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Environmental benefits by adopting agroforestry systems: A case study in the Bundelkhand region of central India

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Abstract
The purpose of this study is to examine the environmental advantages of implementing agroforestry in the Garhkundar-Dabar (GKD) watershed through a focus group of households. Agroforestry is the term used to describe a group of land-use systems where woody perennials (trees, shrubs, etc.) are grown alongside herbaceous plants (crops, pastures) or livestock, either in a spatial arrangement, a rotation, or both; these interactions are typically both ecological and commercial. Understanding the effects of agroforestry on the ecosystem in the Garhkundar-Dabar watershed in central India is the primary goal of this project. The benefits to the environment, farmers' desire, reduced runoff, increased soil fertility, and study area climate change are all interpreted in this study.

Keywords: Agroforestry, runoff, soil fertility, environment and climate change

Introduction
While tree-agriculture techniques have been used for thousands of years, the name "agroforestry" was first used in 1977 [4]. "Growing trees on farms" is the most basic definition of agroforestry [28]. "Agroforestry refers to a group of land-use systems where woody perennials, such as trees and shrubs, are grown alongside herbaceous plants, such as crops and pastures, or livestock. These plants are arranged spatially, rotate, or both, and there are typically interactions between the trees and other system elements on both an ecological and economic level" [16]. This is an example of integrated land use, which integrates forestry and agricultural components into a system of sustainable production. Here, controlling complexity is more important than minimising it. Agroforestry is a method of managing natural resources that is "dynamic, ecologically-based, and based on the ecosystem of natural woodlands" [15]. Greater structural and functional complexity, a focus on multipurpose trees, and the production of various outputs balanced with protection of the resource base are key traits that set agroforestry systems apart from agriculture and forestry [19]. Agroforestry can help achieve the Millennium Development Goals of reducing hunger, poverty, disease, illiteracy, environmental degradation, and discrimination against women, according to six approaches highlighted by the World Agroforestry Centre (ICRAF) [10].

1. Use agroforestry techniques for land regeneration and soil fertility to end hunger.
2. Use locally based, market-driven tree-cultivation methods to create assets and produce money in order to lessen poverty.
3. Improve the rural poor's diet and general health.
4. Conserve biodiversity by using integrated conservation-development strategies based on agroforestry.
5. Preserve the services provided by watersheds and make it possible for the underprivileged to get paid for them.
6. Assist the impoverished in rural areas to adjust to climate change and reap the rewards of growing carbon markets [10].

Degradation of production base, high livestock and human population pressure, and absolute poverty are some of the issues that most emerging countries, including India, are facing and cannot be solved. [9]. The 142 million hectares of arable land in India, of which 65% are rainfed, have very poor productivity (1–1.5 Mg/ha), mostly because of the low 35–45% rainwater use efficiency for crop cultivation. In these regions, integrated watershed management has emerged as a key strategy for livelihood security and resource preservation. A partnership led by ICRISAT conducted a thorough evaluation of watershed programmes in India, including a meta-analysis of 627 case studies. Bundelkhand's agroecosystem is typified by its rough, undulating terrain, heavily eroded and dissected land, poor soil fertility, limited groundwater resources, irregular rainfall that causes frequent droughts, subpar irrigation systems, high biotic pressure on the forests, insufficient vegetation cover, and frequent crop failures that leave farmers short on food, fodder, and fuel [20].

The implementation of agri-environment programmes to motivate farmers to use agroforestry and other sustainable techniques. Traditionally, agroforestry has provided fruits, forage, fuel, fibre, and other household necessities. In ecologically vulnerable habitats, tree crops have been widely planted as a means of replenishing the protective cover and improving soil fertility [1, 21]. Through the restoration of degraded land and microclimate control, agroforestry has balanced environmental conditions while increasing productivity. Agroforestry not only creates jobs for millions of people but also supplies 40% of forest products and more than 95% of fuel wood. Now that organised agroforestry research is over sixty years old, agroforestry rural development projects have seen uneven success rates in many parts of the world due to inadequate adoption rates and/or abandonment soon after adoption. This is despite some impressive scientific and technological advances over the last forty years.

This paper describes the adoption of agroforestry in the Garhkundar-Dabar watershed of the Yamuna basin, which is located in the Bundelkhand region of Central India. It interprets the benefits to the environment, farmer willingness, runoff reduction, improved soil fertility, and study area climate change. Initiated in the semi-arid region of central India's Garhkundar-Dabar watershed of Bundelkhand, agroforestry interventions were implemented in watershed development programmes.

Material and Methods

General Description of the Study Area

The study was conducted in the Tikamgarh district of Madhya Pradesh, India, at the Garhkundar-Dabar (GKD) watershed, which is situated between 78° 52' 39" and 78° 54' 44" E longitude and 25° 26' 23" to 25° 28' 32" N latitude. The altitude of the watershed varies from 230 to 280 m above mean sea level (MSL). This watershed is a portion of the Yamuna sub-basin's Betwa river catchment.

The watershed's agro-climate is defined by warm, humid rainy season, dry, scorching summers, and chilly winters punctuated by sporadic downpours. The average yearly temperature is between 24 and 25 °C. The average summertime temperature (April, May, and June) is 34 °C, with the possibility of a maximum temperature increase to 46 to 49 °C in May and June. The average winter temperature (December, January, and February) is 16 °C, with December and January potentially seeing lows of 3^0–5 °C. The range of the mean annual relative humidity is 40–60%. The majority of the Bundelkhand region's agricultural land is covered by a rainfed agro-ecosystem. Despite being the people's primary source of income, barely 20% of the net sown area is irrigated.

The Bundelkhand region receives between 800 and 1300 mm of rainfall annually, with the majority falling during the South-West monsoon season (Singh *et al*. 2002). Aquifers in the research area are either unconfined or perched, with low storage capacity (porosity of 0.01–0.05%). The hard rocks of Archaen granite and gneiss dominate the region's geology, which is primarily formed of crystalline igneous and metamorphic rocks. The only main sources of water for domestic and agricultural use in this area are shallow dug wells, which are excavated to a depth of 5 to 15 metres, because these hard rock aquifers have poor transmissibility. The region's agricultural productivity is extremely low (0.5-1.5 t ha-1) because to its undulating topography, weak groundwater potential, high temperatures, and inconsistent and insufficient rainfall. Depending on temperature and rainfall patterns, Bundelkhand's growing season can last anywhere from 90 to 150 days. Drastic conditions and little precipitation are typical. The watershed's soils are shallow (10–50 cm), characterised by coarse, light-textured gravel and a limited water-holding capacity. They range in colour from raddish to brownish red (Alfisols and Entisols). Scrub land, wasteland, and degraded forests make up the remaining 70% of the watershed area, with agriculture accounting for over 30% of it.

Data collection

In order to promote the growth of agroforestry, over 191 farm households in the watershed were contacted and urged to implement agroforestry on their properties. Eighty farmers, or 42% of all the households in the watershed, who represented every caste, creed, religion, gender, and landholding status, provided the data for the study. Personnel interviews in the study region were used to gather information on elements such as motivational and inhibiting factors, planting systems, and willingness to adopt agroforestry.

Results and Discussion

Perceptions of farmers about the integration of trees in farming systems: Only 5% of farmers were willing to implement a fruit-based agroforestry system, compared to 45% both before and after the extension. Nearly half of the people refused to accept the addition of trees to their farms, despite three years of persistent efforts and persuasion (Table 1). Furthermore, border plantations were favoured by roughly 44% of farmers for fruit trees, followed by intercropping (34%), and boundary plantations by 52.5% of farmers for wood trees, followed by block plantations (30%). All of the farmers favoured block plantations on solely degraded or waste lands and were not prepared to plant timber and forage trees on their farms using the intercropping plantation method (Table 2).

Table 1: Farmers willingness to plant trees on croplands (N=80)

Type of tree	Before extension		After extension	
	N	(%)	N	(%)
Fruit	18	22.5	36	45
Timber	4	5.0	4	5
Not Willing	58	72.5	40	50

Table 2: Preferred system for tree plantation (N=80)

System preferred	Fruit		Timber		Forage	
	N	(%)	N	(%)	N	(%)
Boundary plantation	35	43.75	42	52.5	20	25
Intercropping	27	33.75	-	-	-	-
Block plantation	5	6.25	24*	30*	48*	60*
Around habitat	13	16.25	14	17.5	12	15

Fruit crops have a higher economic value than other crops, and farmers favoured them since they can guarantee revenue even during drought years. Even in smaller amounts, fruits can be sold in the neighbourhood weekly markets to generate consistent revenue. The current study confirms the findings of Banninster and Nair (2003), who found that farmers make judgements about tree culture based on characteristics of their households and fields, and that farmers evaluate trees differently depending on how they fit into their farm-family strategy. Although agroforestry has not been widely adopted, 41% of farmers thought it was an effective strategy of land management (Table 3).

Agroforestry's benefits for the environment

Agroforestry integrates trees into farming systems to provide a multitude of ecosystem benefits while protecting the environment. Agroforestry has an effect on the environment in a variety of ways, from soil structure and quality to societal and environmental effects on a regional or global scale.

Table 3: Farmers motives for agroforestry adoption (N=80)

Motive	Number	Frequency (%)
Efficient land use	33	41.25
High production and income	25	31.25
Risk proof land use	10	12.50
Self sufficiency	8	10.00
Protection from hot and cold winds	4	5.00

Soil

An important component of agroforestry systems is soil management. In temperate and tropical regions alike, agroforestry systems are created and put into practice to reduce soil erosion and degradation and enhance the quality and health of the soil.

Deterioration

Natural forests were replaced by crops and grasslands, and in many agricultural areas, the presence of scrublands hastened erosion and increased runoff. Tree roots can boost water infiltration and storage by increasing the number of soil pores, which increases the structural stability of the soil. Tree roots and trunks function as a barrier to limit runoff and silt, and macropores perform as channels for surface water flow and allow air and moisture to enter the soil, reducing the risk of soil erosion.

The ability to reproduce

Agroforestry systems help to improve soil nutrients and lessen reliance on outside inputs when nutrients are carried by tree roots across soil layers and then returned to the soil through leaf fall. For instance, nitrogen released from poplar leaf litter was equal to 7 kg N/ha/yr, and leaf fall from 6-year-old poplars increased mean soil nitrate production rates in the nearby crop-alley by up to twice that of soils 8.0 to 15.0 m from the tree row [24]. The ability of 650 woody species to fix atmospheric nitrogen is comparatively rare in temperate zones; among them, the nitrogen-fixing capabilities of black locust (Robinia), mesquites (Prosopis), alder (Alnus), and oleaster (Eleagnus) has been studied [16]. A study that revealed that 32 to 58% of the total nitrogen in maize grown in alleys was fixed by the nearby red alder (Alnus rubra) revealed a significant transfer of fixed nitrogen to crops [12, 13].

Water agroforestry altered the hydrological cycles by altering soil erosion, evapotranspiration rates, runoff, river flow, irrigation effects, and the structural makeup of embankments and drainage systems. Studies have indicated that agroforestry, whereby tree strips are planted next to water courses, might mitigate pollution resulting from grazed grasslands and crops. There are five main strategies to reduce non-point source water pollution from agricultural land [26].

1. Diminishing field surface runoff.
2. Surface runoff filtration.
3. Screening runoff from groundwater.
4. Minimising bank eroding.
5. Water filtration in streams.

The potential importance of agroforestry in temperate regions with a changing climate is demonstrated by the utility of agroforestry systems in semi-arid regions where water scarcity limits agricultural viability. Because plant water intake is outweighed by reduced evapotranspiration in the tree shadow, soil water content beneath tree canopies can be higher in semi-arid regions than in open pastures [11, 3].

Cutting down on pollution

It has been observed that buffer strips can reduce pollutant run-off by 70–90% for suspended particles, 60–98% for phosphorus, and 70–95% for nitrogen [5]. A switch-grass/woody buffer removed 97% of the silt, 94% of the total N, 85% of the nitrate-N, 91% of the total P, and 80% of the phosphate P in the runoff, according to a research conducted in central Iowa, US [14]. In addition, agroforestry systems may lessen the spread of veterinary antibiotics from manure-treated agro-ecosystems to surface water resources [6] and lessen the migration of dangerous bacteria like Escherichia coli into water sources [9].

Cutting down on runoff

In agroforestry systems, the risk of flash flooding after periods of heavy rainfall is reduced by decreasing surface runoff and increasing infiltration and soil water holding capacity. The tree trunks and roots act as permeable barriers to reduce the amount of silt and debris that is loaded into rivers after floods. Excessive runoff of surface water is a major contributor to both soil erosion and non-point source pollution. Compared to a control watershed, agroforestry decreased surface water runoff by 9% after just two years of establishment [26]. Agroforestry can enhance water infiltration and water storage while lowering the amount of water in the soil during crucial periods, such as fallow seasons. Additionally, in agroforestry systems, aboveground stems, leaf litter, and pruning debris can lower runoff flow rates, which improves sedimentation within the agroforestry strip and increases infiltration [23].

Changes in climate

Carbon substitution can be achieved through increasing the use of biofuels, increasing the conversion of forest biomass into long-lasting wood products to replace things that require a lot of energy, and improving the use of harvesting waste as biofuel feedstock [17]. Because agroforestry incorporates trees and bushes, it can absorb more carbon than monocultures of crops or grassland [12]. Agroforestry systems are predicted to store 9, 21, 50, and 63 Mg C ha-1 of carbon on average in semiarid, subhumid, humid, and temperate climates, respectively [22]. The greater rates in temperate locations are thought to be a result of longer rotations and longer-term storage. Based on an estimate of 1023 million hectares of agroforestry worldwide, the expected contribution of agroforestry to global carbon sequestration over 50 years is 1.9 Pg of carbon [19]. Globally, 585 to 1274 × 106 ha of appropriate land may be developed into agroforestry systems, storing 12 to 228 Mg C ha-1 [7]. An estimated 630 million hectares of unproductive croplands and grasslands might be converted to agroforestry, which could sequester 391,000 Mg C yr-1 by 2010 and 586,000 Mg C yr-1 by 2040 [27].

Conclusion

Farmers in the study area did not effectively embrace agroforestry land use, despite significant efforts and growth in the area. The findings indicate that water resources must be created through natural resource management, with farmers having confidence in the availability of a sufficient amount of water. Farmers should also be encouraged to adopt agroforestry on their own, with proper education provided through exposure visits, and a small number of farmers should be initially supported by offering incentives such as high-quality planting material, improved crop seeds, and fertilisers. All of the advantages that apply to agriculture should be extended to agroforestry as well, in order to incentivize farmers to plant trees on their private property, including wastelands, by offering comparable advantages such as price support, unrestricted produce movement, long-term credit support based on priority, and so forth. We must continue to learn about the ways that agroforestry maintains and strengthens systems that support livelihoods.

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