Multifunctional Agroforestry Systems in India: Science-Based Policy Options

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The Rajasthan State Pollution Control Board is a body corporate constituted under section 4 of the Water (Prevention and Control of Pollution) Act, 1974. It was first constituted on February 7, 1975, with the objectives of prevention, and control of water pollution and maintaining or restoring of wholesomeness of water. Later, it was also entrusted with the responsibilities of prevention, control and abatement of air pollution under the provisions of Air (Prevention and Control of Pollution) Act, 1981. Water (Prevention and Control of Pollution) Cess Act, 1977 has been enacted to make the State Board financially independent. Under this act the State Board has been given powers to collect cess on the basis of water consumed by the industries and others. Besides, the State Board is also implementing the provisions of the Public (Liability) Insurance Act, 1991. Enactment of the Environment (Protection) Act, 1986 has further widened the scope of the activities of the Board. This act being umbrella legislation, different rules for addressing the problems of various sectors have been enacted under this act. Currently, the State Board is engaged in implementation of the following rules under EPA, 1986:

- Hazardous Waste (Management, Handling and Transboundary Movement) Rules, 2008.
- Manufacture, Storage & Import of Hazardous Chemical Rules, 1989.
- Public (Liability) Insurance Act, 1991.
- Public (Liability) Insurance Rules, 1991.
- Environmental Impact Assessment (Aravali) Notification Dated 7.5.1992.
- Environmental Impact Assessment Notification dated 14.09.06.
- Bio Medical Waste (Management & Handling) Rules, 1998.
- Plastic Waste (Management & Handling) Rules, 2011.
- Noise (Pollution Control & Regulation) Rules, 2000.
- Municipal Solid Waste (Management & Handling) Rules, 2000.
- Batteries (Management & Handling) Rules, 2001.

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Summary

Land-use options that increase resilience and reduce vulnerability of contemporary societies are fundamental to livelihoods improvement and adaptation to climate change. Agroforestry as a wide-spread land-use adaptation may potentially support livelihoods improvement through simultaneous production of food, fodder and firewood as well as mitigation and adaptation to climate change. Drawing on the representative literature from peer-reviewed research, this paper critically examines the contribution of agroforestry systems in India to: (i) biodiversity conservation; (ii) yield of goods and services to society; (iii) augmentation of the carbon storage in agroecosystems; (iv) enhancing the fertility of the soils; and (v) providing social and economic well-being to people. Agroforestry systems in India contribute variously to ecological, social and economic functions, but they are only complementary—and not as alternative—to natural forests. A winning strategy for conservation and human welfare can be achieved by protecting the largest possible area of natural ecosystems while growing food on the smallest possible area to reconcile food production with conservation. Yet, this combination is not always feasible. Therefore, a trade-off strategy for addressing multiple functions is required. Accordingly, agroforests need to be strengthened by innovations in technology, domestication, governance and market regimes. Taking into account the available stock of knowledge efforts are needed to connect science to decision-making. In addition, future research is required to eliminate many of the uncertainties that remain, and also carefully test the main functions attributed to agroforestry against alternative land-use options in order to know unequivocally to what extent agroforestry served these purposes.

Key words: Biodiversity Conservation, Biological Pest Control, Carbon Sequestration, Ethnoforestry, Food Security, Global Climate Change, Soil Fertility Enhancement

Introduction

Land-use options that increase livelihood security and reduce vulnerability to climate and environmental change are necessary. Traditional resource management adaptations, such as agroforestry systems, may potentially provide options for improvement in livelihoods through simultaneous production of food, fodder and firewood as well as mitigation of the impact of climate change[1,2]. Reframing the challenge in another way, agroforestry systems may provide part of the answer to a central challenge for sustainability on how to conserve forest ecosystems and farmland biodiversity as well as the services that they provide while simultaneously enhancing food production for an increasing population under the condition of land and water scarcity[3-5].

Livelihoods improvement is not just about the positive change towards better quality of life and human well-being but it takes into account the local and global change which determines livelihoods[6]. The adverse impact of climate change may be more severely felt by poor people who are more vulnerable than rich. Appropriate policy responses combining the agroecosystems as key assets can strengthen adaptation and help build the resilience of communities and households to local and global change[7,8]. There is, thus, a need for intensified management and governance efforts to generate products and services in agroecosystems. Tree growing in combination to agriculture as well as numerous other vegetation management regimes in cultural landscape including in farms, watersheds and regional landscape can be integrated to take advantage of services provided by adjacent natural, semi-natural or restored ecosystems[9].

Increasing the livelihood security and reducing the vulnerability call for societal adaptation[10]. Such adaptations are possible when combined with traditional resource management systems. Agroforestry as a local adaptation, therefore, is a promising area of interest for scientists, policy-makers and practitioners. This review examines the multifunctional agroforestry systems in India as a potential option for livelihoods improvement, climate change mitigation and adaptation, and biodiversity conservation in agroecosystems. The synthesis of the available literature also helps to identify remaining uncertainties and thus the future directions for management and research.

Trees in Agroecosystems

Agroforestry systems in India include trees in farms and a variety of local forest management and ethnoforestry practices[11]. India is estimated to have between 14,224 million[12] and 24,602 million[13] trees outside forests, spread over an equivalent area of 17 million ha[14], supplying 49% of the 201 million tonnes of fuelwood and 48% of the 64 million m^3 of timber consumed annually by the country[15]. Forest Survey of India earlier has estimated that 2.68 billion trees outside forests exist over an equivalent area of 9.99 million ha. More recent estimates suggest that an equivalent area of 92,769 km^2 (i.e., 2.82% of the geographical area) is under tree cover in India[16]. The current growing stock has been estimated to be about 1.616 billion cubic metres[17]. For these calculations the tree cover has been defined as tree patches less than 1 ha with the canopy density >10%.

In some states where good analyses are now available, the Haryana and Kerala are a case in point. With merely 3.5 percent of Haryana's area under forests, the state has become self-sufficient in small wood, fuelwood and industrial timber by establishing large-scale plantations on farmlands. Trees in agroecosystems have increased the extent of area under forest and tree cover to 6.63 percent[18]. These plantations sustain about 670 wood-based veneer, plywood and board, manufacturing units, one large paper mill and about 4 300 sawmills that depend on agroforestry produce. Similarly, the case of Kerala suggests that the state has a surplus of 0.027 million m^3 of wood in terms of consumption. While the total wood production in the state is 11.714 million m^3, the forests provide only about 10 percent and trees in home gardens and mixed cropping multi-tier agroforestry system contribute to the remaining 90 percent[19] (see also **Table 1**).

Agroforestry Systems as Carbon Sinks

Land management actions that enhance the uptake of CO_2 or reduce its emissions have the potential to remove a significant amount of CO_2 from the atmosphere if the trees are harvested, accompanied by regeneration of the area, and sequestered carbon is locked through non-destructive (non-CO_2 emitting) use of such wood.

Agroforestry for carbon sequestration is attractive because[20]: (i) it sequesters carbon in vegetation and in soils depending on the pre-conversion soil C, (ii) the more intensive use of the land for agricultural production reduces the need for slash-and-burn or shifting cultivation, (iii) the wood products produced under agroforestry serve as substitute for similar products unsustainably harvested from the natural forest, (iv) to the extent that agroforestry increases the income of farmers, it reduces the incentive for further extraction from the natural forest for income augmentation, and finally, (v) agroforestry practices may have dual mitigation benefits as fodder species with high nutritive value can help to intensify diets of methane-producing ruminants while they can also sequester carbon[21].

Evidence is now emerging that agroforestry systems are promising management practices to increase aboveground and soil C stocks to mitigate greenhouse gas emissions. The C sequestration potential of tropical agroforestry systems in recent studies is estimated between 12 and 228 Mg ha^{-1} with a median value of 95 Mg ha^{-1}. Other estimates based on the global status of the area suitable for the agroforestry (585-1215 x 10^6 ha), suggests that 1.1-2.2 Pg C could be stored in the terrestrial ecosystems over the next 50 years[22]. Another estimates of C stored in agroforestry systems, derived from a recent review of studies with global coverage, range from 0.29 to 15.21 Mg ha^{-1} yr^{-1} aboveground, and 30 to 300 Mg C ha^{-1} up to 1-m depth in the soil[23].

In India, average sequestration potential in agroforestry has been estimated to be 25tC per ha over 96 million ha[24] but there is substantial variation in different regions depending upon the biomass production. However, compared to degraded areas agroforestry may hold more carbon. For example, above ground biomass accumulation in a central Himalayan agroforestry system has been found to be 3.9

t $ha^{-1}yr^{-1}$ compared with 1.1 t $ha^{-1}yr^{-1}$at the degraded forestland[25]. The strip-plantations in Haryana sequestered 15.5 t ha^{-1} carbon during the first rotation of 5 years and 4 months[26]. In agroecosystems of Indo-Gangetic Plains about 69% of soil carbon in the soil profile is confined to the upper 40 cm soil layer where C stock ranges from 8.5 to 15.2 t C ha^{-1}. Agricultural soils of Indo-Gangetic Plains contain 12.4 to 22.6 t ha^{-1} of organic C in the top 1 m soil depth[27].

The role of trees outside forests in carbon balance has been considered only recently, reporting that trees outside forests in India store about 934 Tg C or 4 Mg C ha^{-1}, in addition, to the forests[28]. The net annual carbon sequestration rates for fast growing short rotation agroforestry crops such as poplar and Eucalyptus have been reported to be 8 Mg C $ha^{-1}yr^{-1}$ and 6 Mg C $ha^{-1}yr^{-1}$ respectively[29]. Poplar-based agroforestry systems in Saharanpur (UP) and Yamunanagar (Haryana) store 27- 32 t ha^{-1} carbon in boundary system and 66-83 t ha^{-1} in agrisilviculture system at a rotation period of 7 years[30]. Studies from Punjab suggest that at a rotation of seven years, poplar timber carbon content could be 23.57 t ha^{-1} and an equal amount may be contributed by roots, leaves and tree bark[31]. In smallholder bamboo farming system in Barak Valley, Assam[32], a traditional homegarden system, C estimate in aboveground vegetation ranged from 6.51 (2004) to 8.95 (2007) Mg ha^{-1} with 87%, 9% and 4% of the total C stored in culm, branch and leaf respectively. The mean rate of C sequestration was 1.32 Mg $ha^{-1}yr^{-1}$.

In tropical homegardens of Kerala, average aboveground standing stocks of C ranged from 16 to 36 Mg ha^{-1}, where small homegardens often have higher C stocks on unit area basis compared to large- and medium-sized ones[33]. In soils, Within 1 m profile, soil C content ranged from 101.5 to 127.4 Mg ha^{-1}. Smaller-sized homegardens (<0.4 ha) with higher tree density and plant-species richness had more soil C per unit area (119.3 Mg ha^{-1}) of land than larger-sized ones (>0.4 ha) (108.2 Mg ha^{-1})[34]. Studies in Khammam district, Andhra Pradesh, on technical potential for afforestation on cultivable wastelands, fallow, and marginal croplands with Eucalyptus clonal plantations found baseline carbon stock to be 45.3 t C/ha, mainly in soils. The additional carbon sequestration potential under the project scenario for 30 years has been estimated to be 12.8 t C/ha/year inclusive of harvest regimes and carbon emissions due to biomass burning and fertilizer application. If carbon storage in harvested wood is considered, an additional 45% carbon benefit can be accounted[35].

In terms of potential, currently area under agroforestry worldwide is 1,023 million ha[36], and areas that could be brought under agroforestry have been estimated[37] to be 630 M ha of unproductive croplands and grasslands that could be converted to agroforestry worldwide, with the potential to sequester 586 Gg C yr^{-1} by 2040. In fact 5 to 10 kg C ha^{-1} can be sequestered in about 25 years in soils of extensive tree-intercropping systems of arid and semiarid lands to 100-250 kg C ha^{-1} in about 10 years in species-intensive multistrata shaded perennial systems and homegardens of humid tropics[38].

Such estimates for India based on holistic studies are not available, and therefore research and synthesis is required. Another major uncertainty, and thus an issue for future research, is that even the estimates that are available globally, are mostly derived through biomass productivity and often do not take into account the carbon sequestration in soils[39].

The potential of agroforestry systems as carbon sink varies depending upon the species composition, age trees and shrubs, geographic location, local climatic factors, and management regimes. The growing body of literature reviewed here indicates that agroforestry systems have the potential to sequester large amounts of above and belowground carbon compared to tree-less farming systems. In order to exploit the mostly unrealized potential of carbon sequestration through agroforestry in both subsistence and commercial enterprises innovative policies, based on rigorous research results, are required.

Enhancing Soil Fertility and Water Use Efficiency

Trees in agroecosystems can enhance soil productivity through biological nitrogen fixation, efficient nutrient cycling, and deep capture of nutrients and water from soils[40]. Even the trees that do not fix nitrogen can enhance physical, chemical and biological properties of soils by adding significant amount of above and belowground organic matter as well as releasing and recycling nutrients in tree-bearing farmlands[41].

Ecological intensification of cropping systems in fluctuating environments often depends on reducing the reliance on subsistence cereal production, integration with livestock enterprises, greater crop diversification, and agroforestry systems that provide higher economic value and also foster soil conservation. Maintenance and enhancement of soil fertility is vital for the global food security and environmental sustainability. Although India is self-sufficient in terms of food production currently, but for a population expected to rise further[42], country will need to enhance both the food production as well as tree biomass. The next green revolution and concurrent environmental protection will have to double the food production[43]. Maintaining and enhancing the soil fertility of farmlands to grow food grains as well as tree biomass can help meet the demand in future. Ecologically sound agroforestry systems such as intercropping and mixed arable-livestock systems, involving legume-based rotations, which reduce water runoff and improve soil fertility can increase the sustainability of agricultural production while reducing on-site and off-site consequences and may be a road to sustainable agriculture[44,45]. Although tree species have potential to conserve moisture and improve fertility status of the soil in agroforestry systems, legumes are the most effective for promoting soil fertility. In addition, deep rooted species could reduce competition for nutrients and moisture with crops by pumping from deeper layers of soil[46].

Agroforestry may hold promise for regions where success of green revolution is yet to be realized due to lack of soil fertility. A useful path, complementary to chemical fertilizers, to enhance soil fertility is through agroforestry. Alternate land use systems such as agroforestry, agro-horticultural, agro-pastoral, and agro-silvipasture are more effective for soil organic matter restoration[47]. Soil fertility can also be regained in shifting cultivation areas with suitable species. For instance, a field experiment to study the N_2 fixation efficiency suggests that planting of stem cuttings and flooding resulted in greater biological N_2 fixation, 307 and 209 kg N ha^{-1} by *Sesbania rostrata* and *S. cannabina*, respectively. Thus, *S. rostrata* can be used as a green manure by planting the stem cuttings under flooded conditions[48]. Even in the dry regions, the mean annual litter fall by neem trees can be 6059 kg ha^{-1} at the density of 400 trees ha^{-1} with potential return of 98, 2.25, 32 and 131 kg ha^{-1} of available nitrogen, phosphorous, potassium and calcium[49].

Through a combination of mulching and water conservation, trees in agroecosystems may directly enhance the crop yields of coarse grains. For instance, in the arid region of Haryana, the effect of *Prosopis cineraria*, *Tecomella undulata*, *Acacia albida* and *Azadirachta indica* on the productivity of *Hordeum vulgare* (barley) was found to be positive. *P. cineraria* enhanced the grain yield by 86.0%, *T. undulata* by 48.8%, *A. albida* by 57.9% and *A, indica* by 16.8% over the control. Biological yield was also higher under the trees than that in the open area. The soils under different tree canopies were rich in organic carbon content, moisture availability and nutrient status[50].

Recent studies have found that multiple-use species such as *Bambusa nutans* has potential to help in soil nutrient binding during restoration of abandoned shifting agricultural lands (jhum fallows) in north-eastern India under the *B. nutans*. A Comparison of jhum cultivation and agroforestry suggests that agroforestry is an option to address the challenges of slash-and-burn[51].

A study of nutrient cycling, nutrient use efficiency and nitrogen fixation in *Alnus*–cardamom plantations in the eastern Himalaya found that nutrient standing stock, uptake and return were highest in the 15-year-old stand. Annual N fixation increased from the 5-year-old stand (52 kg ha^{-1}) to the 15-year-old stand (155 kg ha^{-1}) and then declined with advancing age. Thus, *Alnus*–cardamom plantations performed sustainably up to 15–20 years[52].

Significant improvement in soil biological activity has been reported under different tree based agroforestry systems in Rajasthan[53]. For instance, soil microbial biomass C, N and P under agroforestry varied between 262–320, 32.1–42.4 and 11.6–15.6 μg g^{-1} soil, respectively, with corresponding microbial biomass C, N and P of 186, 23.2 and 8.4 μg g^{-1} soil under a no tree control. Fluxes of C, N and P through microbial biomass were also significantly higher in *P. cineraria* based land use system followed by *Dalbergia sissoo*, *Acacia leucophloea* and *Acacia nilotica* in comparison to a no-tree control[54]. In *Prosopis cineraria* and *Tecomella undulata* systems optimum desnisty of trees rather than maintaining random trees in farming system are more useful[55]. Such improvements are vital for long term productivity and sustainability of the soil in tropics, where level of soil biological activity is low due to lower soil organic matter.

Trees with their comparatively deeper root system improve ground water quality by taking up the excess nutrients that have been leached below the rooting zone of agricultural crops. These nutrients are then recycled back into the system through root turnover and litterfall, increasing the nutrient use efficiency of the agroecosystems[56]. There is robust evidence that agroforestry systems have potential for improving water use efficiency by reducing the unproductive components of the water balance (run-off, soil evaporation and drainage)[57]. Examples from India[58] and elsewhere show that simultaneous agroforestry systems could double rainwater utilisation compared to annual cropping systems, mainly due to temporal complementarity and use of runoff in arid monsoon regions[59,60]. For instance, combination of crop and trees use the soil water between the hedgerows more efficiently than the sole cropped trees or crops, as water uptake of the trees reached deeper and started earlier after the flood irrigation than of the *Sorghum* crop, whereas the crop could better utilize topsoil water[61]. Integration of persistent perennial species with traditional agriculture also provides satisfactory drainage control to ameliorate existing outbreaks of salinity[62]. Agroforestry in periurban agriculture can also be useful for utilization of sewage-contaminated wastewater from urban systems[63,64] and biodrainage to prevent water logging in canal-irrigated areas[65].

It must be pointed out that although agroforestry systems may reduce crop yield for a variety of reasons, there may be a trade-off. For instance, studies on traditional agroforestry system in central India[66] found that effect of residual nitrogen on the yield of rice crop after removal of 15-year old *Acacia nilotica* trees resulted in increase in the crop yield (12.5 t ha^{-1}) that was almost equal to the reduction in the crop yield suffered during 15 years of the tree growth in agroforestry system. Yield reductions may also be compensated in the long run by microclimate modification[67]. A short-term on-farm experiment conducted in Khammam district of Andhra Pradesh found intercrop yields were 45% of the sole crop in eucalyptus system and 36% in leucaena system during the 2 year. Yet, study found that leucaena variety K636 and eucalyptus clonal based agroforestry systems are profitable alternatives to arable cropping under rainfed conditions[68]. Economic analysis in agroforestry in Andaman found that net profit from the black pepper was negative for the first and second cropping year in the beginning, but okra alone compensated it. From the third cropping year black pepper alone not only compensated its establishment cost, but also earned a reasonably good income. Moreover, net return in black pepper over the seven cropping years of the experiments not only compensated the negative returns from the system, but also made the alley cropping system 4.46 times more profitable than without the black pepper[69].

Even when trees are not removed through total harvest, the species combination may be designed for nutrient release that benefits crops. Chemical characteristics and decomposition patterns of six multipurpose tree species, viz., *Alnus nepalensis, Albizzia lebbek, Boehmeria rugulosa, Dalbergia sissoo, Ficus glomerata* and *F. roxburghii* in a mixed plantation established on an abandoned agricultural land in a village at 1200 m altitude in Central Himalaya is a case in point. These species gave the highest rates of N and P release during the rainy season. Thus, *kharif* crops (rainy season crops) are unlikely to be nutrient stressed even if leaf litter is the sole source of nutrients to crops in mixed agroforestry. A diverse multipurpose tree community provides not only diverse products but may also render stable nutrient cycling[70].

Agroforestry as an adaptation

Agroforestry systems can be useful in maintaining production during both wetter and drier years. During the drought deep root systems of trees are able to explore a larger soil volume for water and nutrients, which will help during droughts. Furthermore, increased soil porosity, reduced runoff and increased soil cover lead to increased water infiltration and retention in the soil profile which can reduce moisture stress during low rainfall years. Tree-based systems have higher evapotranspiration rates and can thus maintain aerated soil conditions by pumping excess water out of the soil profile more rapidly than other production systems. Finally, tree-based production systems often produce crops of higher value than row crops. Thus, diversifying the production system to include a significant tree component may buffer against income risks associated with climatic variability[71], in synergy with climate change mitigation and support to help vulnerable populations adapt to the negative consequences of climate change[72].

In drought-prone environments, such as Rajasthan, as a risk aversion and coping strategy, farmers maintain agroforestry systems to avoid long-term vulnerability by keeping trees as an insurance against drought, insect pest outbreaks and other threats, instead of a yield-maximizing strategy aiming at short-term monetary benefits[73]. Numerous examples of traditional run-off agroforestry discussed in this article and elsewhere are other examples of adaptation to climate variability[74-78].

Adaptation to climate change is now inevitable. Research on agroforestry as an adaptation to climate change and as a buffer against climate variability is still evolving. Main pathway through which agroforestry may qualify as an adaptation to climate change is through diversifying production systems and increasing the sustainability of smallholder farming systems. The role of agroforestry in reducing the vulnerability of agroecosystems—and the people that depend on them—to climate change and climate variability needs to be understood more clearly.

Biodiversity Conservation

Biodiversity is threatened worldwide, and despite some local successes, the rate of biodiversity loss does not appear to be slowing[79]. This can decrease ecosystem functioning and services. Different species promote ecosystem functioning during different years, at different places, for different functions and under different environmental change scenarios. The species needed to provide one function during multiple years are often not the same as those needed to provide multiple functions within one year[80]. Therefore, precautionary investments are required for managing biodiversity over the landscape[81]. Actions focused on enhancing and restoring biodiversity are likely to support increased provision of ecosystem services[82].

The literature on the role of agroforests in biodiversity conservation is growing rapidly. A large body of research in India[1] and elsewhere[83] suggests five major roles of agroforestry in conserving biodiversity: (i) agroforestry provides habitat for species that can withstand a certain level of disturbance in agroecosystems; (ii) agroforestry helps preserve germplasm of socially useful and associated species; (iii) agroforestry helps reduce the rates of conversion of natural habitat by providing goods and services alternative to traditional agricultural systems that may involve clearing natural habitats; (iv) agroforestry provides connectivity and acts as stepping-stone by creating corridors between habitat remnants and thereby conservation of area-sensitive plant and animal species; and (v) agroforestry helps conserve biological diversity by providing other ecosystem services such as erosion control and water recharge, thereby preventing the degradation and loss of surrounding habitat.

Society needs to craft synergies among sustainable livelihoods, the Kyoto Protocol, the Convention on Biological Diversity, and other international instruments. Genetic diversity of landraces and trees in agroecosystems is particularly of immediate concern as there is a danger of erosion in ethnocultivars as well as knowledge that has generated such diversity[84]. Using agroforestry systems as carbon sinks, and by designing a suitable emissions trading system, the Kyoto Protocol provides a new source of financial support for protection and management of biological diversity[85].

Continued deforestation is a major challenge for forests and livelihoods. In addition, decreasing biological diversity through species reduction in managed agroforestry systems is also emerging as a challenge. Although agroforestry may not entirely reduce deforestation[86], but in many cases it acts as effective buffer to deforestation. Trees in agroecosystems in Rajasthan and Uttranchal have been found to support threatened cavity nesting birds, and offer forage and habitat to many species of birds[87]. These systems also act as refuge to biodiversity after catastrophic events such as fire[88]. Agroforestry also leads to a more diversified and sustainable rural production system than many treeless farming alternatives and provides increased social, economic, and environmental benefits for land users at all levels. What constitutes enough biodiversity in agroecosystems depends upon the goal in question and will differ depending on whether the aim is to increase yields to support livelihoods improvement or deal with salinity, ground water levels, soil erosion, leaching of nutrients or weed control.

If we are concerned about conserving important biodiversity, then protected areas are the preferred choice, and biodiversity conservation may not be a primary goal of agroforestry systems. Nevertheless, agroforestry systems, in some cases, do support as high as 50-80% of biodiversity of comparable natural systems[89], and also act as buffers to parks and protected areas[90] as natural vegetation alongside agroforestry allows noncrop-crop spillover of a diversity of functionally important organisms[91]. The landscape mosaics created by the interplay of rainwater harvesting as an adaptation to climate change and consequent growth of vegetation in agroforestry systems[92,93] acts as corridor providing avenues for dispersal and gene flow in wildlife population[94,]. An example of buffer is provided by agroforestry around Hyderabad-Secunderabad. Biomass assessment within 100 km radius of twin cities suggests that annual increment of trees and forests in the region approximately equals with the estimated annual wood and fuelwood intake of the cities and villages[95]. This supply has acted to buffer the pressure on natural forests.

Tree diversity indeed can be large in some Indian village ecosystems. Study in Sirsimakki village of Karnataka by Shastri *et al*.[96] found 952 individuals belonging to 93 species in just 1.7 ha of agroecosystem. An additional 44 species on non-agricultural lands in the village ecosystem that included *soppina bett*a, minor forest and reserve forest were found. The overall agroecosystem had more trees (556 trees/ha) and diversity (diversity index 3.5) compared to the non-agro ecosystem that had 354 trees/ha and a species diversity of 3.87. The overall village ecosystem tree density of 418.8 per ha, with 144 species in 2238 individuals in the sampled area of 5.34 ha is a useful resource. Furthermore, home-gardens, with tree species varying between 20 and 40 on each unit with an average area of 376 m^2, support in all 93 tree species counted in just 1.7 ha. In southern States of India, 269 tree species were recorded in the 544 farms sampled over 61 districts of Karnataka, Kerala and Tamil Nadu[97]. Arecanut agroforestry systems of south Meghalaya conserve 160 species of plants (83 tree species, 22 shrub species, 41 herb species and 14 climber species) in addition to cash income, medicine, timber, fuelwood and edibles for household consumption and sale[98].

Indeed, numerous regions of India can be designated as agricultural biodiversity heritage sites based on the crop diversity and numerous tree species in traditional agroforestry systems to enhance food security and adaptation to climate change[99].

Recent investigations involving biodiversity and crop productivity data for smallholder tropical agroforests elsewhere suggest that moderate shade, adequate labor, and input level can be combined with a complex habitat structure to provide high biodiversity as well as high agricultural yields and thus supporting both conservation and food security[100].

We must provide a caution here. There is a growing corpus of research demonstrating that while there are some wildlife-friendly and biodiversity-rich farming systems that support high species richness, a large proportion of wild species cannot survive in even the most benign farming systems[101]. To conserve those species, protection of wild lands will remain essential. Thus, although not a substitute for continuous and intact natural systems, fragments of all sizes and shapes, nonetheless, have conservation relevance. Feeding the world is possible without agriculture further engulfing natural ecosystems but considerable changes in policies, institutions and practices are necessary to make that happen[102].

Biological Pest Control

Agroforestry systems create landscape structure that is important for the biological pest control. In small-scale, subsistence agriculture in the tropics, traditional farming practices have evolved that provide a sustainable means of reducing the incidence and damage caused by pests including nematodes. The biodiversity inherent in multiple cropping and multiple cultivar traditional farming systems increases the available resistance or tolerance to nematodes[103]. In structurally complex landscapes, parasitism is higher and crop damage lower than in simple landscapes with a high percentage of agricultural use[104]. In understanding the effect of complexity, it is also important to evaluate the quality of seminatural areas surrounding croplands in terms of agroecological functions for natural enemies and pests[105].

Results from a meta-analysis on 552 experiments in 45 articles published over the last 10 years to test if plant diversification schemes reduce herbivores and/or increase the natural enemies of herbivores as predicted by associational resistance hypotheses, the enemies hypothesis, and attraction and repellency model applications in Agricaulture are instructive. The study found herbivore suppression, enemy enhancement, and crop damage suppression effects were significantly stronger on diversified crops than on crops with none or fewer associated plant species. The unambiguous and encouraging results from this meta-analysis should help in effective crop diversification schemes for improved pest regulation and enhanced crop yield[106].

Breaking the Poverty and Food Insecurity Circle

Agroforestry could contribute to livelihoods improvement in India where people have a very long history and accumulated local knowledge. India is particularly notable for ethnoforestry practices and indigenous knowledge systems on tree-growing. In terms of household income central Indian upland ricefields provide an illuminating economics[107]. The farms often have an average of 20 *Acacia nilotica* trees per ha. of 1 to 12 years of age. Small farms have more tree-density. At a 10 years rotation, these trees provide a variety of products including fuelwood (30 kg/tree), brushwood for fencing (4 kg/tree), small timber for farm implements and furniture (0.2 m^3), and non-timber forest products such as gum and seeds. Thus, trees account for nearly 10% of the annual farm income—distributed uniformly throughout the year than in rice monoculture—of smallholder farmers with less than 2 ha farm holding. The combination of Acacia and rice traditional agroforestry system has a benefit/cost (B/C) ratio of 1.47 and an internal rate of return (IRR) of 33% at 12% annual discount rate during a ten- year period.

In northeast Indian state of Meghalaya the guava and Assam lemon based agrihorticultural agroforestry systems (i.e. farming systems that combine domesticated fruit trees and forest trees) gave 2.96 and 1.98-fold higher net return respectively in comparison to farmlands without trees. Average net monetary benefit to guava based agroforestry systems was Rs. 20,610/ha (US$ 448.00) and (Rs. 13,787.60/ha or US$ 300.00 to Assam lemon based agroforestry systems. Such systems are most useful livelihoods improvement strategies in the rainfed agriculture of Meghalaya[108]. Similarly, The net present value for the different agroforestry models on six years rotation in Haryana varied from Rs. 26626 to Rs. 72705 ha^{-1} yr^{-1} whereas the benefit:cost ratio and the internal rate of return varied from 2.35 to 3.73 and 94 to 389%, respectively. Thus, agroforestry has not only uplifted the socioeconomic status of the farmers but also contributed towards the overall development of the region[109].

In order to maximize the trade-off in yield of crops and wood some new models are now emerging. For instance in regions such as Andhra Pradesh, where annual rainfall is around 1,000 mm and soils are fairly good, eucalyptus at a density of 1,666 plants per ha can be planted in uniformly spaced wide-rows (6 m) or paired rows at an inter-pair spacing of 7-11 m for improving intercrop performance without sacrificing wood production[110]. Likewise, in Rajasthan, yield of the annual crops can be optimized in combination with *Prosopis cineraria* at optimum tree densities of 278 trees/ha at 6 and 7 years, 208 trees/ha at 10 year and <208 trees/ha at 11 years of age[111]. Studies on *Tecomella undulata* L. (Rohida) intercropped with *Cyamopsis tetragonoloba* (L.) Taub (Clusterbean), *Vigna radiata* (L) (mungbean), *Pennisetum glaucum* (L.) R.Br. (pearlmillet) suggest that seedling density of 833 stem ha^{-1} and 417 stems ha^{-1} were optimum for total production at the age of four and five years, respectively[112]. Beyond that age, 287 stems ha^{-1} was most favourable for crop production at the age of 6-7 years and 208 stem ha^{-1} at 10-11 years[113]. Neem (*Azadirachta indica* A. Juss) and understorey crop black gram (*Phaseolus mungo*) experiments suggest that crop yield under the tree canopy decrease but are compensated by increase in wood volume and fruit yield of neem and thus giving higher economic returns[114].

There are numerous non-timber forest products collected from the wilderness for subsistence and cash income. Often, harvesting is unsustainable because of a lack of knowledge about silviculture of species and destructive exploitation strategies driven by market forces. Domestication of such species aimed at commercialisation and production of valued products can reduce the pressure on natural ecosystems[115,116].

Domestication of forest fruit trees and other species grown in agroforestry systems offer significant opportunity for livelihoods improvement through the nutritional and economic security of poor people in tropics[117]. The wild edible plants form an important constituent of traditional diets in the Sikkim Himalaya where about 190 species are eaten and almost 47 species are traded in local market. Wild edible fruit species have high carbohydrate content ranging between 32 and 88%[118]. Such fruit trees can be taken up for domestication in agroecosystems on priority action.

Trees in agroforestry systems can provide host to globally valued products, and thus, support livelihoods locally. A study of 8 year old agroforestry intervention in Palamau District of Jharkhand found that community dependent solely on rainfed farming and animal husbandry definitely gains positively by agroforestry interventions[119]. Suitable community plantations of non-timber forest products in tribal areas such as Jharkhand can potentially serve dual purpose of conserving the useful species as well as livelihoods improvement of local people[120]. Such programmes in tribal areas have enhanced likelihood of success as communities are dependent on the wild resources for livelihoods. In Jharkhand, trees in agroecosystems are particularly valued as host to insects that yield marketable products such as silk[121], lac products[122], honey[123].

Woodcarving industry is emerging as an important source of income to local artisans worldwide[124]. Promotion of species used in woodcarving industry facilitates long term locking-up of carbon in carved wood and supports local knowledge, therefore, strengthens livelihoods. For example, Jodhpur in Rajasthan has emerged as a major centre of woodcarving exporting the woodcrafts worth Rs. 60 million annually facilitated by the traditional knowledge and skills, and growing tourism. Suitable agroforestry programmes may enhance the availability of wood in agroecosystems thereby improved ability of developing countries to participate in the growing global economy[125].

Enhancing Adoption of Agroforestry Innovations

An intriguing aspect in India is the low adoption of agroforestry system beyond what has already existed for millennia. It has been hypothesised that part of the problem can be related to the location-specificity of agroforestry systems. This begs the question that even as agricultural systems are site specific, yet modern agricultural technologies have gained widespread adoption in India. Many answers have been postulated to this problem[126]: The problem can unlikely be the site-specificity of agroforestry, but perhaps due to lack of a science base in agroforestry. It could also be that the scientific principles of successful indigenous systems have not been yet adequately understood or recognized nor are the ‘modern’ agroforestry technologies based on sound scientific principles. It could be that there are serious disincentives to agroforestry adoption in terms of social, cultural, economic, and policy issues. We still need to develop a better understanding of the role of risk and uncertainty, insights into how and why farmers adapt and modify adopted systems, factors influencing the intensity of adoption, village-level and spatial analyses of adoption, the impacts of health morbidity on adoption, and the temporal path of adoption[127].

There are some successful cases such as poplar-based agroforestry systems, but there is a general lack of robust and comprehensive studies that could provide insights on the critical adoption factors on agroforestry systems in India. Some of the dominant conclusions available in the studies for various contexts are as follows:

- **Western Himalayan region:** In Himachal, a combination of biophysiscal and social factors including farm size, agroclimatic zone, soil fertility, mobility and importance of tree for future generations and use of indigenous knowledge of farmers are key factors which may influence tree growing[128]. Expert-designed agroforestry programs are often not adopted if they are not built on existing experience in traditional agroforestry systems. Adoption could be enhanced by integrating agroforestry into other economic and agricultural developments programmes[129]. Perceptions of the change in the forest area around the village, restrictions on felling of trees from their own land (regulations controlling the use of on-farm tree resources)[130] and restriction on transport of the wood were the most important psychological factors affecting agroforestry adoption[131]. Higher availability of fuelwood from State forests could lead to lower levels of agroforestry adoption. 'Need' may not be a necessary condition to motivate farmers to adopt agroforestry, rather, it is accessibility of tree products which influence agroforestry adoption[132]. Furthermore, training of foresters in agroforestry has remained oriented towards learning silvicultural aspects rather than social issues. Re-orienting the training curriculum towards learning extension and agricultural besides the silvi-technical skills is required. There is also a need for interaction between foresters and farmers, better co-ordination with other departments and absolving agroforesters of their policing role. Foresters perception is that restriction on felling green trees growing on private land and selling them in the market is the most important factor restraining agroforestry adoption. Provision of incentives to the villagers for tree growing on private land was the major factor from the foresters' perspective that will encourage tree growing on private land[133].

- **Northern region:** Additional income and an emergency source of cash have been cited to be the farmers' major reasons for adopting agroforestry in Uttar Pradesh[134].

- **Bundelkhand region**: Farmer's willingness to adopt agroforestry has been found to increase with time through constant persuasion and developmental activities such as water harvesting. Efficient land use and high production and income producing capability are the main motives of farmers to adopt agroforestry[135].

- **Central region:** The ease of management of the indigenous system, the autogenic regeneration and robust nature of the *Acacia nilotica* trees and the multiple products and services the species provides, and easy marketability of the products are the major factors that encourage farmers to adopt the system. As the farmers have secure ownership rights to their land, that they invest in long-term measures such as plantings and management[136]. State-led programmes with subsidies, on the other hand, did not benefit the poor thus a need for instituting measures to compensate the poor[137].

- **Eastern region:** Adoption of agroforestry is determined by the farmers' attitude to agroforestry, which in turn is likely to be shaped by information received through farmer-to-farmer and farmer-to-extension contact. The customised mode of communication for each target group is crucial[138]. Common assumption that only large landowners with a substantial income are innovators is not true. The likelihood of adopting agroforestry is dependent on the progressive attitude of farmers, availability of lands, membership of village organisations, their wealth status and, more importantly, their perceived risk concerning agricultural production[139,140].

- **North-eastern region:** In Nagaland, the strategy with farmer-led testing, where farmers themselves selected agroforestry technologies, implemented the field tests and assumed responsibility for disseminating the results locally has been found to be very successful in stimulating replication of the agroforestry[141].

- **Southern region:** Consideration of differences in resource constraints in farming systems and risk-taking attitudes of farmers towards their allocation decisions is likely to enhance the successful adoption of agroforestry[142]. Farmers with higher income have often been the main beneficiaries of agroforestry promotion, but adoption of home gardens has been successful for both income groups[143]. Removing many barriers would also be required as farmers are often averse to plant more indigenous timber trees and multipurpose trees due to lack of institutional support mechanisms, inadequate attention to land tenure questions, non-availability of quality planting stock, and policy constraints. Removing contradictions existing between the dichotomous approaches adopted in the agriculture and forestry sectors is also required. Forest policies that impose restrictions on timber harvest from farmlands under the garb of protecting natural forests act as disincentive for maintaining tree-based mixed production systems on farmlands[144].

These insights notwithstanding, there is no specific policy for agroforestry in India. Indeed, little research is available to inform about what kinds of approaches and institutions operating under what kind of conditions are most effective in producing and mobilizing scientific knowledge to inform action on agroforestry systems[145,146]. Learning from comparative analysis of natural resource management programmes under the auspices of the Consultative Group on International Agricultural Research (CGIAR) and sustainability science can be instructive[147,148]. Gap between knowledge and action can be bridged by combining different kinds of knowledge, learning, and boundary spanning approaches; by providing all partners with the same opportunities; and by building the capacity of all partners to innovate and communicate[149,150]. The seven propositions that may be adapted after appropriate testing in the context of agroforestry in India are as follows[149]:

- **Problem definition:** Projects are more likely to succeed in linking knowledge with action by employing processes and tools that enhance dialogue and cooperation between those who possess or produce knowledge and those who use it, with project members together defining the problem they endeavor to solve.

- **Program management:** Research is more likely to inform action if it adopts a "project" orientation and organization, with leaders accountable for meeting use-driven goals and the team managing not to let "study of the problem" displace "creation of solutions" as its research goal.

- **Boundary work:** Projects are more likely to link knowledge with action when they manage boundaries between scientists and practitioners. The boundary is a negotiated space that protects the integrity of each side—the science and practice. Bridging it requires special structures for joint accountability across the boundary[151]. Particularly important aspects are arrangements regarding participation of stakeholders, accountability in governance, and the use of 'boundary objects' such as maps, policy-briefs, workshops etc[152].

- **Systems integration:** Projects are more likely to be successful in linking knowledge with action when they recognize that scientific research is just one "piece of the puzzle," apply systems-oriented strategies, and engage partners best positioned to help transform knowledge cocreated by all project members into actions (strategies, policies, interventions, technologies).

- **Learning orientation:** Research projects are more likely to be successful in linking knowledge with action when they are designed as much for learning as they are for knowing. Such projects are essentially experimental, expecting and embracing failures so as to learn from them throughout the project cycle. Such learning demands that risk-taking managers are not discouraged; rather they are rewarded, funded and regularly evaluated by external experts.

- **Continuity with flexibility:** Getting research into practice requires strengthening links between organizations and individuals operating locally, building strong networks and innovation and response capacity, and cocreating communication strategies and boundary objects and products.

- **Manage asymmetries of power:** Efforts linking knowledge with action are more likely to be successful when they manage to "level the playing field" to generate hybrid, cocreated knowledge and deal with the often large asymmetries of power felt by stakeholders.

Caveats and Clarifications

All nature-society interactions have trade-offs and agroforestry systems are no exception. Although agroforestry is an effective land use option, it requires some careful planning and studies on the remaining challenges such as farm yield decline under agroforestry systems. There may not be an entirely convincing rationale for the argument that agroforestry systems are the answer for livelihoods improvement. Nevertheless, this review does provide some pointers in that direction.

Although, large body of research in India has demonstrated the potential of agroforestry[1], and some practices have been widely adopted, the vast potential is yet to be fully exploited[153,]. Research is needed to further refine the key points of agreement and also to fill the crucial knowledge gaps (**Table 2**). There is, evidently, a major gap in our understanding on the extent to which agroforestry systems contribute to rural livelihoods improvement in comparison to other land use systems. Future research is required to remove many of the uncertainties that remain, and also carefully test the main functions attributed to agroforestry against alternative land-use options in order to know unequivocally to what extent agroforestry served these purposes.

Agroforestry practices are strongly dependent on access to land within the community. Households that do not have ownership to lands may not be able to benefit from the agroforestry interventions for livelihoods improvement, unless market regimes permit their inclusion through value addition services.

Trees in variety of ethnoforestry and agroforestry systems contribute to food security, rural income generation through diversity of products and services, and can enhance nutrient cycling, improve soil productivity, soil conservation and soil faunal activities. Nonetheless, trees in agroforestry systems can also cause competition with the associated food crops. Agroforestry may, thus, reduce the yield of the agricultural produce in farmlands. Interestingly, the species that did not negatively affect the yield, are indigenous trees occurring in traditional agroforestry systems, and they are economically more useful for providing multiple benefits. Selection of such species to enrich agroforestry systems shall be useful for local and national food security.

Not all species desirable for livelihoods improvement can be grown without designing an optimum species combination. Many fruit-yielding species that are although suitable to tolerate highly alkali soil (pH > 10) become susceptible to water logging. Their otherwise desirability for agroforestry systems due to high potential for livelihoods improvement requires special techniques for planting. For example, pomegranate (*Punica granatum*) trees are unable to tolerate water stagnation. To avoid mortality due to water stagnation during the monsoon the raised and sunken bed technique may be necessary for agroforestry practices on highly alkali soil[154].

Designing a sustainable tree mixture for agroforestry systems is another challenge. In agroforestry differences in functional group composition do have a larger effect on ecosystem processes than does functional group richness alone. Thus, much time and expense need to be invested in finding species or genetic varieties that combine in more diverse agroecosystems to improve total yield. For instance, a five year field experiment of tree mixtures for agroforestry system in tropical alfisol of southern India involving mango (*Mangifera indica*), sapota (*Achrus sapota*), eucalyptus (*Eucalyptus tereticornis*), casuarina (*Casuarina equisetifolia*) and leucaena (*Leucaena leucocephala* found that growth of sapota can be enhanced by 17% when grown in mixture with leucaena. But a reduction of 12% in the growth of mango may occur when co-planted with casuarina or leucaena[155]. Eucalyptus is incompatible with mango and sapota because these species suffer due to Eucalyptus. Furthermore, because many species suffer from root competition and thus selection of tree species with either low root competitiveness or trees with complementary root interaction is of strategic importance in agroforestry systems[156].

The Future

Although numerous issues are involved as discussed here, agroforestry systems are of multifunctional value. In India and other developing countries the path to sustainable development could be a decentralized planning and implementation of strategies that promote local biomass production in agroforestry systems. Such decentralized systems in India can provide critical inputs for livelihoods improvement and sustainable development. Along with mitigating the climate change agroforestry systems can at least partially meet the energy needs of 1 billion people in India through bioenergy options by a prudent use of agricultural residues and biomass generated in agroforestry systems. Biomass energy-based supply options can create rural wealth and employment necessary for livelihoods improvement and sequester large amount of carbon in a decentralized manner. Such a strategy would also ensure ecological, economic and social well-being. Thus, energy and food self-sufficient taluka (a small administrative unit) can be a new model of rural development in India[157].

Agroforestry options for carbon sequestration are although attractive, as discussed earlier, they presents critical challenges for carbon and cost accounting due to dispersed nature of farmlands and dependence of people on the multiple benefits from agroforestry. Additionally, important concerns regarding monitoring, verification, leakage and the establishment of credible baselines also need to be addressed. Another challenge is incentives that promote tree-growing by rural people. Not everyone is willing to adopt agroforestry. We shall need effective strategy for connecting science to decision making to extend innovations among the people to adopt and maintain agroforestry.

In conclusion, in order to use agroforestry systems as an important option for livelihoods improvement, climate change mitigation and adaptation, and sustainable development in India, research, policy and practice will have to progress towards: (i) effective communication with people in order to enhance the agroforestry practices with primacy to multifunctional values; (ii) maintenance of the traditional agroforestry systems and strategic creation of new systems; (iii) enhancing the size and diversity of agroforestry systems by selectively growing trees more useful for livelihoods improvement; (iv) designing context-specific silvicultural and farming systems to optimize food production, carbon sequestration, biodiversity conservation; (v) maintaining a continuous cycle of regeneration-harvest-regeneration as well as locking the wood in non-emitting uses such as woodcarving and durable furniture; (vi) participatory domestication of useful fruit tree species currently growing in the wilderness to provide more options for livelihoods improvement; (vii) strengthening the markets for non-timber forest products, (vii) and addressing the research needs and policy for linking knowledge to action. Prevalence of a variety of traditional agroforestry systems in India offers opportunity worth reconsidering for carbon sequestration, livelihoods improvement, biodiversity conservation, soil fertility enhancement, and poverty reduction.

Table 1: Regional examples multifunctional agroforestry systems in India

No.	Region	Challenge	Changes observed due to agroforestry
1.	Himalayas (Kurukshetra)[158]	Improvement of sodic soils	Increase in microbial biomass, tree biomass and soil carbon; enhanced nitrogen availability
2.	Himalayas[33]	Restoration of abandoned agricultural sites	Biomass accumulation (3.9 t ha^{-1} in agroforests as compared to 1.1 t ha^{-1} in degraded forests); improvement in soil physico-chemical characteristics; carbon sequestration
3.	Western Himalayas[159]	Reducing soil and water loss in agroecosystems in steep slopes	Contour tree-rows (hedgerows) reduced runoff and soil loss by 40% and 48% respectively (In comparision to 347 mm runoff, 39 Mg ha^{-1} soil loss per year under 1000 mm rainfall conditions)
4.	Sikkim Himalaya[160,161]	Enhancing the litter production and soil nutrient dynamics	Nitrogen-fixing trees increased N and P cycling through increased production of litter and influenced greater release of N and P; nitrogen-fixing species helped in maintenance of soil organic matter, with higher N mineralization rates in agroforestry systems
5.	Indo-Gangetic plains (UP)[162]	Biomass production and nutrient dynamics in nutrient deficient and toxic soils	Biomass production (49 t ha^{-1}/decade)
6.	Himalayas (Meghalaya)[163]	Enhancing tree survival and crop yield	Crop yield did not decrease in proximity to *Albizzia* trees
7.	Western India (Karnal)[164]	Improvement of soil fertility of moderately alkaline soils	Microbial biomass C which was low in rice-berseem crop (96.14 gg^{-1} soil) increased in soils under tree plantation (109.12 gg^{-1} soil); soil carbon increased by 11-52% due to integration of trees and crops.
8.	Western India (Rajasthan)[165]	Compatibility of trees and crops	Density of 417 trees per ha was found ideal for cropping with pulses
9.	Central India (Raipur)[166]	Biomass production in N & P-stressed soils	*Azadirachta indica* trees were found to produce biomass in depleted soils.
10.	Central India[167]	Soil improvement	Decline in proportion of soil sand particles; increase in soil organic C, N, P and mineral N
11.	Southern India (Hyderabad)[168]	Optimality of fertilizer use	
12.	Southern India (Kerala)[169]	Growing commercial crops and trees	Ginger in interspaces of *Ailanthus triphysa* (2500 trees ha^{-1}) helps in getting better rhizome development of ginger, compared to solo cropping

Table 2: Unresolved challenges for future agroforestry research and innovations in India

1. Crop yields: Increase or decrease?	Although some traditional agroforestry systems do increase crops yields near trees, there are instances where fast growing trees have reduced crop yields in the short-term. Context-specific long-term studies are required to resolve this issue.
2. Nutrients: additional supply or redistribution?	Mature and scattered agroforestry trees are associated with improved soil nutrient supply in traditional agroforestry systems, it is not known if trees additionally supply nutrients by increasing the total quantum of nutrients in agroecosystems or just redistribute the available quantity horizontally and vertically.
3. Water-Tree interaction: high water uptake or no change?	High water use by fast-growing species and therefore alleged groundwater depletion is a common concern in dry regions that remains unresolved. Do trees actually extract more groundwater or use the residual water available either through irrigation, or use the rainwater when crops have been harvested? It may be possible that rather than letting the rains be lost as runoff, agroforestry may increase the utilization of rainwater by extending the growing season. Furthermore, it is not clearly understood if trees harvest and accumulate water from surrounding area and release it during the soil-moisture stress. If this is so then, agroforestry as an adaptation to monsoon variability may actually benefit the crops.
4. Climate change mitigation and adaptation	Studies on the carbon sequestration potential are limited both by their location-specificity as well as uncertainty related to sequestration in biomass and soils. Often, the rate of carbon sequestration is derived from the growth of above ground biomass. In addition, role of agroforestry in as an adaptation to climate change needs to be explored further.
5. Soil amelioration and conservation	Agroforestry systems with mature trees capable of yielding enough litter are known to conserve soils and ameliorate soil nutrient status, but knowledge on the full range of species and their attributes useful for all the agro-climatic regions and problem-soils in India are required.
6. Genetically improved trees	Genetically improved trees may provide more biomass and other products valued by the society, but presently research results in this field mostly remain in the laboratory. A full mechanism starting from developing and registration of clones, decentralized certification, and mass multiplication of suitable stock to ensure availability to farmers is required.
7. Multiple-use species adapted to multiple agro-climatic conditions	Multiple-use species with a wide range of geographic and climatic adaptation can enhance the success and spread of agroforestry. This is a crucial area of research involving multi-location research in all the climatic regions in India.
8. Domestication of useful species	Many wild populations of species that yield commercially-valued products are getting depleted, research efforts are required to domesticate these species and integrate with the agroforestry systems in India.
9. Policies to promote linkages between markets and tree-growing in agroecosystems	On the one hand smallholder systems in India supply about 50% of wood and fuelwood demand, on the other here are still many restrictive regulations that potentially deter farmers from growing trees in agroecosystems and selling these in markets. This issue needs to be addressed.
10. Value addition innovations	NTFPs have the potential to improve livelihoods of poor farmers, but vigorous efforts are needed to provide knowledge on the on-farm value addition innovation.

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