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Crafting State-of-the-art Agroforestry for Bundelkhand using Insights from Past

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Abstract: Bundelkhand, a pivotal land area in Central India, is geographically demarcated across the states of Uttar Pradesh and Madhya Pradesh. The 13 districts in both states share similarities in cultural and socio-economic aspects. This paper commences with a descriptive portrayal of the Bundelkhand region, delving into the agricultural scenario, which is highly influenced by rainfall patterns. The region boasts a dominant agrarian rural population, with more than 40% comprising women. Owing to the lower productivity of wheat, farm diversification has been consistently recommended. In this context, agroforestry presents a respite, fostering resilience at the farm level. Agri-silvicultural and silvipastoral systems are typically recommended for this region and are detailed alongside the traditionally prevailing agroforestry practices of the area. This review synthesizes the need for agroforestry adoption for four major reasons and its impact on the Bundelkhand region. Furthermore, it presents the constraints, problems, and motivational factors for adopting agroforestry, ultimately providing directions for the way forward.

Key words: Trees, Agriculture, Productivity, Rural, Population, Women

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The Bundelkhand region, a significant area in central India, encompasses seven districts in Uttar Pradesh (UP) - Jhansi, Jalaun, Lalitpur, Mahoba, Hamirpur, Banda, and Chitrakoot - and six districts in Madhya Pradesh (MP) - Datia, Tikamgarh, Chhatarpur, Panna, Damoh, and Sagar (Sandhu *et al*., 2016). Bundelkhand region, stretching between 23° 20′ and 26° 20′N latitude and 78° 20′ and 81° 40′E longitude, covers approximately 7.07 million hectares. This region supports a population of 18.33 million predominantly rural, reflecting the traditional agricultural lifestyle of the region.

Historically, traditional agricultural practices in Bundelkhand have been a subsistence farming model. Agriculture in Bundelkhand faces significant challenges due to its drought-prone, resource-poor environment. Issues include water scarcity, soil infertility, erosion, poor land distribution, groundwater depletion, and outdated farming practices (Dhaarna and Devadas. 2022). Irregular rainfall and frequent droughts, notably from 2003 to 2009, severely impact crop yields and the regional economy. Small and marginal farmers, lacking modern methods and market access, often migrate to cities. The region's agricultural productivity is low, particularly

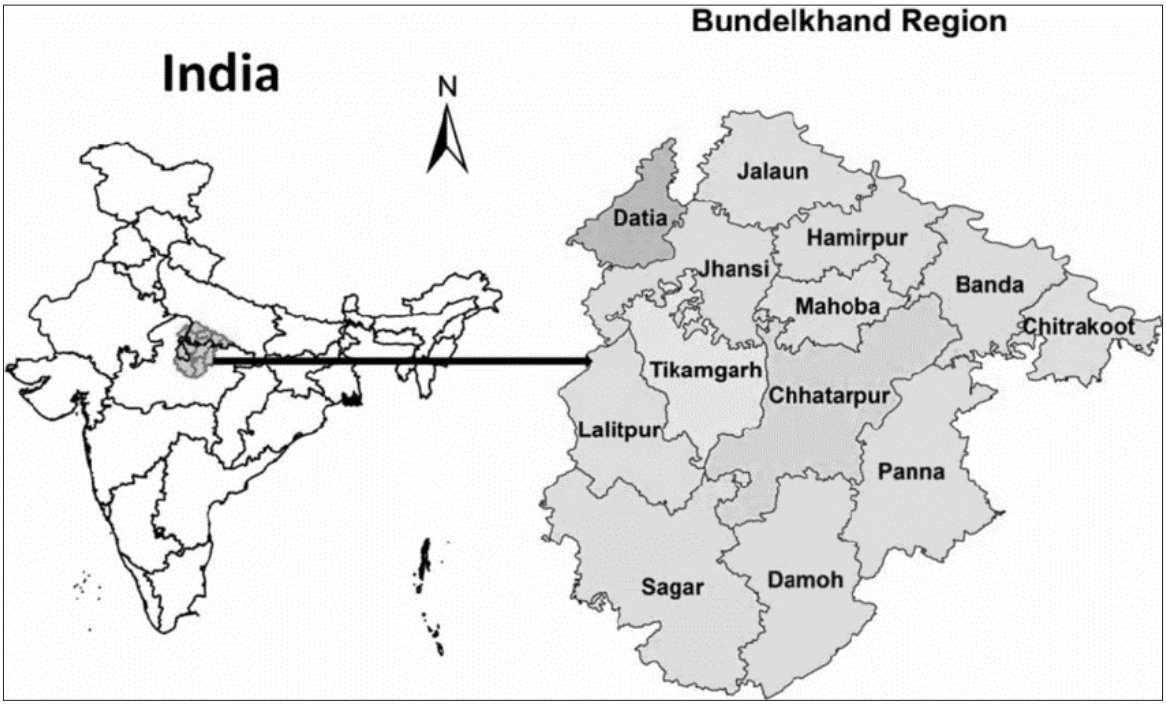

Fig. 1 Indicative map of Bundelkhand (Source: Bundelkhand Development Society, 2021. https://bdsup.org/districts-of-bundelkhand/).

for wheat, though groundnut and green gram yields are better than national averages (Sah *et al*., 2022). Bundelkhand's reliance on monsoon rains and minimum support prices highlights its agricultural vulnerability and economic struggles.

Agroforestry in Bundelkhand: Transformation

Traditionally farmers have intuitively been practising the art of growing trees in the farmlands i.e., agroforestry. Farm diversification is one of the main reason for growing trees on farmlands. This practice can be categorised as the agri-silvicultural system, which integrates crops with tree cultivation, and the silvo-pastoral system, which combines forage crops with woody perennials. Such systems have not only enhanced soil and water conservation but also supported the livelihoods of the local communities through improved nutritional security and additional income.

The agri-silvicultural system in Bundelkhand, for instance, allows for the cultivation of up to 800 trees per hectare without significant crop yield compromise in the initial years. Subsequent thinning of trees ensures a balance between tree density and crop productivity, with the yield loss being offset by the benefits derived from fruit-yielding perennials. Similarly, the silvo-pastoral system supports the growth of forage crops alongside trees, optimizing land use and productivity. Traditional models of agroforestry in Bundelkhand, such as the Aonla, Teak, Neem (Tiwari and Dobriyal, 2023), Butea (Prasad *et al*., 2014), Guava, Citrus, Ber (Singh *et al*., 2016), and Mahua-based systems (Singh, 2018), highlight the region's rich agroforestry heritage. These models illustrate the successful integration of diverse crops, such as Urd, Moong, Groundnut, Wheat, Mustard, and various other Kharif and Rabi crops, with different tree species, ensuring year-round agricultural output and resilience against climatic challenges (Table 1).

Drawing on these traditional insights, the future of agroforestry in Bundelkhand has been transformed into a state-of-the-art system that leverages modern techniques and scientific advancements while preserving the ecological and socio-economic benefits of past practices. By integrating traditional knowledge with contemporary innovations, Bundelkhand can achieve sustainable agricultural growth, environmental conservation, and enhanced rural livelihoods.

Over the years the traditional agroforestry has evolved. The following are some of the classical examples of agroforestry practice

Table 1. Traditional agroforestry models of Bundelkhand region

Name of the model	Intercrops yield
Aonla based agroforestry system	Urd, Moong, Groundnut, Wheat, Mustard.
Teak based agroforestry system	All kharif and rabi crops
Butea based agroforestry system	All kharif and rabi crops
Neem based agroforestry system	20-25 kg of fruits
Guava based agroforestry system	Groundnut-wheat-blackgram Wheat, Sesame-wheat
Citrus based agroforestry system	Groundnut-wheat-blackgram Wheat, Sesame-wheat
Ber based agroforestry system	All kharif and rabi season crops
Mahua based agroforestry system	Wheat, Barely, Chickpea and Paddy

in the Bundelkhand region. From the aspect of subsistence production, an agri-horti-silviculture based model with three horticulture plants *Citrus limon*, *Aegle marmelos*, and *Carissa carandas*, and one gum-yielding species *Acacia Senegal* were found to be viable with intercropping of *Triticum aestivum* var. HUW 234 Z-1, and *Brassica campestris* var. Varuna during winter (Rabi) (Prasad *et al*., 2018). In case of choice for timber trees, *Ailanthus excelsa*, *Hardwickia binnata*, *Tectona grandis*, *Dalbergia sissoo*, *Madhuca indica*, *Acacia nilotica* and *Azadirachta indica* are some of the preferred species in the Bundelkhand region. (Newaj *et al*., 2012). From the production augmentation aspect, bamboo is a versatile option for increasing income. The option of inclusion of bamboo (*Dendrocalamus strictus*) along with nitrogen-fixing chickpea in *rabi* followed by oil crop sesame in the *kharif* was tapped and the financial analysis revealed that the benefit: cost ratio was 2.83 and the land equivalent ratio was 1.95-2.14 (Dev *et al*., 2020). The bamboo culm yield was reported to be higher compared to the arable cropping and sole bamboo. Overall, the recommended spacing for bamboo-based agroforestry was 10x10m and 10x12m spacing with intercropping for 3-5 years without maximum yield reduction in the third, fourth, fifth, sixth, and seventh years it was 26.1, 23.7, 24.2, 17.4 and 17.4% in productivity respectively. In another model, nitrogen-fixing *Albizia procera* was included in the green gram-wheat and black gram-mustard cropping pattern and overall, the model was viable with intercropping feasibility for the first 5 years followed by pruning at 70% will reduce the intercrop yield loss (Newaj *et al*., 2012). Food–fodder alley cropping is a popular form of agroforestry in the red soils of the Bundelkhand region. A combination of sorghum + pigeonpea intercropping with the application of 50% inorganic fertilizers (30 kg N + 8.7 kg P/ha) + 3 tonnes of *Leucaena* leaves/ha from the boundary plantation was viable (Aryai *et al*., 2000). This finding proved that the inclusion of short-duration fodder crops in the rainy season (*Kharif*) will be an added advantage.

Palsaniya *et al*. (2010) studied agroforestry development in 80 households during 2005-2008 in the Garhkundar-Dabar watershed with the goal of the willingness to plant trees in cropland. The willingness of farmers to use agroforestry increased from 0 to 50% (45% for fruit trees and 5% for wood trees). For fruit trees and wood trees, nearly 44% and 53% of farmers favoured boundary plantation systems, respectively. Some agroforestry system demonstration (2007-2008) is *Psidium guajava*-based, *Citrus* based and *Emblica officinalis*-based system. Fruit-based agroforestry system has been popular among farmers of Bundelkhand in the same manner fruit trees coupled with forage/fodder crop has also been reported to be commercially viable in the Bundelkhand region. i) Ber + anjan tree (*Hardwickia binata*) + grass/legume, ii) Custard apple + babul+ Israeli babul + kala siris + grass/legume, iii) Mango + Custard apple + grass/legume, iv) Ber + grass/legume/Siratro, and v) Custard apple + grass/legume/Siratro) and the combination of Karonda + Napier Bajra Hybrid + *Stylosanthes* produced more forage yield (S.K. Sharma, 2009).

One of the finest examples of agroforestry-based watershed interventions in the Parasai-Sindh which increased the water table level and drastically augmented production and productivity. Change village-level landscape. The Watershed has been the most adopted

Table 2. Agroforestry systems/models in Bundelkhand

Agroforestry models	Tree	Crop	Features	Source
Agri-silvicultural system	*Azadirachta indica, Albizia lebbeck, Dalbergia sissoo* and *Acacia nilotica*	Chickpea	Benefit : cost ratio (BCR) and the net present worth was the highest when Chickpea was intercropped with *Acacia nilotica* followed by intercropping with *Dalbergia sissoo*	Prasad *et al*. (2008)
Agri-silvicultural system	*Albizia procera*	Blackgram, Mustard	70% Pruning of trees improved the yield twice of blackgram and mustard compared to unpruned trees. This implies that pruning is mandatory to improve the yield of crops in agroforestry	Newaj *et al*. (2010)
Agri-horti-silviculture system	*Aegle marmelos*	Wheat, Mustard	Mustard yield was 290 kg in 0.4 ha and wheat yield was 1270 kg in 0.4 ha with additional income from tree	Prasad *et al*. (2018)
Eucalyptus-based agroforestry model	Eucalyptus	*Sesbania aculeata* (kharif) and *Hordeum vulgare* (rabi)	BCR was highest in wider spacing (17 m×1 m×1 m; 1:1.57), followed by 6 m×1.5 m spacing (1:1.44), sole Eucalyptus (1:1.25) and sole agricultural crops (1:1.2)	Dhillon *et al*. (2018)
Melia dubia based agroforestry system	Melia dubia	Kharif - blackgram, cowpea, greengram, okra and groundnut; Rabi - sorghum, vegetables, wheat Perennial- ginger, turmeric, banana, papaya, sandal	Melia gives Rs. 10,25,000 ha after 5 years	Handa *et al*. (2020)
Agri-horti-silviculture model	Moringa, Guava	Wheat, chickpea, field pea (rabi season), dhaincha, sweet corn, hybrid corn, urd bean, paddy (kharif season)	Climate-resilient production system with diversified output	Handa *et al*. (2019)
Short rotation tree-based agroforestry system	*Anthocephalus cadamba, Melia dubia* and *Leucaena leucocephala*	Black gram, wheat	Yield of crops under fast-growing trees at two different spacing 4 x 5 m as well as 8 x 2.5 m was not statistically significant. This indicates that geometry of planting trees has no effect on the crop yield and only tree density matters the most.	Krishivaniki Annual Report. (2019)
Bamboo based agroforestry system	Bamboo (*Dendrocalamus strictus*)	Sesame, chickpea	Overall bamboo yield was higher by 3.20 and 4.96% over sole bamboo in 12 m × 10 m and 10 m × 10 m. Intercrop improved the yield but intercrop productivity declined from 3rdyear onwards - 26.1, 23.7, 24.2, 17.4 and 17.4% during the 3rd, 4th, 5th, 6th and 7th year, respectively	Dev *et al*. (2020)
Acacia senegal based agri-horti-silviculture model	*A. senegal, Citrus limon* and *Carissa carandas*	Greengram, Blackgram, Mustard, Lentil, Wheat	3rd year B:C ratio was 1.0; 10th year B:C ratio was 1.32	Prasad *et al*. (2020)
Hardwickia based agroforestry model	*Hardwickia binata*	*Chrysopogon fulvus, Panicum maximum* and *Cenchrus ciliaris*	*C.fulvus* produces maximum pasture yield (dry: 6.25 t ha^{-1} yr^{-1}) followed by *C. ciliaris* (dry: 5.93 t ha^{-1} yr^{-1}) and *P. maximum* (dry: 5.47 t ha^{-1} yr^{-1}) after 8 years	Ram *et al*. (2021)
Conservation agroforestry model	*Aegle marmelos, Tectona grandis*	Blackgram-Mustard, Greengram-Barley	Neither tillage treatments had significant influence on the tree growth and there was no significant yield variation of crop in *Rabi* but there was difference in the *Kharif* blackgram yield was better under minimum tillage (MT) (407.8 kg ha^{-1}) than conventional tillage (CT) (418.8 kg ha^{-1}). Similarly, greengram yield was recorded as 733.5 kg ha^{-1} (MT) and 756.8 kg ha^{-1} (CT).	Dev *et al*. (2022)
Bamboo based agroforestry system	Bamboo (*Bambusa bambos*)	Wheat, Mustard and Barley	Bio-fence to protect field crop. The initial cost to develop a bamboo bio-fence was estimated at INR 5,796 for a length of 100 m.	Kumar *et al*. (2022)
Silvipastoral system	*Tectona grandis, Swietenia mahogani*	*Cenchrus ciliaris* and *Stylosanthes seabrana*	Soil erosion has been reduced drastically from 15.25 t ha^{-1} to 6.14 t ha^{-1} in *Tectona grandis* based system while the *Swietenia mahagoni* did not survive well in this region.	ICAR-CAFRI Annual report.(2023)

Table 3. Economic Impact of Trees in Bundelkhand

Species	Product	Period of collection	Stakeholder	Production/ Tree/ year	Employment/Person (man-days/annum)
Butea monosperma	Gum	December-January	Sahariya tribe	300g	15
	Lac	October-November	Farmer	1.5-2.0 kg	-
	Dona	Whole year	Farmer	1200-1500	300-320
Phoenix sylvestris	Broom	Except rainy season	Landless/ Bargunda tribes	5-8	200-250
	Crown	December-March	Artisans	1	30-45
	Jaggery	September-January	Farmers	10-12 kg	60-100
	Basket	-	Bargunda tribes	1	-
Madhuca indica	Flowers	March- April	Farmer and tribals	50-100	30-45
	Seed	May-June	Farmers	70-100	30-45
Diospyros melanoxylon	Leaves	April-may	Tribals/Farmer	500 leaves (10 bundles)	40-60
Dendrocalamus strictus (Bamboo)	Bamboo sticks	Year around	Farmer	5-8	250-300

Source: Chavan *et al.* (2016)

unit for most natural resource management activities. Based on this, a series of interventions including soil and water conservation efforts led to the transformation of the Parasai-Sindh watersheds (Dev *et al*., 2022). Fruit-based agroforestry system has been a traditional agroforestry system in the Bundelkhand region. Aonla based agroforestry is an ideal agroforestry system for rainfed areas of the Bundelkhand region. Aonla (*Emblica officinalis*) can be intercropped with different crops like Urd, Moong, Groundnut, Wheat, and Mustard (Tiwari and Dobriyal, 2023). Teak is widely planted tree in Bundelkhand due to its economic benefits and sturdy nature. This important agroforestry tree species is planted in different models, combinations with crops (both Kharif and Rabi) and pastures, block plantation with an average yield of 12-15 cft after 25 years (Tiwari and Dobriyal, 2023). Mahua (*Madhuca indica)* is a multipurpose tree of traditional agroforestry system in Bundelkhand region. This multipurpose tree of Bundelkhand has been protected on bunds of crop field for obtaining a number of benefits by indigenous people of this region since generations (Singh, 2018). Mahua provides a range of NTFPs such as flower, seed, seed oil, seed cake, leaves, and stem bark. It prefers tropical and sub-tropical climate, grows well in rocky, gravelly red soils, saline and sodic soils and can withstand drought admirably (Singh *et al*., 2008).

According to Zomer *et al*. (2016), 10% of all agricultural land globally is under tree cover. Therefore, we can presume 294170 ha are the 10% under tree cover because the net sown area of UP Bundelkhand is 1942162 ha. In India, 0.6 billion farmland trees exist excluding block plantations despite more than 5 million large farmland trees (about 67 m^2 crown size) have vanished, during the period 2018-2022 (Brandt *et al*., 2024). While the forest and tree cover in the UP Bundelkhand as per FSI (2021) is 226325 ha (7.69%), it is evident that only 17.69% of UP Bundelkhand area against the recommended 33% forest covers. In a similar estimation for the MP Bundelkhand, we can deduce that 32.20% area is under forest and tree cover. Thus, we need to increase the tree cover in the UP Bundelkhand and MP Bundelkhand region to achieve the recommended level. Given that more than 50% of the land is under agriculture, it is prudent to have an agroforestry-based food production system in this region. Further, among the wasteland land category of the Bundelkhand region 4% (1,06,818 ha) of the area is under degraded vegetation and it can be suitable reclaimed using agroforestry approach.

Moreover, the agricultural labourers are surplus in the Bundelkhand region whose average daily wage is 249 INR which is less

than the national daily wage is 348 INR (Agricultural Wages India; 2019-20). As per the agroforestry area estimation Arunachalam *et al*. (2022) the states of Rajasthan, Maharashtra, and Madhya Pradesh are the top three states with agroforestry areas. In these states, the average agricultural wage per day is INR 320. These are some of the pro-agroforestry factors of this region. The availability of labour at low wages in the Bundelkhand region has far-reaching implications for the establishment and development of agroforestry. This development of agroforestry in the drought-affected region of India would be a win-win approach for environment and socio-economic well-being.

Constraints, problems and motivation for agroforestry adoption in Bundelkhand

The boundary between UP Bundelkhand as well as MP Bundelkhand has divided this homogeneous region has an important policy implication, including up scaling agroforestry. Apart from this, the documented constraints, problems and motivation factors for agroforestry are as follows.

Constraints (before the adoption of Agroforestry)

Mindset of farmer/Attitude farmer for Agroforestry; lack of Quality plant materials (Handa *et al*., 2019); available of cheap and surplus agricultural labour; propose monocropping; limitation of soil depth in certain region; shade tolerant variety of commonly cultivated crop; lack of dedicated support schemes from state missionary; the myth and misconception of certain tree species like *Eucalyptus* has demotivated farmer to take up in agroforestry; limitation regarding choices of species ignorance amount farming community on the diversity of woody perennials suitable to their farm (Sharma *et al*., 2017).

Problems (after the adoption of Agroforestry)

Anna pratha; lack of dedicated regulated timber markets/industries and lack of buy-back scheme; farmers do not do pruning and thinning activity on the farm which will ensure intercropping even when canopy closure; establishment of agroforestry is costlier; in alley cropping rodents like rats and squirrels tend to destroy certain cereals crops like maize and sorghum; hurdles in cutting and transport of woody perennials components, especially timber despite the amendments in the felling transit rules; water logging and frost injury during initial establishment of agroforestry misleading repeated die back to seedling which makes the tree to be fork (lack of clean bole leading, the more shade in agroforestry); allelopathy; competition for space and nutrients (Suman *et al*., 2017).

Motivations among agroforestry farmers

Efficient land use; improved soil fertility; reduced weed growth; increased soil moisture; high production and income; self-sufficiency; improved microclimate and better sharing of water and nutrients (Palsaniya *et al*., 2010).

Way forward

Agroforestry, an important aspect in traditional agricultural systems, has continuously shown resistance to climatic variations (Krishnakanth and Nagaraja 2020). Based on the five decades of extensive agroforestry research and extension in Bundelkhand, we would like to point out certain pathways for future efforts. Firstly, fruit-yielding perennials have garnered the attention of the farmers in the region and agroforestry systems based on fruit trees have been profitable and viable too. Even previous studies by Kareemulla *et al*. (2007) who undertook a cooperative-based agroforestry upscaling in states of UP and MP concluded that natural resource development through agroforestry is viable and creditworthy. Further, they also suggested emphasis should be on fruit and medicinal plants-based agroforestry. As a more practical suggestion, they recommended that fruit trees be incorporated into the commercial timber-based agroforestry models that are popular in the Bundelkhand region. In another study, Palsaniya *et al*. (2010) reported the preference of farmers for timber-based agroforestry did not increase or decrease despite the popularization of agroforestry. We can deduce that farmers of Bundelkhand do realize the contribution as well as nuances of the timber-based agroforestry and therefore there was no aversion or hatred for planting timber trees on a smaller scale (Aryai *et al*., 2000; Ramanan *et al*., 2022).

Secondly, Women play a major role in agroforestry-based food production systems.

Women are the primary users responsible for starting the fuel wood, fruit, and fodder collection to fulfil the nutrition requirements for the family as well as livestock. Sometimes, women are heads of the households in this region and they play a major role with regard inclusion of trees in the farms. The region has more than 45% of women in rural area and they can play a great role upscaling agroforestry. Based on data reported by Tewari *et al*. (2020) women are typically involved in tree planting and take care of fruit trees and flower-oriented crops in the Bundelkhand region. Women's empowerment is unquestionably important for increasing agroforestry adoption among smallholders and a campaign with the tagline "*ladko ko khet, ladkiyon ko med aur har med par 100 saagon ke ped*" was also taken up in the Bundelkhand which had a positive impact in the past and continuing the momentum will provide further acceleration.

Finally, Agroforestry researchers and findings have proved that agroforestry can improve income as well as natural resource management and Singh *et al*. (2023) have proved that 1% of improved tree density or diversity significantly increased food security by 0.23% using the problem confection index method. Agroforestry systems have positively influenced farmers' livelihoods, with related advantages such as increased crop yield, food security, improved resilience of rain-fed systems of agriculture, and hence production sustainability (Abukari and Larweh. 2022). Now given the out-migration of human labour in Bundelkhand, (28,61,015 persons in 2018-19). There is need to quantify the implication of up scaling agroforestry towards reduction in out-migration. As stated in the constraint and problem sections, the efforts need to be channelized in coherence with the National Agroforestry policy to transform the agriculture-dependent Bundelkhand landscape by adopting district specific agroforestry approach.

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