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Bund Based Agroforestry Using *Eucalyptus* Species: A Review

ABHISHEK RAJ[1], M.K. JHARIYA[2] and S.S. BARGALI[3]

[1]College of Agriculture, I.G.K.V., Raipur-492012 (C.G.) India.
[2]Department of Farm Forestry, Sarguja University, Ambikapur-497001 (C.G.) India.
[3]Department of Botany, DSB Campus, Kumaun University, Nainital, Uttarakhand-263002, India.

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ABSTRACT

Agroforestry system as an ecologically sustainable land use option alternative to the prevalent subsistence farming patterns for conservation and development. It is an old traditional practice but recently named as an agroforestry. A large hectare is available in the form of boundaries, bunds, wastelands where this system can be adopted. *Eucalyptus* is a cropland agroforestry tree species planted along with various annual crops like paddy, wheat, and cereals and other cash crops in farmers' lands either in scattered or in bund. The main purpose of this review to provide/generates an idea about how *Eucalyptus* on bund behaves with associated crops i.e. interaction between both are studied in many aspects comprises outcome of yield, which is depends upon tree spacing, density, type and nature of existing bund plantation, their shading effects on morphology (internodes length, leaf area) and flower initiation/fruit-set of associated crops and their negative impacts on ecosystem includes competition of trees with crops for resources, allelopathic effects, rapid growth of trees occupy space of crops, etc. This review also includes carbon sequestration ability of *Eucalyptus* plantation with their growth and price trend behavior.

Keywords: Agroforestry, Carbon sequestration, Ecology, Bunds, Allelopathy.

INTRODUCTION

Eucalyptus is one of the most planted woody species in the world next to *Pinus* and *Cunninghamia*[1]. *Eucalyptus* belongs to the family Myrtaceae, mostly found in tropical region is a native to Australia. *Eucalyptus* spp. grows under wide range climatic and edaphic conditions in their natural habitats[2]. It is fast growing, easy to care, drought tolerate, and can be grown in poor or less fertile soil. It is a main material for paper pulp production, and a major source of bio-energy. It distributed to other parts of the world in the late 19th century and the beginning of 20th century when the demand for fuel and energy escalated in Europe, South America, Asia and Africa[3]. FAO has reported the area of productive eucalypt plantations by country, species and age class (Table 1). As per this report the percentage area of eucalypt plantation was decreased as per increasing age class in following order: 47.27 % area (0-5 year) > 28.45 % area (5-10 year) > 21.04 % area (10-20 year) > 2.98 % area (20-30 year) > 0.21 % area (30-40 year) > 0.02 % area (more than 40 year). Similarly, Brazil covered maximum area (41.17 %) of eucalypt spp plantation followed by China (32.61 %), Chile (8.87 %), Sudan (6.54 %), Australia (6.47 %), India (2.86 %), Argentina (1.34 %) and least in Myanmar (0.09 %) [1]. Foresters and wood industries support its expansion looking at its socio-economic benefits. Because of their demand in fuelwood production, wood for industrial need, construction materials, easy to grow and care, fast growing ability, drought tolerate, and growing potential in poor or less fertile soil, these resources are planted under cropland agroforestry along with various annual crops like paddy, wheat, and cereals and other cash crops in farmers' lands either in scattered or in bund. Boundary plantation under agroforestry program includes trees planted along boundaries or on bunds in such way to holding the soil against erosion and improving soil fertility (by fixing nitrogen or bringing minerals from deep in the soil and depositing them by leaf-fall). In agroforestry model, a suitable combination of nitrogen fixing and multipurpose trees with field crops are played a major role in enhancement of better yield productivity, soil nutrient status and microbial population dynamics which plays a major role in nutrient cycling to maintain ecosystem[4]. In northern parts of India, particularly in Haryana and Punjab Eucalypts and Populus are commonly grown along the field's boundary or bunds of paddy fields[5]. Now a days *Jatropha* spp. are being planted in the farm bunds for the direct income generation as well as for live fence[6]. Interaction between eucalyptus and associated crop are beneficial in aspect of yield i.e. higher net returns from *Eucalyptus*+ wheat than wheat alone[7] and harmful i.e. eucalyptus trees might negatively impact seed germination and growth of native species[8]. Also, *Eucalyptus* is blamed for heavy use of soil moisture, leaf litter and soil humus, consumption of soil nutrients, less soil conservative, non-fodder and habitat[9]. In shorts, relieving wood product scarcity, landscape re-greening, contribution to poverty reduction, biodiversity restoration and conservation are valuable contribution of eucalyptus in forest sector.

Agroforestry potential

Nair[10] has reported that area currently under agroforestry worldwide is 1,023 million ha. The current area under agroforestry in India is estimated as 25.32 Mha, or 8.2% of total geographical area of the country, under which 20.0 Mha is cultivated lands (7.0 Mha in irrigated and 13.0 Mha in rainfed areas) and 5.32 Mha is other areas such as shifting cultivation (2.28 Mha), home gardens and rehabilitation of problem soils (2.93 Mha)[11]. Due to increasing population pressure with increasing need of food and shelter are necessitates the deforestation[12] resulting loss of forest cover but by agroforestry practices the forest cover are maintained upto 33% as per given national forest policy of 1952. Agroforestry also provids livelihood opportunities through lac, gum, resin, fibre, fruits, apiculture and sericulture cultivation[13,14]. Therefore, agro-forestry has many potential, such as enhance the overall (biomass) productivity, soil fertility improvement, soil conservation, nutrient cycling, micro-climate improvement, carbon sequestration, bio drainage, bio energy and bio fuel etc[15,16,17]. The inter-play and complementarily between negative and positive interactions play an important role in the ecological sustainability and suitability of any agroforestry

Table 1: Area of productive eucalypt plantations by country, species, and age class[1]

		Area (1,000 ha) by age class (years)						Subtotal area	Percentage
Country	**Species**	**0-5**	**10-May**	**20-Oct**	**20-30**	**30-40**	**> 40**	**(1,000 ha)**	**(%)**
India	spp	43	64.4	103.2				210.6	2.86
China	spp	683	576.4	982.7	154.4			2396.5	32.61
Sudan	spp	118.2	189.1	165.5	8			480.8	6.54
Australia	regnans	5.2	0.2	2.8	3.7	4.7	1.1	17.7	0.24
	globulus	131.2	260.1	48.7	1.1	0.4		441.5	6
	grandis	5.2	5.5	0.5	1.4	4.6	0.4	17.6	0.23
Brazil	spp	2118.1	756.5	121	30.3			3025.9	41.17
Argentina	grandis	15.8	32.6	34.5	11.8	3.9		98.6	1.34
Chile	spp	353.4	204.1	85.4	7.2	2		652.1	8.87
Myanmar	camaldulensis	1.1	2.1	2.2	1.1	0.5		7	0.095
Subtotal area (1,000 ha)		3474.2	2091	1546.5	219	16.1	1.5	Total area =7348.3	
Percentage (%)		47.27	28.45	21.04	2.98	0.21	0.02		Total% =100

system. It can yield positive results only if positive interactions outweigh the negative interactions[18].

Why *Eucalyptus* in Agroforestry

Eucalypt has a long history in India. It was first planted around 1790 by Tippu Sultan, the ruler of Mysore, in his palace garden on Nandi hills near Bangalore. According to one version he received seed from Australia and introduced about 16 species[19]. Subsequently, regular plantations of *E. globulus* were raised to meet the demands for firewood, from 1856[20]. As per Bhatia (1984) [21] in early some 170 species, varieties, provenances of *Eucalyptus* were tried, out of which the most outstanding and favoured has been the *E*. hybrid, because of fast growing, capable of over topping weeds, coppices well, is fire hardy, browse resistant and it has the ability to adapt to a wide range of edaphoclimatic conditions. Reason behind plantation of *Eucalyptus* is very clear. Thanks to green revolution to mitigate and increase food production but requirement of firewood is also essential to cook food. The National Commission on Agriculture (1976) predicted that by the turn of the century the requirement of pulpwood in the country would be around 17 million m^3 and there would be a gap of 13 million m^3 and there was a great need to improve the productivity of Indian forests[22]. Therefore, *Eucalyptus* plantation can reduce pressure on natural forest, bridge gap between demand and supply of pulp and fire-wood, meet industrial need of timber, maintain biodiversity in globe.

***Eucalyptus* on Farm bunds**

Eucalyptus is a perennial and mostly evergreen tree, which is extensively used under the agroforestry program, either on farm-land or as a boundary plantation. Other than *Eucalyptus* some other MPTS include *Terminalia arjuna*, *T. tomentosa*, *Albizia procera*, *Mangifera indica*, *Butea monosperma*, *Zizyphus mauritiana, Azadirachta indica* and *Gmelina arborea* are also practices on the farm bunds. Neem (*Azadirachta indica*) is an important plant for social forestry, agroforestry, reforestation and rehabilitating the wasteland and degraded industrial lands[23].

Eucalyptus globulus trees are unpalatable to goats, sheep and cattle[24]. Thus they have a distinct advantage as boundary planting in recommended inter-row spacing and are aligned east–west or north-south direction. In this environment, eucalypt boundaries produce a harvestable tree crop within four to five years after planting[25]. The outcome of yield is depends upon tree spacing, density, type and nature of existing bund plantation and their shading effects which include effects on morphology (internodes length, leaf area) and effects on flower initiation/fruit-set of associated crops.

Effects of plantation age on biomass and productivity

In traditional agroforestry, crop density, above ground biomass, below ground biomass and their productivity are affected by tree canopy size, age and distance from tree trunk. As per Bargali and Singh (1995)[26] the biomass of 25 years old *Eucalyptus* plantation (262.9 t ha^{-1}) was two times higher than 8 years old plantation (126.7 t ha^{-1})[27] but the primary productivity values are almost similar. Similarly, nutrient returns to the soil through litter fall (87.4 Kg h^{-1} yr^{-1} of N and 4.8 Kg h^{-1} yr^{-1} of P) and decomposition rate of leaves (0.242% day^{-1}) were higher than that of 8 years old plantation (75.6 Kg h^{-1} yr^{-1} of N, 4.3 Kg h^{-1} yr^{-1} of P and 0.223% day^{-1})[26]. This is very significant information which compares of biomass, productivity and nutrient parameters as per age groups of *Eucalypts tereticornis* species. The biomass of vegetation, forest floor litter mass, tree litter fall and net primary productivity (NPP) of trees and shrubs increased with the increase in plantation age, whereas herb biomass and NPP significantly ($P < 0.01$) decreased with the increase in plantation age. The total plantation biomass increased from 7.7 t ha^{-1} in the 2-year-old to 126.7 t ha^{-1} in the 8-year-old plantation and NPP from 8.6 t ha^{-1} yr^{-1} in the 2-year-old to 23.4 t ha^{-1} yr^{-1} in the 8-year-old plantation[28]. Although nutrient content in trees and shrubs increased and in herbs it decreased with increase in plantation age[29]. Similarly Bargali (1994)[30] has investigated that under seasonal dynamics of forest floor biomass, rainy season has maximum (5.99 t ha^{-1}) total forest floor biomass (including herbaceous vegetation) followed by summer (5.49 t ha^{-1}) and winter (3.58 t ha^{-1}). Forest floor biomass increase significantly ($P < 0.01$) but herbaceous live biomass significantly decrease ($P < 0.01$) with increase in plantation age[30].

Effect of tree line distance on biomass

Distance from tree base also played significant role on the yield of grain crops. The yield of wheat as well as paddy increased with the increase in distance from the boundary tree lines. Further, as a distance increase the grain yield also increase[31]. In Ethiopia, tef (*Eragrostis tef*) yield was significantly reduced up to a distance of 12 m from *Eucalyptus* tree line[25], whereas in India wheat (*Triticum sp.*), chickpea (*Cicer arietinum*), lentil (*Lens esculentum*) yields were depressed between 2 and 12 m from the tree row[32,33] when trees were grown on field boundaries. Similar reduction in yield of intercrop under *Eucalyptus* vegetation has been reported in literature[34] particularly with age of the tree[35]. Wood biomass production rates of *Eucalyptus* on bund also increased (168 kg ha^{-1} y^{-1} to 2901 kg ha^{-1} y^{-1}) with corresponding age (four to twelve years)[25].

Effect of shade on yield performance of crop

Due to shading effect and strong root system of *Eucalyptus* , which compete for moisture and nutrient with crops resulting grain yield near the tree lines was comparatively low. Tree density or spacing between rows of eucalyptus tree is also influence the yield of wheat grain and straw[36]. Even the best trees in soil improvement may be detrimental to biodiversity, especially when planted at a narrow spacing where the reduction in the amount of light reaching the ground may suppress shade intolerant plants[37]. But reverse is favourable for shade loving plant. The better performance of intercrops in widely spaced eucalyptus was likely because of limited competition from trees for light and water[38].

Effects of tending operation on tree-crop parameter

Tending operation including pruning of tree crop also influence the productivity of associated crops and wood biomass of bund tree. Branch pruning effectively reduces light interception by the tree canopy, and thus prolongs the number of years that annual crop production can be practiced. For reducing tree crop competition, tending operation including pruning is an effective tools which enhance the crop productivity otherwise there is reduction in yield (41 to 61% reduction in wheat yield in unpruned *Eucalyptus* tree)[39]. 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[40]. However, to minimize crop yield suppression, farmers often practice intensive pruning annually before planting annual crops. Intensive pruning may enhance crop yield, but it is incompatible with commercial timber production because the growth rate and quality of the over-storey timber trees are severely reduced.

Effect of allele-chemicals on crops parameter

The presence of allele-chemicals negatively affects the neighbouring or successional plants[41]. In case of eucalyptus, interfere negatively with associated crops and leading to decline in plant diversity. This tendency is attributed to the allelopathy effect. *Eucalyptus* is toxic, due to allelopathic properties which serve to reduce germination of other plants[42,43]. Release of toxic chemicals from leaf, stem and roots extracts of *Eucalyptus* may inhibit the germination and seedling growth of crops[44]. Higher levels of allele-chemicals from root exudates and leaf leachate from older trees might be reason for more inhibitory effect on intercrop with age of the *Eucalyptus* plantation[35]. However, the inhibitory role of allele-chemicals is also expected to be more in rabi (less water regime) than that in kharif (high water regime) when the impact of inhibitory chemicals might be diluted due to high water regime and rainfall[45]. The aqueous extract of *E. camaldulensis* at various concentration (10, 15 and 20%) levels inhibited the germination, reduced fresh weights and dry weights of wheat seedlings[41]. Thus, eucalyptus extract had decreased the fresh and dry weight. It was observed that the aqueous extract of *E. globulus* caused inhibition of seed germination in green gram, black gram and cowpea[46]. Similarly, leaf extract of *E. camaldulensis* have allelopathic effect on seed germination and seedling growth of wheat (*Triticum aestivum.*)[47].

Eucalyptus (bio-drainage tree) effects on ground water

Eucalyptus has taken the vast area of the world and raising fears over water resources and Eco hydrological effects[48]. *Eucalyptus tereticornis* (Mysure gum) is fast growing goes straight and thus has low shading effect and has luxurious water consumption where excess soil moisture conditions exist. High water table caused deficiency of oxygen and excess of carbon dioxide in the root zone of wheat, which finally reduced the yield. *E. tereticornis* worked as bio-pumps and lowered the water table. This agroforestry model of bio-drainage has proved a low-cost, socially-acceptable and environment-friendly technique for the reclamation of waterlogged areas. Lowering of water table and associated soil improvement by *Eucalyptus* plantations increased the wheat grain yield by 3.4 times and resulted in reclamation of waterlogged areas[31].

Effects on soil properties

The extent of enrichment in soil properties depends on the tree species, management practices and the quantity and quality of litter and their decay rate. Moreover, the leaf litter deposition from *Eucalyptus* vegetation and resultant soil acidity might also affected intercrop yield. Owing to these negative effects, the positive effects like increased organic matter content from leaf litter decomposition might have resulted in improvement in soil water holding capacity, porosity, texture, essential nutrient and yield improvement of kharif and Rabi crop. Further, Litter fall and decomposition are the two major processes responsible for soil enrichment in agroforestry systems. Decomposition process plays an important role in soil fertility in terms of nutrient cycling and the formation of soil organic matter. Litter fall and their decomposition play a crucial role in pattern of weight loss (more rapid weight loss due to leaf litter decomposition in 1 yr old plantation of *Eucalyptus* species and decrease with plantation age) and nutrient release (potassium was released most rapidly) of any plantation age[49]. As per Bargali (1995 a & b) input of tree litter (ranged from 0.4 to 6.5 t ha^{-1} yr^{-1}) and nutrients in Kg ha^{-1} (62.3-75.6 N, 4.1-4.3 P and 27.9-30.6 K) increased with increasing plantation age (from 1 to 8 years old)[50,51]. Various soil physical and chemical properties (notably organic carbon, total N, P and K) decreased with increasing age of plantation[52,53]. Increase in soil carbon through plantations may also act as an important carbon sink[54]. The better drainage by the bio drainage plantation might have resulted in reduced sulphide toxicity, improved soil aeration, nutrient use efficiency as was reflected in better tillering in rabi paddy and was not evident in nearby field without plantation[45].

Agroforestry practices increase the soil organic matter through litter production which is responsible to enhance the population of beneficial microorganisms. The soil biological attributes are also responsible for determination and maintenance of physical properties of soil[55]. All the microbiological activities in soil enhance cycling of nutrients and other ecosystem functions. Recycling in natural system is one of the many ecosystem services that sustain and contribute to the human well being[56]. The added soil organic matter acts as a source of energy and enhances nutrient cycling and moderates soil microclimate and improves soil aggregate system[57].

Effects on biodiversity

The exotic invasive species are considered to be the second largest cause of biodiversity loss after habitat destruction[58,59]. Exotic invasive plants have been found to change the composition of native communities and been associated with reduced native plant diversity[60]. Most of the exotic plant effects reported have been identified as caused by allelopathic interaction which resulted in interference with physiological and biochemical processes in plants, due to chemicals released by exotic plants[61]. The *Eucalyptus* is now considered a threat to both plant and animal biodiversity because it reduces the growth of under-story and adjacent plant communities by secreting allele-chemicals in the soil and declining the avifaunal and other animal populations by habitat loss[62,63].

For *Eucalyptus* plantation land must be cleared and have nutrients added into the soil. This takes away from the habitat of animals and leaves them dead or in search of a new place to live. However, when grown in areas not native to the *Eucalyptus*, it can also become very grassy around the trees, possibly providing the animals with an area of shelter and habitat to live. On the other hand, farmers would not want this in their plantation and might use pesticides and other chemicals that could adversely affect the animals indirectly. Also, when fire enters eucalypt plantations, the eucalypt can provide shelter and food for most flightless invertebrates. *Eucalyptus* has thicker bark to protect it from the fire, and this can protect those animals as well. But globally, fire makes a bad impact on the surrounding environment causes pollution, ecological imbalance and loss of biodiversity in the natural forest[64]. Therefore, use of controlled fire, fire lines, fuel breaks, fuel load removal and mapping of fire sensitive areas are key principles to minimize fire risk[56].

Carbon sequestration potential

Anthropogenic activities such as land clearing and combustion of fossil fuel are possible contributing factors to the global increase in atmospheric carbon dioxide concentrations, commonly recognized as global warming[65]. There is an increasing concern which has instigated a scheme under the Kyoto protocol to reduce carbon emissions which can be traded and offset by carbon sequesters[65,66]. Trees capture carbon dioxide from the atmosphere, and store it in their wood, roots and leaves to mitigate the global warming. The actual amount stored is proportional to the dry weight of the wood and organic matter. Eucalyptus is particularly good at sequestering carbon because of following characteristics comprises dense wood, fast growth, large growth and long life (Table 2).

Furthermore, by including trees in agrecosystems, agroforestry have an ability to increase the amount of C stored in lands devoted to agriculture for the cultivation of food crops[67]. The total contribution of C content of forests has been estimated as 638 Gt for 2005, which is more that the amount of carbon in the entire atmosphere[68,69]. Similarly, it was estimated that 630 million ha of unproductive croplands and grasslands could be converted to agroforestry worldwide, with the potential to sequester 391,000 Mg C y–1 by 2010 and 586,000 Mg C y–1 by 2040[70]. Another estimate suggests that approx. 1.9 billion ha of land is degraded due to erosion, salinity, fertility depletion, and advancing deserts[71], and the potential of agroforestry to reduce the hazards of erosion and desertification as well as to rehabilitate such degraded land and to conserve soil and water has been well recognized[72,10]. It was estimated that the potential of agroforestry system in term of carbon storage varied from 0.3 to 15.2 Mg C/ha/yr[73]. Parrotta[74] has reported that soil carbon-sequestration potential under mixed stands, *Eucalyptus* + *Casuarina*, *Casuarina* + *Leucaena,* and *Eucalyptus* + *Leucaena* in Puerto Rico was 61.9, 56.6, and 61.7 Mg ha^{-1} at 4 years. It showed that mixed stands of eucalypts has more potential to sequestered carbon[74]. Therefore, the carbon sequestration capacity varied upon tree species, their growing condition and management practices under different agroforestry systems[75].

Table 2: Characteristics of Eucalypt species for favorable carbon sequestration ability

Characteristics	Function
Dense wood	It can holds more carbon for each cubic inch of wood
Grow fast	It can take up carbon quickly
Grow large	It can sequester more carbon in their body parts
Long life	It cannot be giving back the carbon any time soon.

Growth and price trends

Tanvir et al.[76] suggested proper rotation of farm-grown *Eucalyptus camaldulensis* based on maximum volume production and ultimate economic return (Table 3). In this table, height of the tree increased very rapidly for the first four years later on the height increment was quite low showing comparatively slow growth. Similar type of

Table 3: Growth and price trend of Eucalyptus camaldulensis during 10 years of its life span[74]

Age (years)	2	3	4	5	6	7	8	9	10
Height (ft)	25	32.2	39.1	41.2	42.7	44.5	46.7	47.2	48
Relative % Ht	52.08	67.1	81.4	85.8	88..96	92.7	97.29	98.33	100
DBH (inches)	4.37	6.2	7.5	8.9	10.2	11.21	12.3	12.95	13.2
Relative % DBH	33.10	46.96	56.81	67.42	77.27	84.92	93.18	98.10	100
Price/tree (Rs.)	175.4	257.8	304.05	391.1	407.1	516.8	573.05	628.15	660.6
Price/cft (Rs.)	113.16	82.36	59.27	53.28	42.41	41.08	36.6	36.93	36.82

results was also observed i.e. growth of tree species was rapid in early years of their growth and then it gradually slowed down[77,78]. DBH of *Eucalyptus camaldulensis* increased rapidly with more or less constant rate from 1 to 8 years. Later on the increment was very low and somewhat constant up to the 10th year. Similar results are shown in other literature[79]. As a whole, maximum volume was achieved during 7th year. Prices of the trees did not increase in proportion to volume per year. In spite of gradual increase in price per tree, the per cu. ft prices continued to decrease with increase in volume per year. This suggested that trees should be harvested during early years (within 7-8 years) for getting more income per annum.

CONCLUSION

Agroforestry plays an important role to enhance the overall farm productivity, soil enrichment through litter fall, maintaining ecosystem services such as climate change mitigation, phytoremediation, watershed protection and conservation of biodiversity. It gives diversification, provides societal continuum, creates green cover for carbon sequestration, generate fresh drinking water, ground water recharge, increase 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. But on other way agroforestry system including eucalypts could have negative effects on the local environment, e.g., soil degradation, decline of groundwater level and decrease of biodiversity. Therefore, rural people should manage *Eucalyptus* based agroforestry system with the right silviculture treatment, planted in the right site i.e. location specific and tended properly to optimize its positive values and reduce possible negative effects and this scientific management is not only make the income generation for upliftment of socio-economic value but also concern about the ecological and environmental stability on the sustained basis.

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