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## Possibilities and Perspectives of Agroforestry in Chhattisgarh

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Additional information is available at the end of the chapter

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### Abstract

Agroforestry (AF) is an ecofriendly and sustainable modern farming land use practice that maintains overall farm productivity by combining herbaceous food crops with woody perennial trees and livestock on the same piece of land, either alternately or at the same time, using scientific management practices that improve the socioeconomic condition of people. It is the new name for an ancient land use practice and just a compromise between agriculture and forestry. It plays a major role in enhancement of overall farm productivity, soil enrichment through litter fall, maintaining environmental services such as climate change mitigation (carbon sequestration), phytoremediation, watershed protection and biodiversity conservation. It is an effective and alternative management system to meet the target of increasing forest cover to 33 % as given by the national forest policy. Their scope and potential in any state including Chhattisgarh is tremendous. Farmers use generally N<sub>2</sub>-fixing trees like some from the Leguminosae family including *Acacia spp.*, *Dalbergia sissoo*, etc., on their farmland for enhancing their field crops and generating incomes and employment. Therefore, rural people should make some strategy for the implementation of agroforestry model with suitable combination of trees and field crops, and this combination does not only generate income for the upliftment of socioeconomic value but also concerns the ecological and environmental stability on the sustained basis, i.e. emphasis should be more on scientific management of these models.

**Keywords:** Agroforestry, Carbon sequestration, Ecological, Phytoremediation

## 1. Introduction

Agroforestry system is land management practice to cultivate woody perennial and agricultural crops on the same piece of land in temporal and spatial arrangement with sustainable production of crops and ecological and socioeconomic conditions. It is an ecologically sustainable land use option alternative to the prevalent subsistence farming patterns for conservation and development. According to Dhyani et al. [1], in India, the current area under agroforestry is estimated at 25.32 Mha, or 8.2 % of the total geographical area of the country. This includes 20.0 Mha in cultivated lands (7.0 Mha in irrigated and 13.0 Mha in rainfed areas) and 5.32 Mha in other areas such as shifting cultivation (2.28 Mha), home gardens and rehabilitation of problem soils (2.93 Mha). The science of agroforestry system centres around four factors – competition, complexity, sustainability and profitability – and there should be a balance among all these factors to get fruitful returns. Density of trees/shrubs varied from one agroforestry system to another, depending upon the availability of the resources [2]. Agroforestry has much potential, such as the overall (biomass) productivity enhancement, soil fertility improvement, soil conservation, nutrient cycling, microclimate improvement, carbon sequestration, bio-drainage, bioenergy and biofuel [3]. Agroforestry also has the potential to enhance ecosystems through carbon storage, prevention of deforestation, greater biodiversity, cleaner water and less land erosion. Agroforestry provides great opportunities to link water conservation with soil conservation; hence, the major focus has to be on this aspect [4]. It is also noted that sustainable agroforestry can upsurge resilience against environmental change, to enhance carbon sequestration and also to generate income, which will result in improved livelihood of small and subsistence farmers [5].

Traditional agroforestry practices involve planting trees in rows sparsely in crop field and/or along the allies (bunds). These trees provide food, timber, fuel, fodder, construction materials, raw materials for forest-based small-scale enterprises and other cottage industries and in some cases, enrich soil with essential nutrients [6-8]. Management practices for agroforestry are more complex because multiple species having varied phonological, physiological and agronomic requirements are involved [9]. The most important factor for the compatibility of agroforestry [10-11] is the selection of suitable tree and agricultural crop combination; usually trees that have multipurpose benefits like nitrogen fixing and are fast growing and adaptable to harsh conditions and economically important are preferred [12]. Agroforestry systems can be expedient over conservative agricultural and forest production methods [13]. Since agroforests are stereotypically less diverse than native forest, they support a substantial number of plant and animal species. Therefore, agroforestry, if properly developed, has the potential to improve socioeconomically a more sustainable and better landscape [14]. In order to promote agroforestry, it will require appropriate research intervention, adequate investment and suitable extension strategies; providing incentives to agroforestry, removing legal barriers in felling, transporting and marketing of agroforestry produce and developing harvest process technology of new products and market infrastructure; and above all, a forward-looking agroforestry policy to address these issues [15].

## 2. Historical status of agroforestry in India

Agroforestry is as old as the origin of agriculture. But the scientific approach to this system has been realized recently. In India, research work on agroforestry (AF) was initiated during the late 1960s and 1970s by the Indian Grassland and Fodder Research Institute, Jhansi; Central Soil and Water Conservation Research and Training Institute, Dehradun; Central Arid Zone Research Institute, Jodhpur; and ICAR Research Complex for the North-Eastern Hill Region. The National Commission on Agriculture emphasized agroforestry education in the seventh five-year plan period, and all state agricultural universities have introduced it into the agriculture syllabus in accordance with the recommendation of the task force constituted during the first agroforestry seminar organized at Imphal, India, in May 1979. Indian Society of Tree Scientists (ISTS) organized a national seminar on 'Agroforestry for Rural Needs' in 1987. ICAR had already launched the All India Coordinated Research Project on Agroforestry which spread over 22 centres in the country in 1983. This programme was subsequently extended to 11 more centres covering all the 23 state agricultural universities, and it was decided that a National Research Centre for Agroforestry would be established during the seventh five-year plan of India (1985–1990). The Greening India mission under the National Climate Change Action Plan targets 1.5 Mha of degraded agricultural lands and fallows to be brought under agroforestry; about 0.8 Mha are under improved agroforestry practices on existing lands and 0.7 Mha of additional lands under agroforestry [16]. Also, there are a number of schemes and programmes being discussed and likely to be initiated in the near future. As per the Government of India initiative to encourage crop diversification in the earlier 'green revolution' states, Punjab wants to bring an additional area of 2 lakh ha under agroforestry to its present 1.3 lakh ha has crop diversification strategy [17]. Simultaneously, the post of Assistant Director General (Agroforestry) was also created at the ICAR headquarters in Delhi to coordinate the total research on agroforestry in India.

## 3. Scope of agroforestry in India

Agroforestry is an ideal land use option as it optimizes trade-offs between increased food production, poverty alleviation and environmental conservation [18]. This system is adopted in a large hectare of boundaries, bunds and wasteland area and permits the growing of suitable tree species in the field where most annual crops are growing well. Agroforestry assures permanent sources of higher income even in extreme adverse conditions. The role and scope of agroforestry are also studied in way of biodiversity conservation, yield of goods and services to society, augmentation of the carbon storages in agroecosystems, enhancing the fertility of the soil and providing social and economic well-being to people [19]. Realizing such scope, the All India Coordinated Research Project on Agroforestry was initiated in 1983 to initially operate at eight Research Institutes of the Indian Council of Agricultural Research (ICAR) and twelve agricultural universities, and now it is being extended to a large number of universities and institutes. Since agroforestry is a land use management system without deterioration of

its fertility that results in more output, this adds to the national economy. Thus, a bright future of agroforestry in India is inevitable.

#### 4. Practices of agroforestry in India

The practices of growing agricultural crops under scattered trees on farm land are old practices, for example, *Prosopis cineraria* in north-western India and poplars in north India, *Prosopis cineraria* and *Zizyphus* in arid area, *Acacia nilotica* in Indo-Gangetic plains, *Grewia optiva* and other tree species in the hills of Uttarakhand and Himachal Pradesh, *Eucalyptus globules* in the southern hill of Tamilnadu and *Borassus flabellifer* in the peninsular coastal region.

Farmers retain tree of *Acacia nilotica*, *Acacia catechu*, *Dalbergia sissoo*, *Mangifera indica*, *Zizyphus mauritiana* and *Gmelina arborea* and are preferred in Gujarat with crops. In Bihar, *Dalbergia sissoo*, *Litchi chinensis* and mango are frequently grown on field, but for boundary plantation, *Sissoo* and *Wendlandia exserta* are most commonly used. Farmers of Sikkim, grow bamboo (*Dendrocalamus*, *Bambus*) all along the irrigation channels. In Andaman, farmers grow *Gliricidia sepium*, *Jatropha* spp., *Ficus*, *Ceiba pentandra*, *Vitex trifolia* and *Erythrina variegata* as live hedges. In Chhattisgarh, *Acacia nilotica*, *Gmelina arborea* and *Albizia*-based agroforestry system are used. Under protein bank (silvopasture system), protein-rich fodder trees including *Acacia nilotica*, *Albizia lebbeck*, *Azadirachta indica*, *Leucaena leucocephala*, *Gliricidia sepium* and *Sesbania grandiflora* are planted.

In south India (Kerala), home garden (agrisilvipastoral system) is used which is the combination of trees, shrubs, vegetables and other herbaceous plants with livestock animals. Farmers retain the suitable species like *Anacardium occidentale*, *Artocarpus heterophyllus*, *Citrus* spp., *Psidium guajava*, *Mangifera indica*, *Azadirachta indica*, *Cocos nucifera*, etc. [20].

#### 5. Potential of agroforestry in Chhattisgarh

Chhattisgarh is a predominantly tribal region in the eastern part of India, comprising a total geographical area of 137.90 lakh ha. The geographical location of Chhattisgarh is from 17° 46' north to 24° 5' north latitude and from 80° 15' east to 84° 20' east longitude. The total area of agro-climatic zone (eastern plateau and hill region) in Chhattisgarh is 23.29 lakh ha, which is 24.90 % of the total geographical area of the state. The loamy and clayey soil of this plain area is very fertile, and climate generally varies from moist subhumid to dry subhumid. Chhattisgarh state is rich in forest and has a vast variety of minor forest products to favourable agro-climatic conditions resulting in good forest area, i.e. 43.6 % of the total. Rice is the main crop cultivated in Durg District of Chhattisgarh state, India [21-22]. Agroforestry model in Chhattisgarh state is very prominent and applied. Certain MPTs like *Acacia nilotica*, *Butea monosperma*, *Terminalia arjuna*, *Albizia procera* and *Zizyphus mauritiana* are an integral part of the rural agroforestry practices of the region and have tremendous importance in poverty alleviation and income generation in the predominantly rainfed agrarian economy of the region. While

traditional models with *Acacia nilotica* and *Butea monosperma* and homestead cultivation of horticultural crops have to be encouraged, extensive research inputs have to focus on increasing crop yields through better management of the tree crops and on minimizing competition for resources in the tree-crop interface [23]. Agroforestry system affects the carbon storage capacity and biomass production other than sole crop and tree plantation. A comparative study was done at Forestry Research Farm of Indira Gandhi Agricultural University, Raipur, Chhattisgarh; the total stand biomass is substantially higher in plantations (35 %) than agrisilviculture system, and agrisilviculture system had also the least net C storage (soil + tree) as compared to *Gmelina arborea* monoculture stands [24].

In Chhattisgarh, trees most commonly found in fields are *Acacia nilotica*, *Butea monosperma*, *Terminalia arjuna*, *Azadirachta indica*, *Pongamia pinnata*, etc. Fruit trees like *Carica papaya*, *Citrus* spp., *Mangifera indica* and *Psidium guajava* are very common and popular in Chhattisgarh. MPTs in the region include *Terminalia arjuna*, *T. tomentosa*, *Albizia procera*, *Mangifera indica*, *Butea monosperma*, *Zizyphus mauritiana*, *Azadirachta indica* (neem) and *Gmelina arborea* grown on paddy field bunds. Neem has a lot of importance in social forestry, agroforestry, reforestation and rehabilitation of the wasteland and degraded industrial lands. Thus, large-scale plantation of neem trees helps to combat desertification, deforestation and soil erosion and to reduce excessive global temperature [25]. *Bamboo* which was another highly preferred species could be encouraged for planting on field bunds, farm boundaries and homesteads. *Jatropha* spp. are also raised in the farm bund as a live fence, and it also generates the source of rural employment [26]. The prevalent agroforestry models/practices are *Acacia nilotica*, paddy model (most popular and widely accepted); *Butea monosperma*, paddy model (second most popular system and nearly 48 % of the farmers maintained them); and MPTs like *Albizia procera*, *Terminalia arjuna* and *Gmelina arborea* on field bunds as windbreaks or live hedges on boundaries. *Zizyphus mauritiana*-based homestead gardens are also used. In traditional agroforestry, crop density, aboveground biomass, belowground biomass and their productivity are affected by tree canopy size, age and distance from the tree trunk. Generally, as a distance increases, the grain yield also increases [27]. Also with increase in age, crown diameter and DBH of *Acacia nilotica* tree, the productivity of gram reduced from 37.73 % (6 year-old tree) to 68.49 % (20 year-old tree) [28]. For reducing tree-crop competition, tending operation including pruning is an effective tool which enhances the crop productivity; otherwise, there is reduction in yield (41 to 61 % reduction in wheat yield in unpruned *Eucalyptus* tree; [29]. Farmers often practice severe branch pruning every season before the planting of crops, to reduce tree-crop competition as well as to improve tree form [30].

## 6. Tree-crop interaction

Various interactions take place between the tree and herbaceous plants (crops and pasture), which are referred to as the tree-crop interface. Interaction is defined as the effect of one component of a system on the performance of another component and/or the overall system [31]. Regarding this, ICRAF researchers have developed an equation for quantifying tree-crop interaction (I), considering positive effects of tree and crop yield through soil fertility enrich-

ment (F) and negative effects through crop competition (C) for growth resources between tree and crop  $I = F - C$ . If  $F > C$ , the interaction is positive; if  $F < C$ , the interaction is negative; and if  $F = C$ , interaction is neutral. Studying tree-crop interaction in agroforestry would help to devise appropriate ways to increase overall productivity of land. Increased productivity, improved soil fertility, nutrient cycling and soil conservation are the major positive effects of interactions, and competition is the main negative effect of interaction, which substantially reduces the crop yield. It may be for space, light, nutrients and moisture. Ecological sustainability and success of any agroforestry system depend on the interplay and complementarity between negative and positive interactions. It can yield positive results only if positive interactions outweigh the negative interactions [32].

## 7. Agroforestry contribution

Agroforestry contributes a vital role in Indian economy and has potential to satisfy three objectives, viz. to protect and ameliorate the environment, enhance sustainable production of economic goods on a long-term basis and improve socioeconomic condition of rural people. It has many contributions like rehabilitation of degraded land, increased farm productivity and capability of conserving natural resource and it is an option to increase the forest cover to 33 % in the country. Besides meeting the subsistence need of food, fruits, fibre and medicines, this farming practice meets almost half of the demand of the fuel wood, two-thirds of the small timber, 70–80 % wood for plywood, 60 % raw material for paper pulp and 9–11 % of green fodder requirement of livestock. Also, agroforestry practices have enhanced overall biomass productivity from 2 to 10 t ha<sup>-1</sup>y<sup>-1</sup> in rainfed areas in general and the arid and semiarid regions in particular [1]. Agroforestry is also providing livelihood opportunities through lac, apiculture and sericulture cultivation, and suitable trees for gum and resin have been identified for development under agroforestry [33]. Under agroforestry system, tree cultivation on agricultural land improves biomass productivity per unit area and also uses nutrients from different soil layers. Further, land such as bund and avenues that are hitherto not cultivated would increase the tree cover of the landscape [34].

## 8. Carbon sequestration

Active absorption of atmospheric carbon dioxide (CO<sub>2</sub>) from the atmosphere through photosynthesis and its subsequent storage in the biomass of the growing trees or plants is referred to as carbon sequestration [35]. The carbon sequestration capacity depends upon tree species and their growing condition and management practices under agroforestry system. Further, allocation of sequestered carbon in different tree components may also vary. As per Rajendra Prasad et al. [36], carbon content in different tree species was in the order of *Eucalyptus tereticornis* = *Azadirachta indica* = *Acacia nilotica* = *Butea monosperma* > *Albizia procera* = *Dalbergia sissoo* > *Emblica officinalis* = *Anogeissus pendula*. The order of carbon content in tree components was branch = stem > root > foliage > stem bark = branch bark. Among all the studied tree species, *Albizia procera* was found to be the most efficient in capturing C (127.74 kg C/tree) and removing

CO<sub>2</sub> from the atmosphere (46.83 kg/tree/year), while *Anogeissus pendula* was the least with corresponding values of carbon (8.22 kg C/tree) and CO<sub>2</sub> (3.01 kg/tree/year), respectively.

Agroforestry is also an attractive option for climate change mitigation as it sequesters carbon in vegetation and soil, produces wood, serves as substitute for similar products that are unsustainably harvested from natural forests and also contributes to farmer's income [37]. As per Alavalapati and Nair [38], agroforestry is widely considered as a potential way and low-cost method to sequester atmospheric carbon and recognized as one of the strategies for climate change mitigation. In agroforestry system, tree components are managed and pruned for reducing competition, and these pruned materials are generally non-timber products. Such materials are returned to soil to increase carbon biomass. By including trees in agricultural production systems, agroforestry can, arguably, increase the amount of C stored in lands devoted to agriculture while still allowing for the growing of food crops [39]. The total C content of forests has been estimated at 638 Gt for 2005, which is more than the amount of carbon in the entire atmosphere [40-41]. It was estimated that over 2 billion ha of degraded land exists globally [42], of which 1.5 billion ha is located within tropical lands. Restoration of these afforestation and agroforestry practices to sequester 8.7×10<sup>9</sup> Mg C year<sup>-1</sup> in the tropical and 4.9 × 10<sup>9</sup> Mg C year<sup>-1</sup> in the temperate above-ground C pools [43] is the major benefit to the ecosystem. Hence, the combining information on above-ground, time-averaged C stocks and the soil C values for the estimation of C-sequestration potentials in agroforestry systems is an obligation [44-45].

Agroforestry model	Carbon storage capacity	Region	Author
Silvopastoral system (5 years)	9.5–19.7 tC/ha	Semiarid	[47]
Silvopastoral system (aged 6 years)	1.5–18.5 tC/ha	Northwestern India	[48]
Block plantation (aged 6 years)	24.1–31.1 tC/ha	Central India	[49]
Agrisilviculture system (aged 8 years)	4.7–13.0 tC/ha	Arid region	[50]
Agrisilviculture system (aged 11 years)	26.0 tC/ha	Semiarid region	[51]
Eucalyptus bund plantation	59,361 t	Punjab (Rupnagar district)	[52]
Poplar block plantation	330,510 t		
<i>Populus deltoides</i> 'G-48' + wheat	18.53 tC/ha	Tarai region of central Himalaya	[53]
<i>P. deltoides</i> + wheat boundary plantation	4.66 tC/ha		
Silvopasture	31.71 tC/ha	Himachal Pradesh	[54]
Natural grassland	19.2 tC/ha		
Agrihorti silviculture	18.81 tC/ha		
Hortipastoral	17.16 tC/ha		
Agrisilviculture	13.37 tC/ha		
Agri-horticulture	12.28 tC/ha		

**Table 1.** Carbon storage capacity as per agroforestry model in different regions of India

There are various literatures (Table 1) on carbon storage capacity which varies from region to region and also depends upon the nature and performance of tree crop under different agroforestry models. Also, Nair et al. [46] summarized that the potential of agroforestry system in term of carbon storage varied from 0.3 to 15.2 Mg C/ha/yr; the highest being in the humid tropics receiving high rainfall. Thus, the importance of agroforestry as a land use system is receiving wider recognition not only in terms of agricultural sustainability but also in issues related to C-sequestration or climate change.

## 9. Agroforestry for biodiversity conservation

Agroforestry is not something new but a new set of old farming practices that integrate crops and/or livestock with trees and shrubs under which one set of practices provides multiple benefits either in a tangible or an intangible way including diversified income sources, increased biological production, better water quality and improved habitat for both humans and wildlife. Young [55] described it as a collective name for land use systems in which trees are grown in association with agricultural crops and/or pasture either in a spatial arrangement or a time sequence with economic and ecological interaction between the tree and non-tree components of the system. It is a multiple land use system in which perennials are grown in conjunction with agronomic crops and/or livestock either simultaneously or in sequence with an ecological and economic interaction between the tree components of the system [55-56]. This land use farming system has integration of variety of tree species with herbaceous crops increase the biodiversity and increase the overall productivity consumed by households, reduce soil loss and improve the physical and chemical properties of soil. Similarly as per Singh et al. [57], agroforestry system has many diverse contributions comprised of biodiversity conservation, yield of goods and services to society, augmentation of the carbon storage in agroecosystems enhancing the fertility of the soils and provision of social and economic well-being to people. Tree plays a diverse function under the different agroforestry models/systems. As per Muthappa [58], under the coffee agroforests, trees are mainly retained in the farm for shade and fuel wood (100 %), support for pepper and timber (98 %), religious value (96 %), food (76 %) and others (69 %), resulting in reduction in pressure on the natural forest. Agroforestry practices such as home garden (agrohortisiviculture) systems, live fences around farmlands, agrisilviculture system, agroforestry species for green manure, silvofishery system, trees in and around the agricultural fields and silvopasture system were found most promising for biodiversity and meeting the diverse needs to uplift the socioeconomic status of farmers. As per Murthy et al. [59], agroforestry practices may use only 5 % of the farming land area yet account for over 50 % of the biodiversity, improving wildlife habitat and harbouring birds and beneficial insects which feed on crop pests. Therefore, under the agroforestry systems, trees can contribute nesting sites, protective cover against predators, access to breeding territory and access to food sources in all seasons and encourage beneficial species such as pollinators.

## 10. Utilizing wasteland

Wastelands are degraded lands that lack their life-sustaining potential as a result of inherent or imposed disabilities such as by location, environment, chemical and physical properties of the soil or financial or management constraints [60]. It includes area affected by water logging, ravine, sheet and gully erosion, riverine lands, shifting cultivation, salinity, wind erosion, extreme moisture deficiency, etc. Due to complete loss of top soil, these degraded lands are ecologically unstable and are unsuitable for cultivation. The main causes responsible for development of wasteland include deforestation, shifting cultivation, overgrazing, unskilled irrigation, industrialization activities, etc. Deforestation on a vast scale has increased soil erosion, disturbed water regimes and resulted in scarce supply of fuelwood, fodder and small timber on which the vast majority of India's rural population has been dependent for centuries. The degradation of wasteland can be overcome by participatory approach like social forestry, joint forest management, community forestry, etc., with the help of local people in the planning and management of lands [61] through afforestation of suitable species like *Jatropha*, neem [25-26], *Acacias* species, etc. Further, these degraded, and wasteland are reclaimed and restored through a scientific plantation technique, either sole tree plantation under afforestation scheme or practices of different agroforestry models based on specific location. Agroforestry models for fodder production, viz. silvopasture, hortipasture, hortisilvipasture and agrisilviculture system, are usually established in degraded cultivable lands. The wastelands could be effectively utilized for fodder production parallel to livestock production through agroforestry system, which is also an environmentally safe system of land use. Silvopastoral system increases the dry fodder biomass yield from 1.25–4.50 tons (natural pasture) to 4.50–8.70 tons per hectare per year and could hold 8–15 sheep per hectare. The average dry fodder production potential of the hortipasture, horti-silvipasture and horti-silvi system is normally 3.855, 4.410 and 1.282 tons per hectare per year, respectively, under rainfed condition. Agrisilviculture system of fodder production (Napier-Bajra hybrid grass + *Sesbania grandiflora*) yields more dry fodder biomass and protein under irrigated condition. Among the agroforestry models, Napier-Bajra hybrid grass + *Leucaena leucocephala*/*Sesbania grandiflora* as agrisilviculture system of fodder production is more successful for irrigated lands. Silvopasture with *Leucaena leucocephala* + *Gliricidia sepium* + *Albizia lebbek* as tree components and *Cenchrus ciliaris* + *Stylosanthes scabra* as pasture components was recommended for greening of wastelands in rainfed condition [62]. In addition, government organizations can lease 'wasteland' from the state government for *Jatropha* cultivation. This land has been initially allocated to government organizations for a period of 20 years, and this may be extended for a further 10 years [63].

As per latest agricultural statistics, about 173.6 million ha of land in India is degraded, and these lands may be utilized for some kind of tree plantations and agroforestry system to meet the requirement of forage, fuel, food and other forest products. In afforestation programme, forest plantation constitutes 5 % of the world's total forest area or around 187 million ha [64]. The average rate of successful plantation establishment over the last decades was 3.1 million ha per year, of which 1.9 million ha was in the tropical area. Of the estimated 187 million ha of plantations worldwide, Asia has by far the largest area of forest plantation, accounting for 62 % of the world total [65]. In India, silviculturally, ANR (assisted natural regeneration) is

used as an approach of afforestation. ANR forms the major strategy of treating degraded forest through joint forest management approach under the national afforestation plan (NAP) and externally aided forestry projects (EAP). It is the dominant plantation model of forest treatment in India. ANR in India is treated as a tool for afforestation. It forms the dominant component of the national afforestation plan (NAP), Government of India's flagship afforestation program. NAP aims to support and accelerate the ongoing process of devolving forest protection, management and development functions to decentralized institutes of joint forest management committee (JFMC) at the village level. It has covered a total area of about 1.69 million ha during 2000-2010 and spread over 42535 JFMCs in 800 Forest Development Agencies (FDAs) at a cost of Rs. 2237.36 crores [66]. ANR also forms the major strategy for rehabilitation of forest land under externally aided forestry projects being operated in 11 states of India at an investment of Rs. 5718 crores [67]. So, for making a good and clean environment, a huge-scale plantation should be done on the plain and hilly areas. Degraded lands, i.e. unfertile land, barren land and wasteland, are also reclaiming by with the help of large-scale suitable plantation of suitable tree species. Moreover, wasteland can be reclaimed through afforestation activities like agroforestry, silviculture and social forestry; these should be adopted to protect agricultural lands from further deterioration arising out of degradational processes.

## 11. Nutrient cycling in agroforestry

Forest ecosystems represent closed and efficient nutrient cycling systems, meaning that they have high rates of turnover and low rates of outputs or losses from (as well as inputs into) the system. Whereby nutrient cycling systems are open or leaky in agricultural systems and they have low rate of turnover within the system, inputs are comparatively high. Similarly, Nair [68] has reported that more nutrients in the system are reused by plants under the agroforestry before being lost from the system without affecting the overall productivity of the system. Trees can increase nutrient inputs to agroforestry systems by retrieval from lower soil horizons and weathering rock. The basis of this assumption is that, because of their deep roots, trees are able to absorb nutrients from soil depths that crop roots cannot reach.

Generally, agroforestry practices increase the soil organic matter through leaf litter addition. It increases the population of beneficial microorganism and improves biological nitrogen fixation in soil. All microbiological activity in soil contributes to cycling of nutrient and other ecosystem functions, and all soil functions contribute to ecosystem services. Recycling in natural system is one of the many ecosystem services that sustain and contribute to the well-being of human society [69]. Low soil fertility is one of the greatest biophysical constraints of production of agroforestry crops across the world [70]. Cow dung is a very good source for maintaining the production capacity of soil and enhances the microbial population. It is one of the renewable and sustainable energy resources through dung cakes or biogas which replaces the dependence upon charcoal, fuel wood, firewood and fossil fuel. Besides it, application of cow dung in a proper and sustainable way can enhance not only productivity of yield but also minimizing the chances of bacterial and fungal pathogenic disease [71].

Therefore, added organic matter acts as a source of energy and enhances nutrient cycling in soil. In addition, it moderates soil microclimate and improves soil aggregate system [20].

## 12. Agroforestry systems increase inputs through nitrogen fixation

Nitrogen-fixing trees can substantially increase nitrogen inputs to agroforestry systems. Many of the tree and shrub species selected for agroforestry are legumes belonging to the so-called fast-growing nitrogen-fixing trees, notably species of *Leucaena*, *Calliandra*, *Erythrina*, *Gliricidia* and *Sesbania*. *Leucaena leucocephala* is the important tree grown everywhere in arid, semiarid and humid regions and fixes nitrogen up to 100–500 kg N<sub>2</sub> ha<sup>-1</sup> yr<sup>-1</sup> [72]. Similarly as per Dwivedi [73], several Leguminosae trees such as *Leucaena leucocephala*, *Acacia nilotica*, *Dalbergia sissoo*, *Gliricidia* spp., *Sesbania* spp., etc., and some nonlegumes, e.g. *Casuarina equisetifolia*, *Alnus* spp., etc., are important to fix about 50 to 500 kg of nitrogen per ha. Agamuthu and Broughton [74] showed that nutrient cycling in oil-palm plantation where leguminous cover crops (*Centrosema pubescens* and *Pueraria phaseoloides*) were used was more efficient than in plantation where there was no cover crop. In coffee and cacao plantation with shade trees (some of which are N<sub>2</sub>-fixing), 100–300 kg N ha<sup>-1</sup> yr<sup>-1</sup> is returned from litter and prunings, which is much higher than the amount removed during harvest or derived from N<sub>2</sub>-fixation. Other nitrogen-fixing legumes include *Albizia*, *Inga*, *Prosopis* and the numerous *Acacia* species, together with *Faidherbia albida*. The members of family Casuarinaceae and *Alnus nepalensis* are most widely used for plantations in tropics and temperate zones, respectively which are non leguminous.

## 13. Water stress in relation with growth and productivity in agroforestry

One of the growing global concerns is to increase the water productivity for meeting the water demand of the rising population. According to the estimates of the World Commission on Water, demand for water will increase by approximately 50 % over the next 30 years and about half of the world's population will live in conditions of severe water stress by 2025. Due to rapid degradation of water catchments and climate change, there is a major threat in decreasing water supplies in many parts of the world. Further, global warming, climate change and deforestation are majorly responsible for the fluctuation in spatial and temporal distribution of rainfall which finally leads to water deficit.

Water stress in plant is developed during periods of water deficiency because plants are unable to absorb adequate water to match the transpiration rate. A water deficiency exists when the amount of rainfall is less than potential evapotranspiration. Water stress may be either due to water shortage or due to excess of water. Water deficit is one of the key limiting factors for plant growth, productivity and survival and often adversely affects agroforestry practices in arid and semiarid areas [75]. However, plants can normally acclimate to water stress through physiological and morphological responses [76]. However, critical water stress leads to death

of plants. Agroforestry has the potential to improve water productivity in two ways. Trees can increase the quantity of water used in farms for tree or crop transpiration and may also improve the productivity of the water that is used by increasing the biomass of trees or crops produced per unit of water used [77]. The rate of depletion of land and surface water in our country is indeed alarming. So the rational approach is required, like by developing the suitable agroforestry model and/or integrating with the rain water harvesting unit for overcoming the water crisis in the country [78]. So water stress in agroforestry can be minimized by developing the appropriate models in general and growing site-specific species in particular.

#### 14. Socioeconomic upliftment through agroforestry

Agroforestry can improve the livelihoods of smallholder farmers as by providing various production services [79], viz. fruit and nuts, fuel wood, timber, medicine, fodder for livestock, green fertilizers, assets that can be sold in time of need and additional/diversified income. It generates high income and minimizes risks in cropping enterprises. It provides long-term investment opportunity, diversified land use and commercial tree cropping and can generate diversified on-farm employment, wood and non-timber forest product (NTFP) and ensure raw-material supply to forest-based industries. Agroforestry has potential for poverty alleviation and tribal development and generating employment and providing women's empowerment schemes. Farmers will be encouraged to take up farm/agroforestry for higher income generation by evolving technology, extension and credit support packages and removing constraints to development of agroforestry. Suitable species for commercial agroforestry may include *Acacia nilotica*, *Bamboo species*, *Casuarina equisetifolia*, *Eucalyptus species*, *Populus deltoides* and *Prosopis cineraria* for different climatic, edaphic and agricultural conditions.

Agroforestry models for different site conditions have to be developed and demonstrated under different agro-ecological regions in the country. Agroforestry system prevailed in Chhattisgarh which depended on their potential to generate high income of farmers which is measured through their economic analysis. In Chhattisgarh state, agri-horticulture model comprises combination of horticulture tree (aonla) and field crops (groundnut and gram) and their different parameters of economic analysis (input/output) including total expense (tree+crops) per ha (86,494 Rs.), total benefits per ha (93,903 Rs.), net benefit per ha (7,410 Rs.) and B:C ratio (1.09). Similarly, agrisilviculture system comprises combination of tree species (*Gmelina arborea*) and field crop (paddy and linseed), and their economic parameters are total expense (tree+crops) per ha (69,139 Rs.), total benefits per ha (1,19,997 Rs.), net benefit per ha (50,858 Rs.) and B:C ratio (1.74). These economic analyses are sufficient to measure socioeconomic potential of different agroforestry models and give idea about whether this model be accepted or not [80].

## 15. Role of agroforestry in NTFP production

The trees in agroforestry practices generally fulfil multiple purposes, involving the protection of the soil or improvement of its fertility, as well as the production of one or more products [81]. As per Leakey [82], agroforestry is a dynamic, ecologically based, natural-resource management system that, through the integration of trees in farmland and rangeland, diversifies and sustains smallholder production for increased social, economic and environmental benefits. These socioeconomically viable and biologically diverse systems suggest that agroforestry can produce NTFPs commercially and in a sustainable way. Non-wood tree products are used by people every day of their lives for their own need (food, fodder, medicines, building materials, resins, dyes, flavourings, etc.). Multipurpose trees play an important role to fulfil all needs as tangible and intangible benefits. As per ICRAF [83], multipurpose trees and shrubs are those that can produce food, fodder, fuelwood, mulch, fruit, timber and other products. New initiatives in agroforestry are seeking to promote poverty alleviation and environmental rehabilitation in developing countries, through the integration of indigenous trees, whose products have traditionally been gathered from natural forests, into tropical farming systems [84].

Non-timber forest products (NTFPs) include a broad range of edible, medicinal, decorative and handicraft goods harvested from woodlands [85-87]. Seeds, flowers, fruits, leaves, roots, bark, latex, resins, gum and other non-wood plant parts are categorized under NTFPs. The domestication of trees for agroforestry approaches to poverty alleviation and environmental rehabilitation in the tropics depends on the expansion of the market demand for their non-timber forest products. As per Leakey [88], the nutritive values of the flesh, kernels and seed oils of the fruit tree species, viz. *Irvingia gabonensis*, *Dacryodes edulis*, *Ricinodendron heudelottii*, *Chrysophyllum albidum*, *Garcinia kola*, *Adansonia digitata*, *Vitellaria paradoxa*, *Parkia biglobosa*, *Tamarindus indica*, *Sclerocarya birrea*, *Uapaca kirkiana*, *Zizyphus mauritiana*, *Vangueria infausta*, *Azanza garckeana*, *Inga edulis* and *Bactris gasipaes*, have been identified, in four eco-regions of the tropics, by subsistence farmers as their top priorities for domestication under agroforestry practices. As per Ike [89], *Irvingia* species (*wombolu* and *gabonensis*) are common among the trees planted under agroforestry practices, and their major importance to the farmers is the seed which is of significant economic value. The major system (89 %) of exploiting *Irvingia gabonensis* and *Irvingia wombolu* is from the wild. Other exploitation systems were around homestead (85.7 %), agroforestry (83.5 %) and *Irvingia* plantations (39.6 %) [90]. The most important part of *I. gabonensis* to the rural people is its nutritious seeds which have also been found useful in the reduction of cholesterol and body weight in obese patients [91]. In agroforestry practices, rates of growth and reproduction of NTFP, enhancement forest plantings and home gardens may also differ significantly from those in unmanaged forest environments, due to differences in intraspecific competition [92], light [93] or a combination of factors [94].

## 16. Conclusion

Agroforestry has emerged as a robust land use which advocates crop diversification, soil and soil-water conservation, cycling of organic matter and sequestration of CO<sub>2</sub> in plant and soil. This tree-crop combination provides shade to the field crop with making land productive and increasing revenue. Studying tree-crop interaction in agroforestry would help to devise appropriate ways to increase overall productivity of land. Increased productivity, improved soil fertility, nutrient cycling and soil conservation are the major positive effects of interactions, and competition is the main negative effect of interaction, which substantially reduces the crop yield. There are many research reports indicating significantly higher yield of crops in different agroforestry systems compared to sole crop yields. In the present scenario of climate change, agroforestry practices, emerging as a viable option for combating negative impacts of climate change. Convincing people regarding adoption and promotion of agroforestry is a great challenge and can be overcome by capacity building, providing suitable incentives and utilizing public-private partnership. Also, the government incentives and policies are the main task for success of intensive agroforestry system. Nowadays, agroforestry has gained popularity among farmers, researchers, policymakers and others for its ability to contribute significantly in meeting deficits of tree products and socioeconomic and environmental benefits. Therefore, agroforestry system gives diversification, provides societal continuum, creates green cover for carbon sequestration, generates fresh water harvesting potential and ground water recharge and increases the nutrient uptake, and their utilization management practices that lead to improved organic matter status of the soil will lead inevitably to improved nutrient cycling and better soil productivity.

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