruning of trees to allow more sunlight penetration, intercropping with shade-tolerant crops and adjusting tree spacing to optimize light distribution. For example, research by Sarkar *et al.* (2020) suggests that careful management of tree density and arrangement can minimize shading while maximizing the benefits of agroforestry systems.

Therefore while poplar trees offer several advantages in agroforestry systems, their shading effect can negatively impact crop productivity. Farmers' preference for boundary plantations over block plantations reflects the recognition of this shading effect (Pant *et al.*, 2023). Effective management strategies are essential to minimize shading and optimize the coexistence of trees and crops in agroforestry systems, ultimately enhancing overall system productivity and sustainability.

Socio-economic factors influencing the adoption of agroforestry

Farmers in the study area are implementing agroforestry for a number of reasons. Farmers in the Saharanpur district who participated in a sample interview were used to determine the factors impacting agroforestry. Several factors like additional income, emergency money, fuel wood, *etc.* are influencing farmers to adopt agroforestry. The majority (71.69%) of the farmers in the entire sample have said that agroforestry is a source of additional revenue. According to farmers, the additional factors that affect agroforestry are monetary reserves for emergencies (16.98%), employment (2.83%) and fuel wood (8.49%).

Table 4 provides insights into the various factors contributing to additional revenue generation for farmers, based on the responses of a sample of 100 farmers.

The majority of farmers, comprising 71.69% of the sample, identified additional income as a significant factor contributing to their revenue. This additional income could stem from diverse sources such as off-farm employment, non-agricultural activities, or supplementary agricultural practices like agroforestry, livestock rearing, or value-added product processing. The pursuit of additional income reflects farmers' efforts to diversify their revenue streams and enhance financial stability. A notable portion of farmers, accounting for 16.98% of the sample, cited the need for emergency funds as a factor influencing their revenue generation. Emergency money serves as a financial safety net to address unforeseen circumstances such as crop failure, medical emergencies, or natural disasters. Farmers prioritize building emergency reserves to mitigate the financial impact of unexpected events, ensuring resilience in the face of adversity. A smaller percentage of farmers, constituting 2.83% of the sample, identified employment as a source of additional revenue. This likely refers to off-farm employment opportunities, where farmers engage in wage labor or entrepreneurial ventures outside of agriculture to supplement their income. Off-farm employment provides farmers with alternative income streams, diversifying their livelihood portfolio and reducing dependence solely on agricultural earnings.

A minor segment of farmers, representing 8.49% of the sample, highlighted fuelwood as a factor contributing to their revenue generation. Fuelwood serves as a vital resource for rural households, particularly in areas where access to modern energy sources is limited. Farmers may engage in the sustainable harvesting and sale of fuelwood from agroforestry systems or natural woodlots, providing an additional source of income while meeting household energy needs.

Overall, the table underscores the multifaceted nature of revenue generation for farmers, encompassing diverse factors beyond traditional agricultural activities. Employment, in particular, represents an opportunity for farmers to leverage their skills and labor to earn supplementary income. By exploring off-farm employment opportunities and diversifying revenue streams, farmers can enhance their financial resilience and improve livelihood sustainability in rural communities.

CONCLUSION

In Saharanpur, commercial agroforestry is primarily adopted for assured income, while traditional agroforestry focuses on fuel wood. Traditional systems, though less profitable than poplar-based commercial agroforestry,

integrate trees, crops and livestock for sustainability and biodiversity. They enhance soil fertility, microclimate and risk mitigation, reflecting local contexts and indigenous knowledge. Commercial systems prioritize high-value crops and modern techniques for profit. Both systems benefit farmers by improving income, employment and soil fertility. Future research should optimize eucalyptus-based agroforestry for economic and environmental benefits, explore planting strategies and study long-term impacts on soil health and biodiversity.

Conflict of interest

There is no conflict of interest among all authors.

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