A paradigm shift in agroforestry practices in Uttar Pradesh

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Agroforestry is a dynamic and sustainable land management system of deliberately growing woody perennials along with agricultural crops on farmlands to secure both tangible and intangible benefits to the farmers. Uttar Pradesh (UP), one of the largest and densely populated state of India in the Indo-Gangetic Plain with large agrarian communities, had a paradigm shift in the adoption of agroforestry. After successful adoption and commercialization of poplar and eucalyptus-based agroforestry models over two decades in western UP, other parts of central and eastern UP have also been attracted towards remunerative agroforestry projects in the past few years. In UP, agroforestry practices vary according to different agro-climatic zones, land capability and socio-economic status of farmers. The variation is reflected in terms of diversity in agroforestry practices, and comparative advantage prompted a renewed interest to harness the vivid potential. Drawing on the representative literature, we have reviewed the status and pattern of tree–crop combinations of agroforestry practices across various regions of the state as well as productivity under different agroforestry systems, which shows traditional agriculture transforming to multifunctional agroforestry in UP.

Keywords: Agro-climatic regions, agroforestry, paradigm shift, productivity, tree–crop interaction.

THE well-known agrarian belts of northwestern India with poplar (*Poplus deltoides*)-based agroforestry practice in Haryana and Punjab, prompted renewed interest in adjacent western Uttar Pradesh (UP) for adopting agroforestry practices, which have gained momentum and helped establish productive agroforestry systems in the past two decades. In recent years, the agroforestry practices have spread in central and eastern UP due to large-scale adoption, especially in marginal and degraded lands. However, farmers of the eastern region have mixed feelings about agroforestry as they prefer plantations of some fast-growing species like *Eucalyptus*, *Emblica officinalis* (Aonla), bamboos, etc. on bunds and croplands. The shift in the initial line planting of multipurpose trees on the farm bunds to within the fields in spatial and temporal arrangements clearly indicates the preference of the farmers and paradigm shift for adoption of scientific and remunerative agroforestry practices.

UP is not only the most populated state, but also a major contributor to the national foodgrain stock of India. The state spreads over an area of 24.09 million hectare (m ha), comprising 6.8% of the total geographical area of the country. Agriculture is the backbone of the state's economy. According to the National Sample Survey Office (NSSO) Report 2014, about 74.8% of the state's rural households are dependent on agriculture for their income and livelihood support. Farming sector has played a significant role in improving the socio-economic and environmental conditions of the state. The National Forest Policy, 1988 set a target that minimum one-third of the geographical area of the country should be under forest cover. According to the Forest Survey of India (FSI), 2015 report, the forest and tree cover of UP is only 8.82% (forest cover 5.96% + tree cover 2.86%) of the total geographical area against the backdrop of the national average of 24.16%. Hence, to increase the desired forest cover (33%), planting trees outside the forest (TOF) on farmlands in agroforestry seems to be the only viable option. The scope of growth of agroforestry in the state is enormous as 16.56 m ha of land is under net sown area, which is 68.75% of its geographical area.

India is the first country in the world to adopt the National Agroforestry Policy in 2014, under its Ministry of Agriculture and Farmers Welfare. It objective is to expand tree plantation in combination with crops and/or livestock to improve overall productivity, reducing unemployment, generating additional source of income and livelihood support to small landholders. The policy also highlights that agroforestry could be implemented to meet the domestic and industrial requirements of the country for wood and its products. Moreover, in this direction, efforts have been made by the farmers and researchers for introducing promising tree-based farming systems across the different states in order to attain sustainability[1].

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Agroforestry is the deliberate growing of trees in conjunction with agricultural crops on the same unit of land organized in temporal and spatial mixture or sequence for benefits and services[2]. It integrates forestry and agriculture to enhance profitability, productivity and sustainability of land use. It is considered to be more productive and sustainable than forestry and monoculture farming. According to the census 2011, the population of UP is about 199.58 million, which is 16.49% of the total population of the country. The major population of the state is primarily dependent on forests and TOF for fuel and small wood extraction for routine use. The annual estimated production of fuel wood from the forest and TOF of the state is 0.008 and 2.253 million tonnes respectively, which is quite negligible compared to demand[3]. The trees in agroforestry system could supply fuel wood, fodder, fruits and fibre to the rural community to a large extent in order to improve the living conditions of the people through livelihood support and for alleviating poverty[4]. In addition, they offer a number of ecosystem services, socio-economic and environmental benefits[5,6]. The trees also protect the soil from erosion, and improve the productivity and fertility of the soil by adding organic matter[7–11]. Moreover, trees sequester aboveground and belowground carbon, and thus contribute to mitigation of climate change in the long run[2,12,13]. These multipurpose trees are knowingly retained by the farmers on their agricultural land, and their density, frequency and abundance, vary according to the social and climatic factors of the respective areas[14]. Agroforestry, being a sustainable land management system, is capable of providing multiple benefits to the farmers and safeguard the fragile agroecosystem as it is warranted to arrest the process of environmental degradation. Hence, planting trees within agricultural lands is an improved land-use alternative in terms of enhancing productivity, sustainability, profitability, livelihood security and economy of farming communities.

Status of agroforestry in Uttar Pradesh

In UP, agroforestry practices vary according to the agro-climatic zones and socio-economic status of the farmers. Considering the tree diversity, existing cropping pattern, availability of irrigation water, soil, climate, rainfall and other agro-meteorological characteristics of the area, the state is divided into nine agro-climatic zones, viz. (i) Bhabhar and Tarai Zone, (ii) Bundelkhand Zone, (iii) Central Zone, (iv) Eastern Plain Zone, (v) Mid-Western Plain Zone, (vi) North Eastern Plain Zone, (vii) South Western Semi-Arid Zone, (viii) Vindhyan Zone and (ix) Western Plain Zone[15]. The state can also be divided into three distinct physiographic regions. (1) The Sub Himalayan Tarai region in the north is highly fertile and has thick forests with rich flora and fauna. Crops like wheat, rice and sugarcane are commonly grown by the farmers. (2) The Gangetic Plain at the centre is large as it covers nearly two-thirds of the state. The whole region is densely populated and immensely vital for the economy of the state. The soil in the region is mostly alluvial, which is fertile. The main crops of the region include paddy, wheat, sugarcane, grams and millets. The eastern tract of this Plain is subjected to periodical floods and droughts, while, the western and central tracts are comparatively better with a well-developed irrigation system. (3) The Vindhyan Hills and plateau in the south which majorly comprises the Bundelkhand division. Rainfall is scanty and erratic with limited or scarce water resources which force the practice of dryland farming on a large scale in the region. There are two main cropping seasons in the state, viz. *rabi* and *kharif*. The *kharif* cropping season is from July to October during the southwest monsoon. Paddy, maize, jowar, bajra, pulses (arhar, black gram, green gram), potato, cotton, groundnut and soybean are the various crops grown in the *kharif* season. *Rabi* cropping season is from October to March, and the important *rabi* crops are wheat, barley, peas, chickpea and mustard. *Zaid* season is between *kharif* and *rabi*, and the major crops grown during this season include watermelon, muskmelon, cucumber and vegetables. The state produces numerous diverse crops due to its comparative advantage of a wide range of agro-climatic conditions.

Western UP is more advanced in terms of agriculture and agroforestry practices compared to other regions of the state. This region has well-developed agroforestry models due to well-developed wood-based industries, which have been promoting tree-based agroforestry framers to meet the demands of raw material[16,17]. The farmers of this region are adopting industrial agroforestry models and raising eucalyptus, poplar and bamboo for commercial cultivation to fulfill the demands of industries. The cultivation of trees on farmlands with agricultural crops has helped generate income[18,19]. Traditional agroforestry system is retained by the farmers in the state for domestic purposes. *Azadirachta indica* (neem), *Dalbergia sissoo* (shisham), *Acacia nilotica* (babul), and *Eucalyptus* spp. are the dominant species in traditional agroforestry system in most districts of UP. High demand of wood as raw material for various wood-based industries creates opportunities for enterprising farmers and planters. The need is to establish agroforestry pulpwood plantations to meet the growing needs of the industries, in addition to satisfying domestic demands of the farmers[20]. Continuous emphasis by the UP Government through various schemes like MGNREGA (Mahatma Gandhi National Rural Employment Guarantee Act), RKVY (Rashtriya Krishi Vikas Yojna), National Horticulture Mission, Bamboo Mission, special plantation drives, and by private companies has been promoting plantations on private land. Over 10 lakh saplings were planted at ten locations in the state in 'Clean UP, Green UP' campaign launched by the UP Government on 7 November 2015; on 11 July

2016, UP entered the Guinness World Records for planting 50 million trees; belonging to 80 species on a single day[21]. Plants such as *Ficus infectoria* (pakar), *Tamarindus indica* (imli), *Ficus religiosa* (pipal), *Ficus bengalensis* (bargad), *Holoptelia integrifolia* (chilbil), *Ficus lacor* (pakar, neem), *Terminalia arjuna* (arjun) and shisham were planted. Many special plantation drives have been launched in the state for enhancing the supply of diverse woody and non-woody products by planting trees on forest land, farmers' land, community land and public office premises. The Forest Department is also supplying saplings and planting material of the desired trees at a nominal price or even free of cost to promote agroforestry among the farmers. Road and canal-side tree plantations under MGNREGA are also aimed to provide sustainable, productive and green assets for livelihood of the rural poor and to promote ecological balance by augmenting soil and water conservation practices.

Poplar, a deciduous, short-rotation fast-growing tree which can be economically harvested within 6–8 years, is highly encouraged by the farmers in block and boundary plantation in the state[22]. The main poplar-growing districts of UP are Shaharanpur, Muzaffarnagar, Meerut, Baghpat, Jyotibarao Phule Nagar, Bulandshahr, Hapur, Bijnor, Rampur, Moradabad, Bareilly, Badaun, Pilibhit, Shahajahanpur, Kheri and Bahraich[23]. WIMCO (Western India Match Company), the biggest manufacturer of matches in India, has been promoting poplar-based agroforestry project in UP[23]. Several farmers are growing poplar and eucalyptus as cash crops, while other fast-growing tree species like *Bombax ceiba* (semal), *Anthocephalus cadamba* (kadam), sobabul (*Leucena leucocephala*), *Acacias* and shisham have also been planted and retained by the farmers, however, *Emblica officinalis* and bamboos are also planted on farm land[24].

Eastern UP is now gradually adopting agroforestry, characterized by subsistence agriculture zone with low crop intensity and irrigation facility. Rainfall is the only source of water in the area. Fruit tree-based agroforestry is the most popular system maintained by large and medium farmers in this region. Majority of farmers cultivate vegetables and fruits like *Artocarpus heterophyllus* (jackfruit), *Psidium guajava* (guava), banana and various citrus fruits in their farmlands. In agri-silviculture system, eucalyptus, shisham and poplar are the main woody perennials integrated with agricultural crops by the farmers.

The Eastern Plains and North Eastern Tarai zones of the state need to adopt proper agroforestry systems like agri-silviculture, silvi-horticulture, agri-silvi-horticulture and silvo-pastoral systems instead of monocropping[25]. Silvo-pastoral system is considered beneficial for improving degraded lands in the semi-arid regions of UP (ref. 26). The state has 1.37 m ha of land which is salt-affected (6.73 m ha in India), and soil sodicity is a serious problem of the Indo-Gangetic Plain affecting productivity and livelihood of the people. ICAR–Central Soil Salinity Research Institute in Karnal is engaged in the reclamation of salt-affected soil in central UP using agro-chemical methods, horticulture and agroforestry plantations of salt-tolerant species. *Casuarina*, *Acacia* and *Aonla*-based systems are showing promising results in reclaiming sodic, saline and alkaline soils.

Oil-yielding species like *Jatropha curcas* (jatropha)[27] and *Pongamia pinnata* (karanj) are better suited for the sodic soil and wastelands of eastern UP[25]. Poplar-based agroforestry system is not gaining momentum in central UP due to the saline and sodic conditions in the region. The only way to increase land under agriculture is through utilizing the barren and infertile land by reclamation for additional crop production[28]. Permanent reclamation is possible only by the adoption of agroforestry system to sustain agricultural production and productivity[29–32]. There are several evidences which indicate that sodic soil can be desodified by growing plants on the degraded sites. Subabul, Casuarina and babul are identified as the most capable species for afforestation on deficient soils. *Sesbania sesban* (jayanti) and *Tamarix dioca* (lal jhau) are shrubs which have shown good adaptability in problematic soils[33] and could significantly improve the physical, chemical and biological properties of soils. Many emerging innovative agroforestry models like aqua-farming, dairy farming, goat farming, bee-keeping (apiculture) and sericulture have been developed by the Allahabad Agriculture Institute for utilizing wastelands of the region[34]. The technological advances in agriculture are encouraging new non-crop and off-farm activities in rural areas[35]. Appropriate selection of intercrops, thinning of trees at different ages and promotion of modern agricultural technology are valuable for improving the benefits of agroforestry[36]. Various factors that influence tree planting decisions are size of land holding, overall annual income, area of irrigated land and previous experiences from tree plantation[34,37]. In addition to poplar and eucalyptus, bamboo-based agroforestry has also been encouraged in various parts of the state. Cultivation of bamboo is being practised on a large scale in the wastelands of eastern UP[37]. It provides food, fodder, building material and also raw material for handicrafts, pulp and paper industries and for domestic use among the rural community. Bamboo being one of the fast-growing and high-yielding perennial plant species, is widely used for effectively reclaiming wastelands and degraded areas. It also conserves soil, stabilizes river banks and slopes[34]. Table 1 summarizes the overall status and tree–crop combinations of agroforestry practices in various districts of UP.

Productivity under various agroforestry systems

The gross productivity in agroforestry systems is higher than the sole cropping systems. Approximately 20% higher yields of grain and wood have been reported in

Table 1. Agroforestry practices in various districts of Uttar Pradesh (UP)

Regions (districts)	Major findings
Saharanpur[16]	Wood-based industries, eucalyptus and poplar for commercial agroforestry. Other species mostly on the boundaries are mango, sisham and jamun
Saharanpur[54]	Agri-silviculture, Agri-horticulture with mango and agri-horti-silviculture with mango, *eucalyptus* and poplar. Wheat, mustard, sugarcane and paddy are the dominant crops
Aligarh[16]	Traditional agroforestry – sisham, neem, babul and eucalyptus
Shahjahanpur[36]	Poplar-based agroforestry; intercrops are wheat and sugarcane
Bijnor and Rampur[55]	Poplar-based agri-silviculture – wheat, jowar and sugarcane. Other crops include maize, potato, mustard, soybean, lentils, turmeric, fodder crops and aromatic herbs
Mid-Gangetic Plain and Eastern Plains[25]	Agri-horticulture and Agri-silvi-horticulture
Rampur[56]	Poplar and eucalyptus-based agroforestry
Rohilkhand[57]	Poplar in agroforestry and social forestry in block and boundary plantation
Allahabad[58–60]	Jatropha-based agroforestry in wastelands
Allahabad[34]	Eco-rehabilitation of degraded lands and social upliftment through bamboo cultivation
North Western plains of UP[61]	Agri-horticulture and agri-horti-silviculture systems combined with a livestock component such as dairy, goat-rearing (for meat and milk) and vegetables. Trees – mango, guava, *Citrus* spp., papaya, sisham, jamun, eucalyptus and poplar
Mirzapur[62]	Guava-based agri-horticulture with maize
Indo-Gangetic Plains[63]	Poplar and eucalyptus-based agroforestry, and agri-horticulture. Rehabilitation of lands degraded by salinization, ravines, gullies, and other water and wind erosion hazards
Eastern UP[64]	Preponderance of mango plantations
Mirzapur[65]	Agri-horticultural system – custard apple and guava with moong
Faizabad[66]	Teak with paddy as well as sole plantations

agroforestry system of Haryana and western UP compared to pure agriculture[38]. Another study in a similar area showed that growth and yield of crops in the proximity of tree rows were poor, but the loss was compensated by the wood produced by the trees[39]. Aonla-based agroforestry is considered as highly profitable, productive and sustainable as it requires low management and inputs. The production of horticultural trees as intercrops was found to be more effective for improvement in soil fertility and productivity[27].

The productivity of wheat and mustard grown under 2½ year-old Eucalyptus trees planted at 6 m × 2 m under an agroforestry system in Haryana revealed that grain yield, straw yield and net income were decreased in both the intercrops when compared to crops in open fields. It was concluded that wheat crop was more compatible than mustard for cultivation under eucalyptus-based agroforestry system[24].

Data presented in Table 2 summarize the major findings of different aspects of productivity under various agroforestry practices in different regions of UP.

Opportunities

UP has immense potential to develop a wide range of profitable agroforestry models. Successful agroforestry models are already being adopted in western UP, which can be replicated in the nine agro-climatic zones of the state. Further, the availability of labour, large area under farming, developing agro-based industries, wood-based industries and presence of various agricultural institutes creates abundant opportunity for enhancing the potential and scope of agroforestry in the state.

The possibility for expanding agricultural diversity is worthy, but more work is needed to improve the quality of delivery of programmes through faculty skills upgrading, options for experiential learning, and further development in learning materials[40]. Education, research and development are inter-linked and contribute to the socio-economic development of society. It also influences the farmer's ability to adopt agroforestry in a more profitable and sustainable way for better livelihood. In UP agricultural education is imparted at the high school and higher secondary levels, along with a number of Government and agriculture colleges for higher education. There are several agricultural universities in the state which are engaged in teaching, research and extension in agriculture, agroforestry and related disciplines, there are several agricultural institutes engaged in agroforestry research, training and extension programmes. The Central Agroforestry Research Institute in Jhansi provides training, and conducts basic and applied research for developing and delivering technologies based on sustainable agro-forestry practices on farms, marginal and wastelands for various agro-climatic zones in India. The Indian Grassland and Fodder Research Institute in Jhansi also conducts basic, applied and adaptive research for sustainable agriculture through quality forage production for improved animal

Table 2. Productivity in agroforestry practices in various regions of UP

Agroforestry practices/ combinations	Age of plantation (years)	Regions	Productivity
Wheat crop with poplar boundary plantation	3	Baraut (Baghpat district)[67]	Litter production averaged 1.103 t ha^{-1} in 3- and 4-year-old plantations. No adverse effect was noticed on wheat with poplar
Casuarina-based agri-silvi-horticultural system	–	Eastern UP[68]	The fresh rhizome yield for turmeric was 8.6 t ha^{-1}, which was higher than the yield (7.6 t ha^{-1}) obtained in open area
Eucalyptus tereticornis-based agri-silvicultural system	6	Faizabad[69]	Paddy grain yield was found to be 14.7–19.7% less under agroforestry system and wheat yield grain was 26.4–34.6% lower than open cultivation
Eucalyptus-based agroforestry system	6 and 10	Saharanpur[70]	Biomass productivity varied from 13.6 t/ha for 6-year-old to 33.81 t/ha for 10-year-old plantations
Poplar-based agri-silviculture system	3 and 7	Saharanpur[54]	Estimated timber biomass of poplar at the age of 3 years was 0.126 t $tree^{-1}$, which became 0.267 t $tree^{-1}$ at the age of 7 years
Aonla-based agri-horticulture system	9	Jhansi[27]	Fruit yield of 86 trees ha^{-1} was 6.45 t ha^{-1}; crop yield was 3.005 t ha^{-1} in *rabi* season and 0.902 t ha^{-1} in *kharif* season
Aonla-based horti-pastoral system	13	Jhansi[71]	Fruit yield was 13.65 t ha^{-1}; fodder production with aonla was higher (20.75 t ha^{-1} green fodder) compared to sole crop
Lemon grass (*Cymbopogon flexuosus*) under poplar	–	Allahabad[72]	Herbage yield (48.5 t ha^{-1}) and oil yield (0.197 t ha^{-1}) of lemon grass under poplar trees.
Eucalyptus with aromatic grasses (palmarosa and citronella grass)	–	Rampur[73]	Higher herbage and oil yield was recorded in pure fields of aromatic grass than the intercrops grown under eucalyptus hybrid stands. Maximum oil yield was produced by lemon grass and minimum by palmarosa. Higher quantity of litter was produced in palmarosa than in citronella

productivity. Forestry Training Institute at Kanpur conducts studies and research relating to conservation of environment and forestry and Indian Council for Forestry Research and Education (ICFRE)'s Centre for Social Forestry and Eco-Rehabilitation in Allahabad aims to bring excellence in the field of social forestry and eco-rehabilitation in eastern UP and the Vindhyan region. Other universities like Banaras Hindu University, Varanasi; Rani Laxmi Bai Central Agricultural University, Jhansi; the Indian Institute of Soil and Water Conservation Centre at Datia, and Social Forestry Wing of State Government are also promoting agroforestry. Several traditional universities like Bundelkhand University, Agra University, Purvanchal University, Amity University, private institutes and under industries (through corporate social responsibility programme) are imparting teaching and extension for expansion and sustainable development of agroforestry in the state.

ICAR-Central Soil Salinity Research Institute (CSSRI), Regional Research Station at Lucknow has standardized and developed an auger hole technology for raising forest and fruit plantations on land lying barren due to salinity hazards. Growing forest plantations with plants like eucalyptus clones like ITC – (Bhadrachalam) is recommended, which consume water efficiently suited for bio drainage in water logging areas along with good economic returns. CSSRI is concentrating on diversification through silvi-pastoral systems for sodic, waterlogged, saline lands and bio-saline agriculture, including agroforestry, agri-horticulture and silvipastoral systems[41]. Similarly, the role of farmers in promoting agroforestry is crucial. Farmers must be given information about the benefits, profitability and proper methods to grow trees with crops. They must be trained regarding which tree–crop combination is suitable for the region to increase overall productivity by growing trees on their farmlands.

Challenges in agroforestry

Agroforestry seems to be a viable and economically feasible solution for the farmers to meet the challenges of food, nutrition, energy, employment and environmental security. Promotion and proper implementation of the recently launched Agroforestry Policy of India, 2014 is a big challenge for the Government of India, though agroforestry is one of the solutions to reduce the growing pressure on the forests, enhance tree cover and to fulfil the shortage of industrial timber. It is also considered as a good alternative for food security[32,42] in semi-arid and arid regions[43].

There are several challenges ahead to reap the benefits of agroforestry. There is lack of homogeneity in regulations and policies concerning felling as well as transporting farm-grown timber and other products in different states[44]. There should be moderation in transit and felling permission rules for the tree species preferred by the farmers practising agroforestry. The restriction imposed on harvesting, transporting and marketing of agroforestry tree produce is limiting agrarians and croppers to adopt agroforestry is big challenge to address. Though in UP poplar, eucalyptus, subabul, *Casuarina*, *Ailanthus* spp., *Gmelina arborea*, *Grevillea robusta*, *Morus alba*, *Anthocephalus cadamba*, *Melia composita*, *Acacia* spp., *Albizia* spp., *Borassus flabeliformis*, *Butea monosperma*, *Tamarindus indica* and *Grewia oppositifolia* are partially free to cut on farmland while mango, mahua, bargad, neem and other trees are restricted and permission is obligatory for their harvesting, transport and marketing[45]. Hence, there is a need to overcome such constraints by revisiting the policies for those species which are broadly adopted under agroforestry systems by most of the farmers.

Some farmers are not keen on planting trees on farmlands as basically they are unaware about the economics of tree plantations and have apprehensions that the trees would reduce crop productivity. The enigma of tree–crop management in agroforestry is still unknown for many which discourage a majority of the farmers taking decisions on large-scale adoption of agroforestry systems. Moreover, fear of not getting permission from the Government for cutting trees and poor connectivity with the market and consumers also restrict the practice of agroforestry[46]. The farmers are also facing several constraints while practising agroforestry, like lack of information on selection of trees, shortage of quality planting stock, high labour costs for tree management, poor institutional mechanism and policy impediments and inadequate funding for research and extension[47–49]. Additionally, selection of suitable fast-growing tree species, training facilities to the farmers for capacity building and motivation and development of suitable infrastructure for marketing and processing of the products obtained from the trees in the farmlands should be taken into consideration. Hence, there is a need to strengthen the agroforestry practices by identifying successful models that can be adopted by the farmers on a wide scale. Advancement of contemporary agricultural technology would also be helpful in increasing the yield of sole crops as well as intercrops[22]. The various problems and constraints of agroforestry can be overcome through policy and institutional reforms[50]. Moreover, there is deficiency in the understanding of biophysical concerns correlated with productivity, water-resource sharing, soil productivity, and plant interactions in agroforestry systems, since most of the research is site-specific, observational in nature, and not process-oriented[51].

Farmers with major land holdings will get more benefit by the agroforestry extension programmes than the small and marginal farmers. So, there is a need to introduce special programmes and agroforestry models for marginal and small farmers. Genetically superior planting stock, improved seed varieties and marketing support for agroforestry plantations can enhance agroforestry which generates surplus employment opportunities for the landless farmers and the rural poor. It also contributes towards environmental amelioration and maintains ecological balance. Agroforestry programmes can improve the agricultural productivity by making the soil fertile, conserving water and reducing soil erosion[52]. Planting method, propagation and micro site improvement are the other factors which should be taken into consideration before practising agroforestry[53].

Conclusion

Agroforestry is gaining widespread recognition as a sustainable and supportable land-management system among the farming communities in UP. It is well-established among farmers of western UP due to efforts by the State Government, industries and NGOs. The commercialization of poplar, eucalyptus, and aonla-based agroforestry systems has revolutionized the economy and livelihood of the farmers. UP has immense potential to develop a wide range of agroforestry models, as significant area is affected by various kinds of land degradation. The Indo-Gangetic, Central and Eastern Plain regions of UP have high potential to address the issues of degradation. The sustainable agriculture with profitability by practising agroforestry plays a major role in the rehabilitation of lands degraded by ravines, waterlogging, gullies and alkalinity/salinity. Marketing support for sale of products by minimum support price and further development of commercially viable agroforestry plantations largely contribute to employment opportunities and income for the landless and marginal farmers as well as the rural poor. There is a need of revisiting the various policies and programmes launched by the state government for tree farming in isolation to be brought under the umbrella of single nodal agency to synergize and coordinate effectively for promoting agroforestry. The state government should evolve a State agroforestry Policy in consonance with the National Agroforestry Policy 2014, to plan, prioritize and develop agroforestry action plan suitable for each agro-climatic zone. There should be moderation in transit and felling permission for the species preferred by the farmers practising agroforestry. The state should focus on strengthening research and extension activities through PPP (public–private partnership) mode for developing profitable, ecologically and socio-economically viable agroforestry models for all farmers. Encouragement of wood-based industries, establishment of more nurseries and selecting proper tree–crop combinations in eastern UP are prerequisites to promote agroforestry. Furthermore, planting fast-growing trees as an agroforestry

component, management of problematic soil, promotion of bio-drainage system and adoption of new conservation agriculture technologies will pave the way for intensive adoption of agroforestry even by small and marginal farmers. The promotion of sustainable agroforestry practices on a large scale in future may be possible through amalgamation of proactive farmer policies of the state government, involvement of the industries, support services from NGOs and willingness of farmers in UP.

1. Kareemulla, K., Rizvi, R. H., Kumar, K., Dwivedi, R. P. and Singh, R., Popular agroforestry systems of western Uttar Pradesh in northern India: a socioeconomic analysis. *For., Trees Livelihoods*, 2005, **15**(4), 375–381.
2. Nair, R. P. K., Kumar, B. M. and Nair, V. D., Agroforestry as a strategy for carbon sequestration. *J. Plant Nutr. Soil Sci.*, 2009, **172**(1), 10–23.
3. India State of Forest Report, Forest Survey of India, Ministry of Environment and Forests, Government of India, 2011, pp. 230–235.
4. Bijalwan, A., Sharma, C. M. and Sah, V. K., Productivity status of traditional agri-silviculture system on Northern and Southern aspects in mild hill situation of Garhwal Himalaya, India. *J. For. Res.*, 2013, **20**(2), 137–143.
5. Jose, S., Agroforestry for ecosystem services and environmental benefits: an overview. *Agrofor. Syst.*, 2009, **76**(1), 1–10.
6. Dhyani, S. K. and Handa, A. K., Agroforestry in India and its potential for ecosystem services. In *Agroforestry Systems in India: Livelihood Security and Ecosystem Services*, Springer, 2014, pp. 345–365.
7. Saha, R. and Jha, P., Carbon sequestration potentials of agroforestry systems under climate change scenario – brief review with special emphasis on North-Eastern hill regions. *J. Agric. Phys.*, 2012, **12**(2), 100–106.
8. Atangana, A., Khasa, D., Chang, S. and Degrande, A., Agroforestry for soil conservation. In *Tropical Agroforestry*, Springer, The Netherlands, 2014, pp. 203–216.
9. Yadav, R. P., Sharma, P., Arya, S. L. and Panwar, P., *Acacia nilotica*-based silvipastoral systems for resource conservation and improved productivity from degraded lands of the Lower Himalayas. *Agrofor. Syst.*, 2014, **88**(5), 851–863.
10. Zake, J., Pietsch, S. A., Friedel, J. K. and Zechmeister-Boltenstern, S., Can agroforestry improve soil fertility and carbon storage in smallholder banana farming systems. *J. Plant Nutr. Soil Sci.*, 2015, **178**(2), 237–249.
11. Schwab, N., Schickhoff, U. and Fischer, E., Transition to agroforestry significantly improves soil quality: a case study in the Central mid-hills of Nepal. *Agric., Ecosyst. Environ.*, 2015, **205**, 57–69.
12. Palm, C., Tomich, T., Van Noordwijk, M., Vosti, S., Gockowski, J., Alegre, J. and Verchot, L., Mitigating GHG emissions in the humid tropics: case studies from the alternatives to slash-and-burn program (ASB). *Environ., Develop. Sustainability*, 2004, **6**(1–2), 145–162.
13. Haile, S. G., Nair, P. K. and Nair, V. D., Carbon storage of different soil-size fractions in Florida silvopastoral systems. *J. Environ. Qual.*, 2008, **37**(5), 1789–1797.
14. Bijalwan, A., Dobriyal, M. J. and Bhartiya, J. K., A potential fast growing tree for agroforestry and carbon sequestration in India: *anthocephaluscadamba* (Roxb.) Miq. *Am. J. Agric. For.*, 2014, **2**(6), 296–301.
15. Singh, P., Population and agro climatic zones in India: an analytical analysis. *Proc. Soc. Behav. Sci.*, 2014, **120**, 268–278.
16. Dwivedi, R. P., Kareemulla, K., Singh, R., Rizvi, R. H. and Chauhan, J., Socio-economic analysis of agroforestry systems in western Uttar Pradesh. *Indian Res. J. Ext. Edu*, 2007, **7**(2–3), 18–22.
17. Kareemulla, K., Singh, R., Rizvi, R. H., Dwivedi, R. P. and Kumar, K., Economic analysis of agroforestry systems in western Uttar Pradesh. *J. Trop. For.*, 2008, **24**(1/2), 1–9.
18. Scherr, S. J., Building opportunities for small-farm agroforestry to supply domestic wood markets in developing countries. In *New Vistas in Agroforestry*, Springer, The Netherlands, 2004, pp. 357–370.
19. Sharma, S. K., Chauhan, S., Sharma, S. K., Kaur, B. and Arya, I. D., Opportunities and major constraints in agroforestry systems of western UP: a vital role of Star Paper Mills, Saharanpur (UP), India. *Agric. Biol. J. North America*, 2009, **3**, 343–349.
20. Parthiban, K. T. and Rao, M. G., Pulpwood-based industrial agroforestry in Tamil Nadu – a case study. *Indian For.*, 2008, **134**(2), 155–163.
21. http://news.nationalgeographic.com/2016/07/india-plants-50-million-trees-uttar-pradesh-reforestation/
22. Jain, S. K. and Singh, P., Economic analysis of industrial agroforestry: poplar (*Populus deltoides*) in Uttar Pradesh (India). *Agrofor. Syst.*, 2000, **49**(3), 255–273.
23. Dhiman, R. C., Transforming rural Uttar Pradesh through integrating tree culture on farm land: a case study of WIMCO's poplar programme. *Lucknow Manage. Assoc. Conv. J.*, 2012, **8**(1), 85–98.
24. Kumar, R., Gupta, P. K. and Gulati, A., Agroforestry extension and its impact on socio-economic scenario – a case study of Yamunanagar District (Haryana). *Indian For.*, 2003, **129**(4), 435–445.
25. Rana, B. S., Saxena, A. K. and Parihar, A. K. S., Status and scope of agroforestry development in eastern part of Uttar Pradesh. In *Agroforestry: Systems and Practices* (eds Puri, S. and Panwar, P.), New India Publishing Agency, 2007, pp. 191–211.
26. Rai, P., Yadav, R. S., Solanki, K. R., Rao, G. R. and Singh, R., Growth and pruned production of multipurpose tree species in silvo-pastoral systems on degraded lands in semi-arid region of Uttar Pradesh, India. *For. Trees Livelihoods*, 2001, **11**(4), 347–364.
27. Dwivedi, R. K., Tewari, R., Kareemulla, K., Chaturvedi, O. P. and Rai, P., Agri-horticultural system for household livelihood – a case study. *Indian Res. J. Ext. Educ*, 2007, **7**(1), 22–26.
28. Khan, M. R., Kumar, A. and Khan, S. A., Studies on important plant characters of poplar (*Populus deltoides*) for agroforestry system of central Uttar Pradesh. *J. Non-Timber Forest Prod.*, 2013, **20**(1), 1–5.
29. Khan, S. A. and Khan, R., Improvement of soil quality through agroforestry system for Central Plain Zone of Uttar Pradesh India. In *Developments in Soil Salinity Assessment and Reclamation*, Springer, The Netherlands, 2013, pp. 631–637.
30. Chaturvedi, O. P., Kaushal, R., Tomar, J. M. S., Prandiyal, A. K. and Panwar, P., Agroforestry for Wasteland rehabilitation: mined, ravine, and degraded watershed areas. In *Agroforestry Systems in India: Livelihood Security and Ecosystem Services*, Springer, India, 2014, pp. 233–271.
31. Dagar, J. C., Greening salty and waterlogged lands through agroforestry systems for livelihood security and better environment. In *Agroforestry Systems in India: Livelihood Security and Ecosystem Services*, Springer India, 2014, pp. 273–332.
32. Singh, Y. P., Singh, G. and Sharma, D. K., Bio-amelioration of alkali soils through agroforestry systems in central Indo-Gangetic Plains of India. *J. For. Res.*, 2014, **25**(4), 887–896.
33. Singh, B., Rehabilitation of alkaline wasteland on the Gangetic alluvial plains of Uttar Pradesh, India, through afforestation. *Land Degrad. Develop.*, 1989, **1**(4), 305–310.
34. Lal, S. B., Mehera, B., Chandra, R., Charan, P. and Larkin, A., Eco-rehabilitation and social upliftment through bamboo based agroforestry models in Allahabad district. *New Agric.*, 2005, **16**(1/2), 97–100.
35. Sharma, R. and Poleman, T. T., *The New Economics of India's Green Revolution: Income and Employment Diffusion in Uttar Pradesh*, Cornell University Press, 1993.

36. Jain, S. K. and Singh, P., Performance of intercrops in agroforestry system: the case of poplar (*Populus deltoides*) in Uttar Pradesh (India). *Indian For.*, 1999, **125**(2), 195–205.
37. Ashraf, J., Pandey, R., de Jong, W. and Nagar, B., Factors influencing farmers' decisions to plant trees on their farms in Uttar Pradesh, India. *Small-scale For.*, 2015, 1–13.
38. Dwivedi, A. P. and Sharma, K. K., Agroforestry: its potential. In Paper presented in the seminar on Social Forestry and Agroforestry, FRI Dehradun, 1989.
39. Tewari, D. N., *Agroforestry for Increased Productivity, Sustainability and Poverty Alleviation*, International Book Distributors, Dehradun, 1995, p. 539.
40. Chakeredza, S., Temu, A. B., Yaye, A., Makungwa, S. and Saka, J. D. K., Mainstreaming climate change into agricultural education: challenges and perspectives. ICRAF Working Paper – World Agroforestry Centre, 2009, p. 82.
41. Vision 2050 Report, ICAR-Central Soil Salinity Research Institute, Karnal, 2015.
42. Singh, B. and Gill, R. I. S., Carbon sequestration and nutrient removal by some tree species in an agri-silviculture system in Punjab, India. *Range Manage. Agrofor.*, 2014, **35**(1), 107–114.
43. Meena, L. R., Mann, J. S. and Karim, S. A., Agroforestry practices in arid and semi-arid regions of India: challenges and opportunities. *Indian J. For.*, 2012, **35**(1), 1–8.
44. Pandey, D. N., Multifunctional agroforestry systems in India. *Curr. Sci*., 2007, **92**(4), 455–463.
45. Chavan, S. B., Keerthika, A., Dhyani, S. K., Handa, A. K., Newaj, R. and Rajarajan, K., National Agroforestry Policy in India: a low hanging fruit. *Curr. Sci*., 2015, **108**(10), 1826–1834.
46. Hegde, N. G., Agri-horti-forestry for rehabilitation of tribals and small farmers: BAIF's approach. In Proceedings of Workshop on Agroforestry: Potentials and Opportunities, Agrobios (India) and Indian Society of Agroforestry, Jodhpur, 2003, pp. 319–328.
47. Ajayi, O. C. and Kwesiga, F., Implications of local policies and institutions on the adoption of improved fallows in eastern Zambia. *Agrofor. Syst.*, 2003, **59**, 327–336.
48. Pattanayak, S. K., Mercer, D. E., Sills, E. O. and Yang, J., Taking stock of agroforestry adoption studies. *Agrofor. Syst.*, 2003, **57**, 173–186.
49. Mercer, D. E., Adoption of agroforestry innovations in the tropics: a review. *Agrofor. Syst.*, 2004, **61**, 311–328.
50. Smith, N., Dubois, J., Current, D., Lutz, E. and Clement, C., Agroforestry experiences in the Brazilian Amazon: constraints and opportunities, Federal Government of Brazil, 1998, p. 67.
51. Puri, S. and Nair, P. K. R., Agroforestry research for development in India: 25 years of experiences of a national program. In *New Vistas in Agroforestry*, Springer, The Netherlands, 2004, pp. 437–452.
52. Piare, L., Kulkarni, H. D. and Rao, S. N., Improving land productivity and returns from agroforestry plantations. *Indian For.* 1993, **1**(19), 6.
53. Negi, R. S., Pathak, B. and Sikarwar, R. L. S., Rehabilitation of wastelands through fruit orchard plantations. *Indian For.*, 2014, **140**(3), 291–301.
54. Rizvi, R. H., Dhyani, S. K., Yadav, R. S. and Singh, R., Biomass production and carbon stock of poplar agroforestry systems in Yamunanagar and Saharanpur districts of north-western India. *Curr. Sci.*, 2011, **100**(5), 736–742.
55. Singhal, R. M. and Panwar, B. P. S., Commercial approach to poplar (*Populus deltoides* M.) based agroforestry systems in north-western Uttar Pradesh. *Van Vigyan*, 1992, **30**(1), 29–38.
56. Mohsin, F., Effect of litterfall of short-rotation trees on herbage and oil yield of aromatic plants under agroforestry system. *Indian J. Agrofor.*, 2005, **7**(1), 25–31.
57. Shyam, S. and Srivastava, A. K., Biomass producing potential in an age series of *Populus deltoides* plantation in Rohilkhand region of Uttar Pradesh. *Plant Arch.*, 2011, **11**(1), 231–237.
58. Mehra, B. and Lai, S. B., Input–output analysis of *jatropha* based agroforestry models in district Allahabad, Uttar Pradesh. *New Agric.*, 2007, **18**(1/2), 91–93.
59. Mehera, B. and Lal, S. B., Bamboo based agroforestry models suitable for cultivable wastelands of eastern Uttar Pradesh. *New Agric.*, 2009, **20**(1/2), 123–125.
60. Lal, S. B., Mehera, B., Chandra, R. and Larkin, A., Performance evaluation of *Jatroph acurcas* in different districts of Uttar Pradesh. *New Agric.*, 2004, **15**(1/2), 141–144.
61. Dadhwal, K. S., Sharma, N. K. and Saroj, P. L., Diagnosis and possible interventions in designing agroforestry systems in north-western plains of Uttar Pradesh – a case study. *Indian J. Soil Conserv.*, 1995, **23**(1), 47–53.
62. Rajput, B. S., Shukla, N. N, Sen, A. and Singh, R. K., Row spacing and mulching effect on growth and nutrient uptake of maize (*Zea mays* L.) under Guava (*Psidium guajava* L.) based agri-horti system. *Online Int. Interdiscip. Res. J.*, 2014, **4**(3), 131–138.
63. Pathak, P. S., Dagar, J. C., Kaushal, R. and Chaturvedi, O. P., Agroforestry inroads from the traditional two-crop systems in heartlands of the Indo-Gangetic plains. In *Agroforestry Systems in India: Livelihood Security and Ecosystem Services*, Springer India, 2014, pp. 87–116.
64. Singh, A., Singh, R. K., Kumar, P. and Singh, A., Mango biodiversity in eastern Uttar Pradesh, India: indigenous knowledge and traditional products. *Indian J. Tradit. Knowl.*, 2015, **14**(2), 258–264.
65. Singh, M., Kumar, P. and Prasad, S., Agri-horti systems and weed management practices effect on growth and yield of mungbean [*Vigna radiata* (L.) Wilczek]. *Int. Q. J. Life Sci*., 2014, **9**(4), 1449–1453.
66. Sharma, A., Singh, R. P. and Saxena, A. K., Growth and mineral nutrition of teak (*Tectona grandis* Linn. F.) in sole and rice based agroforestry plantations in sodic soils of eastern Uttar Pradesh, India. *Plant Arch.*, 2011, **11**(1), 79–81.
67. Sharma, N. K., Samra, J. S. and Singh, H. P., Poplar (*Populus deltoides*) based agroforestry systems for an alluvial soil under irrigated condition in western Uttar Pradesh. *Indian For.*, 2001, **127**(1), 61–69.
68. Rana, B. S., Saxena, A. K. and Verma, S. K., Agroforestry research on sodic wasteland in eastern part of Uttar Pradesh. *Indian For.*, 2011, **137**(12), 1410–1422.
69. Verma, S. K. and Rana, B. S., Effect of light intensity on paddy and wheat grain yield under *Eucalyptus tereticornis* Sm. based agri-silvicultural system. *Indian For.*, 2014, **140**(1), 23–28.
70. Rizvi, R. H., Dhyani, S. K. and Maurya, D., Assessment of carbon stock in *Eucalyptus tereticornis* based agroforestry system in Saharanpur district of north-western India. *Range Manage. Agrofor.*, 2012, **33**(1), 92–95.
71. Kumar, S., Shukla, A. K. and Singh, H. V., Intercropping of pearl millet + cowpea as rainfed fodder crops with aonla based agri-horti-system. *Int. J. Hortic.*, 2013, **3**.
72. Raj, A. J., Lal, S. B., Daniel, S. and Gowda, V., Intercropping of lemon grass with poplar (*Populus deltoides* Bartr. ex Marsh) in eastern Uttar Pradesh. *Indian J. Agrofor.*, 2010, **12**(1), 13–17.
73. Mohsin, F. and Singh, O., Litterfall and nutrients return in *eucalyptus* with aromatic grasses under agroforestry system. *Ann. Hortic.*, 2010, **3**(1), 63–68.

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