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Review Research Paper

Multifunctional Agroforestry Systems in Tropics Region

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ABSTRACT

Agroforestry is emerging as a major land use activity in the country after agriculture and forestry. 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. The multifunctional agroforestry systems in tropical region offer innumerable ecological benefits such as carbon sequestration, mitigation of climate change, enhancing soil fertility and water use efficiency, biodiversity conservation, biological pest control, sustainable land use, shelterbelt and windbreaks, microclimate amelioration, breaking the poverty and food insecurity circle, caveats and clarifications. Agroforestry, if established on degraded lands will not only reduce the anthropogenic pressure on existing forest resources but also will enhance the sink potential of CO_2.

INTRODUCTION

During their evolutionary and ecological histories, forest tree species have experienced numerous environmental changes. Changed environments may have lasted as long as 100,000 years (Bowen 1979, Imbrie & Imbrie 1980, Pisias & Moore 1981) or they may have lasted only a decade (i.e. well within the lifetime of an individual tree). Environmental changes may have been gradual or sudden occurring over a relatively few years (Bryson et al. 1970). During the past decade, increased attention has been given to the effects of environmental change on tree species due to the rapid climatic changes thought to have been brought on by recent human activities (Davis & Zabinski 1992, Alig et al. 2002).

Forestry has been recognized as a means to reduce CO_2 emissions as well as enhancing carbon sinks. The role of forests in carbon cycles is well recognized (Singh & Lal 2000). Forests are a large sink of carbon (Dixon et al. 1994a, Wang et al. 2001, Bertini et al. 2011, Merian et al. 2013). There is considerable interest to increase the carbon storage capacity of terrestrial vegetation through land-use practices such as afforestation, reforestation, and natural regeneration of forests, silvicultural systems and agroforestry (Brown 1996, Canadell & Raupich 2008). Agroforestry systems are very important, given the area currently under agriculture, the number of people who depend on land for their livelihoods, and the need for integrating food production with environmental services (Soto-Pinto et al. 2001, Garrity 2004, Makundi & Sathaye 2004, Kumar et al. 2014).

From an ecological and conservation point of view, food crops were found in the homesteads. Tropical homesteads are typical examples of epitome of biodiversity, both structurally and functionally (Kumar 2011). They constitute careful blending of crops, including trees with livestock, poultry, fish production mainly for the purpose of satisfying lifeforms. Increased human population and associated development activities in the last few decades have resulted directly or indirectly in depletion of the natural vegetation, which in turn increase the pressure on the homestead forest, specially in the developing countries, to meet the various needs of human beings (Khan 1998, Bashar 1999, Kumar & Nair 2004, Kumar & Takeuchi 2009, Kunhamu et al. 2015, Kumar, 2016). In these circumstances, correct inventory and assessment of biodiversity in different habitats is necessary for evolving a long term strategy for conserving the endangered species and improvement of the existing species.

In fact, agroforestry systems can function as both source and sink of carbon (Dixon 1995, Montagnini & Nair 2004). There is also clear evidence to suggest that the type of agroforestry system greatly influences the source or sink role of the trees. For example, agri-silvicultural systems, where trees and crops are grown together, are net sinks while agro silvipastoral systems are possible sources of GHGs (Kandji et al. 2006). While most agroforestry systems (e.g., multipurpose trees, silvopasture and energy plantations) have great potential for carbon sequestration, homegardens are unique in this respect. They not only sequester C in biomass and soil, but also reduce fossil-fuel burning by promoting wood, fuel production, and conserve agrobiodiversity (Kumar & Nair 2004). In addition, they help in the conservation of C stocks in the existing natural forests by alleviating the pressure on these areas (Kumar 2006, Falk & Mellert 2011, Linares & Camarero 2012, Lafortezza et al. 2013). There is a need for intensified conservation efforts as well as growing products and generating services in agroecosys-tems (Pandey 2002). Tree growing in combination to agriculture (agroforestry systems) as well as numerous vegetation management regimes in cultural landscape (ethnoforestry systems) may improve nutrient availability and efficiency of use and may reduce erosion, provide firewood and store carbon. Agroforestry systems can also be managed to reduce inputs of weeds and other agricultural pests (Tilman et al. 2002), increasing the livelihood security and reducing the vulnerability call for societal adaptation (Pandey 2005). Such adaptations are possible when combined with traditional resource management systems. Agroforestry as a local adaptation, therefore, is a promising area of interest. This review examines the multifunctional agroforestry systems in India as a potential option for livelihood improvement, climate change mitigation, biodiversity conservation in agroecosystems as well as yield of goods and services to the society. Synthesis of the available literature also helps to identify the remaining uncertainties and thus the future directions for research.

CURRENT SCENARIO OF AGROFORESTRY IN INDIA

The forest and tree cover of India is 78.92 million ha, accounting for 24.01 per cent of the geographical area (ISFR 2013). Agroforestry is contributing to achieve the national goal, as the desired tree cover, from present less than 25 per cent to 33 per cent, in the country can only be achieved by planting trees in farm field/bunds, especially in states that have low tree cover. Agroforestry has an important role in reducing vulnerability, increasing resilience of farming systems and buffering households against climate related risk in addition to providing livelihood security (NRCAF 2013). Agroforestry practices are said to be characterized by four "I" words: intentional, intensive, integrated, and interactive (Gold & Garrett 2009). The conservation and management of forests hasve been strengthened through various policies and legal frameworks, and the management of the forests is now oriented towards watershed function and ecosystem services (Dhyani et al. 2007). With the increase in area from 25.32 million ha to 53.0 million ha in the next forty years, agroforestry will be contributing substantially in meeting the basic needs of the society through increased production and providing environmental benefits (Dhyani et al. 2013).

Agroforestry supplies almost 72 per cent of the demand of fuelwood, 2/3 of the small timber, 70-80 % wood for plywood, 60-80 % raw material for paper pulp, 9-11 % of the green fodder requirement, besides meeting the subsistence needs of households for food, fodder, fruit, fibre, fuel and medicine etc. (Dhyani et al. 2013).

Agroforestry can improve soil fertility, provide fodder, produce tree fruits, expand fuel wood supplies and produce a variety of wood products for farmers own use and sale without demanding additional land. Research results from different agro-climatic regions of the country show that the financial returns generated from agroforestry system vary greatly, but are generally much higher than the returns from continuous unfertilized food crops. The higher returns associated with agroforestry can translate into improved house holding nutrition.

AGROFORESTRY SYSTEM FOR CARBON SEQUESTRATION

During the past two decades, there has been a veritable explosion of the literature on C sequestration. Internet search engines and abstracting services are virtually flooded with all sorts of literature on all aspects of the process. Unfortunately, considerable variations exist among different user groups about the concept of C sequestration and the term is not used or understood uniformly in different contexts (Kumar, 2015, Kumar, 2016a, Kumar, 2016b). This has led to serious difficulties in consolidating and synthesizing available reports and publications according to a uniform pattern and a set of norms.

The United Nations Framework Convention on Climate Change (UNFCCC) defines carbon sequestration as the process of removing C from the atmosphere and depositing it in a reservoir. It entails the transfer of atmospheric CO_2, and its secure storage in long-lived pools (UNFCCC 2007). From the agroforestry point of view, C sequestration primarily involves the uptake of atmospheric CO_2 during photosynthesis and the transfer of field C into vegetation, detritus, and soil pools for "secure" (i.e. long-term) storage (Nair et al. 2010). Different agroforestry systems sequestering varied amount of carbon based on type of system, species composition, soil and climate. Some of the earliest studies of potential carbon storage in agroforestry systems and alternative land use systems in India has estimated a C sequestration of 68-228 Mg C ha^{-1} (Dixon et al. 1994b) and studies from Jha et al. (2001) showed that agroforestry could store nearly 83.6 Mg C ha^{-1}. Average carbon storage by agroforestry practices, of which fertilizer trees are an integral part, has been estimated as 9, 21, 50 and 63 Mg C ha^{-1} in semi-arid, sub-humid, humid and temperate regions, respectively (Montagnini & Nair 2004). Average sequestration potential in agroforestry in India has been estimated to be 25 t C ha^{-1} over 96 million ha (Sathaye & Ravindranathm 1998).

In another estimate, agroforestry contributes 19.30% of total C stock under different land uses. International network on Bamboo and Rattan (INBAR) reports that bamboo biomass and carbon production may be 7 to 30 per cent higher compared to the fast growing wood species. Gratani et al. (2008) studied the growth pattern and photosynthetic activity *Phyllostachys viridi-glaucescens, P. pubescens,* and *P. bambusoides* and stated that owing to the great potential for biomass production, bamboos could be a significant net sink for CO_2 sequestration. Variation in biomass production of *Fargesia yunnanensis*, an alpine bamboo, with sites due to total nitrogen (N) and organic matter status of soil, was reported from China (Shuguang et al. 2009). Yen & Lee (2011) on comparison of aboveground carbon storage between *P. heterocycla* (moso bamboo) and *Cunninghamia lanceolata* (China fir) reported higher carbon storage for China fir forests than for moso bamboo, 99.5 vs. 40.6 mega gram per hectare (Mg ha^{-1}). But there was variation in age between the plantations and the mean aboveground carbon sequestration was higher in moso bamboo (8.13±2.15 Mg ha^{-1}) compared to China fir (3.35±2.02 Mg ha^{-1}). Wen et al. (2011) reported that the capability of carbon fixation of *P. pubescens* leaves had obvious temporal and spatial dynamic variations. Daily and seasonal carbon fixation showed a negative correlation with the CO_2 concentration. Yongfu et al. (2011) studied the dynamic changes in height, biomass, and carbon accumulation in young *Phyllostachys pubescens*. They found that the accumulation of biomass and carbon in young bamboos depends mainly on ground diameter and the length of time after the bamboo shoots sprouted. Studies conducted in Vietnam indicated that a shift in land use from annual crops to bamboo provides an annual net gain of soil organic carbon of approximately 0.44 t ha^{-1} (Proyuth et al. 2012). Kittur (2014) studied the biomass production of 9 year old bamboo (*Dendrocalamus strictus* (Roxb.) Nees) planted under varying spacings (4×4, 6×6, 8×8, 10×10 and 12×12 m; densities: 625, 277, 156, 100 and 69 clumps/ha) in Kerala. Results indicated that the clump wood constituted the largest (60-70 %) share to the total biomass in all the spacings. The leaf biomass in widest spacings were increased by 325 per cent compared to closest spacings. The densest (625 clump/ha) stand, though recorded maximum biomass, the eventual clump-wise biomass was highest in least dense stand (69 clumps/ha). The C in clump wood decreased by 55 % in closest spacings compared to widest spacings. The majority of C was accumulated in clump wood (5.45 to 22 Mg/ha). When spacings increased to 12×12 m, the C storage in above ground biomass increased by 3.61 times compared to densest stand (4×4 m). The potential of agroforestry systems, as carbon sink varies depending upon the species composition, age of trees, geographic location, local climatic factors and management regimes. The growing body of literature indicates that agroforestry systems have the potential to sequester large amounts of above and below ground carbon in addition to soil organic carbon enhancement, as compared to treeless farming systems (Kumar 2015).

Carbon management through afforestation and reforestation in degraded natural forests is a useful option, but agroforestry is attractive because:

1. It sequesters carbon in vegetation and possibly in soils depending on the reconversion soil C.
2. The more intensive use of land for agricultural production, reduces the need for slash-and burn or shifting cultivation, which contributes to deforestation.
3. The wood products produced under agroforestry serve as a substitute for similar products unsustainably harvested from the natural forest.
4. To the extent that agroforestry increases the income of farmers, it reduces the incentive for further extraction from the natural forest for income augmentation.

Based on the notion that tree incorporation in croplands and pastures would result in greater net C storage above and below ground (Haile et al. 2008). Agroforestry system believed to have a higher potential to sequester C than pastures or field crops growing under similar ecological conditions (Kirby & Potvin 2007). The homegardens consisting higher biomass compared to other systems and arid zones agroforestry systems consisting more root biomass. The above ground carbon stocks are 17 to 36 Mg C ha^{-1} in tropical homegardens of Kerala (Kumar & Nair 2011) and 21 to 65.6 Mg C ha^{-1} in popular based systems of North India (Rizvi et al. 2011). Carbon sequestered by trees and stored in above ground biomass and soil contributes to reducing greenhouse gas concentrations in the atmosphere. It has estimated of the carbon sequestration potential of agroforestry systems vary greatly, from under 100 MT CO_2 per year by 2030 to over 2000 MT CO_2 per year over a 30 year period. Regardless of the extract amount, agroforestry systems tend to sequester much greater quantities of carbon than agricultural systems without trees (Neufeldt et al. 2009).

AGROFORESTRY SYSTEM TO MITIGATE THE CLIMATE CHANGE

Human activities are also causing rapid changes in the atmosphere and climate that directly impact production agriculture. Changing climate conditions frequently interact with forest growth at the local level within regional scenarios; the influence of variability and intensity of climate alterations at the forest level may be even stronger than regional trends (D' Aprile et al. 2009). Changing climate conditions can also modify both the extent of the growing season and the months that influence the occurrence of tree growth response (Pretzsch et al. 2014). Atmospheric and climate change began accelerating after the industrial revolution. CO_2 concentrations which averaged about 270 ppm prior to the industrial revolution, have now surpassed 380 ppm, and will exceed 550 ppm by 2050 (Long et al. 2004). A potential positive benefit of rising CO_2 is the stimulation of photosynthesis in C3 crops as the higher CO_2 in future atmospheres will relieve Rubisco limitation on photosynthesis and suppress photorespiratory loss (Farquhar et al. 1980, Long et al. 2004). However, increasing CO_2 is also responsible for more than 60% of the phenomenon known as "greenhouse" effect that is driving global warming and is predicted to cause changes in precipitation and weather patterns that are expected to have negative consequences on agriculture (Lashof & Ahuja 1990). Under the Kyoto Protocol's Article 3.3, A & R (afforestation and reforestation) with agroforestry as a part of it has been recognized as an option for mitigating greenhouse gases. As a result, there is now increasing awareness on agroforesty's potential for carbon (C) sequestration (Nair et al. 2010).

AGROFORESTRY SYSTEM TO ENHANCE SOIL FERTILITY AND WATER USE EFFICIENCY

The major promises of agroforestry is its role in soil fertility enhancement, especially in nutrient-depleted tropical soils and in soil conservation in both tropical and temperate regions (Schroth & Sinclair 2004, Van Noordwijk et al. 2004, Garrett 2009). 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 (Rasmussen et al. 1998, Lal 2008). Trees in agroecosystems can enhance soil productivity through biological nitrogen fixation, efficient nutrient cycling, and deep capture of nutrients and water from soils (Nair 2011). Even the trees that do not fix nitrogen can enhance physical, chemical and biological properties of soils by adding significant amount of above and below ground organic matter as well as releasing and recycling nutrients in tree bearing farmlands (Jose 2009). 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 (Das & Chaturvedi 2008). Patel et al. (1996) reported that 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. Significant improvement in soil biological activity has been reported under different tree based agroforestry systems in Rajasthan (Yadav et al. 2008). 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 *Prosopis cineraria* based land use system followed by *Dalbergia sissoo*, *Acacia leucophloea* and *Acacia nilotica* in comparison to a no-tree control (Yadav et al. 2011). 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.

Agroforestry systems have the potential for improving water use efficiency by reducing the unproductive components of the water balance like run-off, soil evaporation and drainage (Turner & Ward 2002). Trees with their comparatively deeper root system, improve groundwater 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 (Jose 2009). 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) (Turner & Ward 2002).

Examples from India and elsewhere show that simultaneous agroforestry systems could double rainwater utilization compared to annual cropping systems, mainly due to temporal complementarity and use of run-off in arid monsoon regions (Lovenstein et al. 1991, Droppelmann & Berliner 2003). It must be pointed out that although agroforestry systems may reduce crop yield for a variety of reasons, there may be a trade-off. Pandey & Sharma (2003) found that the effect of residual nitrogen on the yield of rice crop after removal of 15-year old *Acacia nilotica* trees resulted in an increase in the crop yield (12.5 t ha^{-1}) on traditional agroforestry system in central India and reported that 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 (Kohli & Saini 2003). A similar study conducted by Sharma et al. (2002) and revealed that 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.

AGROFORESTRY FOR BIODIVERSITY CONSERVATION

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, in some cases agroforestry systems do support as high as 50-80% of biodiversity of comparable natural systems (Noble & Dirzo 1997), and also act as buffers to parks and protected areas. Agroforestry is a system of complex and integrated approach, which provides opportunity to intermingle trees, crops, pastures and animals in a managed aspect and provides shelter for soil flora and fauna, birds, insects and wildlife. Traditional agroforestry systems are best examples of agro-biodiversity conservation (Montagnini et al. 2011). Using agroforestry systems as carbon sink, and by designing a suitable emissions trading system, the Kyoto Protocol provides a new source of financial support for the protection and management of biological diversity (Walsh 1999).

The literature on the role of agroforestry in biodiversity conservation is growing rapidly. Agroforestry also helps in conserving genetic diversity of wild cultivars or landraces and trees, which are in danger of loss and require priority conservation (Pandey 2007). Jose (2009) has suggested five major roles of agroforestry in conserving biodiversity:

1. Agroforestry helps to provide habitat for species that can withstand a certain level of disturbance in agroeco-systems.
2. It helps preserve germplasm of socially useful and associated species.
3. It 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.
4. It provides connectivity and acts as stepping-stone by creating corridors between habitat remnants and thereby conservation of area-sensitive plant and animal species.
5. It 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.

India has a long historical tradition of growing trees on farm lands and around homes. Farmers maintained or preferred trees as a part of their agricultural landscapes where homegardens formed in important component, where several species of plants are grown and maintained by the household members and their products are primary intended for the family consumption. Trees provide shade, shelter, energy, food, fodder and many good and services that enable the farmstead to prosper (McNeely & Schroth 2006, Huai & Hamilton 2009). The importance of homegardens as a site for biodiversity conservation in agricultural landscape was emphasized by several workers (Ramakrishna et al. 1996, Godbole 1998, Martin et al. 2001, Depommier 2003, Das & Das 2005, Srivastava & Heinen 2005, NBPGR 2007, Schroth & Harvey 2007, Sahoo 2009, Deb et al. 2009, Devi & Das 2010, Tynsong & Tiwari 2010, Chandrashekara and Baiju 2010, Devi and Das 2012, Saikia et al. 2012, Kunhamu et al. 2015, Kumar, 2016a, Kumar, 2016b). The forest-like structure and composition of the homegardens (Kumar & Nair 2004) and the specific management practices that tend to enhance nutrient cycling and increase soil organic carbon (Montagnini 2006) are particularly relevant in this respect. Homegarden size and survival strategies of the gardeners are other determinants of biomass (Kumar et al. 1994) and soil C (Saha et al. 2010) pools. However, precise quantitative estimates on the potential of tropical homegardens to sequester atmospheric CO_2 are scarce (Kumar 2006, Saha et al. 2010). Species diversity of tropical homegardens is also quite variable (Kumar & Nair 2004) depending on the geographical location, size of the garden, gardeners' socioeconomic status, and managerial interventions.

Unlike the other regions in India, the farm front of Kerala is characterized by extreme diversity in its bio-physical resource base and agro-climatic endowments providing multiple opportunities for raising a variety of crops (Kumar et al. 1994). According to Nair & Krishnankutty (1984), as the pressure of the population increased, and the size of the holdings decreased, the intensity of tree cropping was increased, miscellaneous tree species were replaced by multiple-use tree species. The arrival of cash crops such as rubber, nutmeg, cocoa etc has threatened the continuity and persistence of the homegardens in Kerala. Homegardens, 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 (Patil & Depommier 2008). 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 (Tynsong & Tiwari 2010). 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. Kunhamu et al. (2015) reported that three size classes of homegardens viz. small (> 0.08 ha), medium (0.04-0.08 ha) and large (0-0.04 ha) from Neyyatinkara Municipality area, Trivandrum, Kerala. Altogether, the total number of species observed in different size classes of homegardens as 24, 48 and 94 respectively. 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 (Phalan et al. 2011). 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.

AGROFORESTRY FOR BIOLOGICAL PEST CONTROL

Agroforestry systems create a landscape structure that is important for 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 (Bridge 1996). In understanding the effect of complexity, it is also important to evaluate the quality of semi natural areas surrounding croplands in terms of agroecological functions for natural enemies and pests (Rusch et al. 2010). Epila (1986) suggested that agricultural insect pest management strategies are duplicatable in agroforestry systems. But the bio-ecological factors governing the population dynamics of the insect pests in the two systems are not necessarily the same. This is largely because agroforestry with time matures into a complex system of perennial woody plants whose ecology is temporarily interrupted by the cultural processes of crop husbandry and harvesting of these annual crops, while the modern, herbaceous-agricultural systems remain perpetually youthful as ripened crops are harvested and the unwanted vegetative parts ploughed down or removed off the fields. He also suggested that new sets of data are required for insect pest management in agroforestry systems. Data on insect pest behaviour as influenced by (i) plant species diversity, (ii) perennial woody plants, (iii) age of the agroforestry system and (iv) the cropping pattern and relatedness of the companion crops are considered.

AGROFORESTRY FOR SUSTAINABLE LAND USE

Agroforestry is an age-old practice. Trees and shrubs are important in the traditional farming systems of the tropics, where woody species form a major component of the bush fallow system and are also widely grown in cropped land. Trees and shrubs benefit the farmer in three main areas:

1. Direct agricultural benefits (plant stakes, mulching materials, green manure, animal fodder and so on),
2. Environmental benefits (shade, soil erosion control, nutrient recycling, carbon sequestration and so on) and
3. Socioeconomic benefits (saleable commodities like timber, fruits, vegetables, cereals, building materials, and so on).

An economic and ecological interaction exists between the tree and non-tree components of the agroforestry system. It has not only benefited farmers, it also supplies raw material to the wood industry, generate employment of various kinds thus benefiting millions in related economic activities like transportation, wholesale, retailing etc. It helps consumers with an affordable supply of wood and contributes to import substitution for timber and timber related products, which India imports worth thousands of crores of rupees a year. Agroforestry is as good, if not better, than degraded forests for environmental improvement, pollution control, etc., especially as it can be initiated in farmers' holdings in villages and nearer to urban conglomerations.

AGROFORESTRY FOR SHELTERBELT AND WINDBREAKS

Shelterbelts and windbreaks are important components of agroforestry systems in rainfed, dry, temperate and desert areas. Windbreaks are located around the field mostly on bunds, but shelterbelts are integrated with cropping systems in the fields. Brandle et al. (2004) stated that windbreaks or shelterbelts are barriers used to reduce wind speed. Cleugh (1998) addressed the mechanisms by which a porous windbreak modifies airflow, microclimates and hence crop yields. These are providing crop assurance to farmers against extreme climatic events by modifying weather condition of the field. Windbreaks and shelterbelts reduce wind velocity, reduce evapo-rative water loss from surface downwind, and thus conserve soil moisture and decrease temperature and also provide shelter against direct sunlight. Therefore, it is considered as good adaptive strategies of climate change (Dixon et al. 1993, Hugues & Philippe 1998, Montagnini & Nair 2004). Prasad et al. (2013) has revealed that how morphological characteristics of different shelterbelts (*Acacia tortilis, Eucalyptus camaldulensis, Dalbergia sissoo, Tecomella undulata*) affect wind regimes, air temperature and soil properties in arid western Rajasthan. They found that all the shelterbelts had caused a maximum reduction (21.5 to 36.0 %) in wind speed on the downwind side at a distance of 2H (H is the average height of shelterbelt). The reduction was more pronounced between 2H and 10H and slowly nullified up to 20H. On an average, more reduction in speed of upwind was caused by double-row shelterbelts. However, single-row belts provided more sheltered area on the lee side. Besides reducing the speed of wind, presences of shelterbelts also enhanced soil organic carbon and reduce daily air temperature in sheltered area. The enrichment of soil and moderation of microenvironment on downwind side was more pronounced up to distance of 5H. Conserving fertile soil, protecting water quality, enhancing air movement and biological connectivity in the landscape, reducing energy bills, capturing carbon, recreation opportunities, aesthetic, bird-watching and cultural identity of a community are few examples of shelterbelts multifunctionality (Newaj et al. 2013). Many of the boundary plantations also help as shelter-belts and wind-breaks, particularly in fruit orchards. In Bihar, *Dalbergia sissoo* and *Wendlandia exserta* are most common boundary plantations. In northern parts of India, particularly in Haryana and Punjab, Eucalypts and Populus are commonly grown along the field boundaries or bunds of paddy fields; other trees which are grown as boundary plantations or live hedge include *Dalbergia sissoo* and *Prosopis juliflora*. Farmers of Sikkim, grow bamboo (*Dendrocalamus, Bambusa*) all along the irrigation channels. In coastal areas of Andhra Pradesh, *Borassus* is the most frequent palm. In Andamans, farmers grow *Gliricidia sepium*, *Jatropha* spp, *Ficus, Ceiba pentandra, Vitex trifolia* and *Erythina variegata* as livehedges.

AGROFORESTRY FOR MICROCLIMATE AMELIORATION

Agroforestry is ecologically dynamic, complex and sustainable system which provides the opportunity to mimic natural forest in farmland with high complementary economical and environmental benefits. Tree systems are having ability to improve microclimatic environment by lowering temperature, evaportranspiration, moisture reduction, and acting as a filter for providing buffer against direct sunlight. Microclimate amelioration is considered as one of the important role of trees in agroforestry systems to provide sustainability. In dry land and low rainfall areas, water availability to crops is paramount and seems to be the dividing factor between absolute crop failure and reasonable food production. Lin (2007, 2010) has revealed on coffee based agroforestry systems mentioned that crops grown under heavy shade (60-80 %) were kept 2-3°C cooler during the hottest times of the day than crops under light shading (10-30%) and lost 41% less water through soil evaporation and 32% less water through plant transpiration. The effect of extremely high temperature on some crops may be reduced through modifying the microclimate e.g. by adding shade and shelter as in agroforestry systems (Cannell et al. 1996). According to Steffan-Dewenter et al. (2007) the removal of shade trees increased soil surface temperature by about 4 °C and reduced relative air humidity at 2 m above ground by about 12%. Soil temperature under the baobab and Acacia tortilis trees in the semi-arid regions of Kenya at 5-10 cm depth was found to be 6°C lower than those recorded in open areas (Belsky et al. 1993). In the Sahel, where soil temperatures often go beyond 50° to 60°C, a major constraint to establish a good crop, Faidherbia trees lowered soil temperature at 2-cm depth by 5° to 10°C depending on the movement of shade (Vandenbeldt & Williams 1992).

About 150 million ha of land in India is subject to serious wind and water erosion, of which 69 million ha are critically affected (Narayana & Rambabu 1983). About 4 million ha is suffering from degradation due to ravines and gullies 11.3 M ha as riverian land (NCA 1976). Coastal sandy areas and steeply sloping lands and more than 9 million ha is salt affected. The deep and narrow gullies are best controlled by putting them to permanent vegetation after closure to grazing. Afforestation with suitable tree species like *Acacia nilotica, Azadirachta indica, Butea moonosperma. Prosopis juliflora, Dalbergia sissoo, Tectona grandis, Bambulsa spp.* and *Dendrocalamus* and other adaptable species such as grasses like *Dichanthium annulatum, Bothriochloa pertusa, Cynodon dactylon* and *Sehima nervosum* will help in stabilizing ravines and gullies and checking their spread.

From the meteorological point of view agroforestry systems are providing two key facts viz., shade tree concept (radiation) and mechanic concept. For the first concept, shade will create microclimates with lower seasonal means in ambient temperature and solar radiation as well as smaller fluctuations. The effect of solar radiation during the day and night times increases the surface temperature considerably and affect the crop during critical periods such as flowering and seed maturing. The shade tree reduces evaporative demands from soil evaporation and crop transpiration. Shade trees are potential adaptive strategy for farmer's vulnerability to reduce water scarcity and microclimate alteration.

AGROFORESTRY AS 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 rice fields provide an illuminating economics (Viswanath et al. 2000). The net present value (NPV) for the different agroforestry models on six year rotation in Haryana varied from Rs. 26,626 to Rs. 72,705 $ha^{-1}yr^{-1}$ 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 (Kumar et al. 2004). Likewise, in Rajasthan, yield of the annual crops can be optimized in combination with *Prosopis cineraria* at optimum tree densities of 278 trees ha^{-1} at 6 and 7 years, 208 trees ha^{-1} at 10 year and <208 trees ha^{-1} at 11 years of age (Singh et al. 2007). Studies on *Tecomella undulata* L. (Rohida) intercropped with *Cyamopsis tetragonoloba* (L.) Taub (Clusterbean), *Vigna radiata* (L) (mungbean), *Pennisetum glaucum* (L.) R.Br. (pearl millet) 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 (Singh et al. 2005). 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 (Singh et al. 2004). 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 (Pandey et al. 2010).

Domestication of such species aimed at commercialization and production of valued products can reduce the pressure on natural ecosystems (Belcher et al. 2005, Chandrashekara 2009). Domestication of forest fruit trees and other species grown in agroforestry systems offer significant opportunity for livelihood improvements through the nutritional and economic security of poor people in tropics (Milne et al. 2006). Suitable agroforestry programmes may enhance the availability of wood in agroecosystems, thereby improved ability of developing countries to participate in the growing global economy (Pandey et al. 2003).

AGROFORESTRY FOR CAVEATS AND CLARIFICATIONS

Agroforestry is a useful land-use management option; it requires 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 livelihood improvement. Households that do not have ownership to lands may not be able to benefit from the agroforestry interventions for livelihood improvement, unless market regimes permit their inclusion through value addition services. Trees in a 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. For instance, in Haryana, *A. indica* and *P. cineraria* did not produce any significant difference in the wheat yield, while *D. sissoo* and *A. nilotica* gave a reduction in yield. *A. nilotica* had a more prominent effect with a reduction of 40 to 60% wheat yield and *D. sissoo* reduced yield by 4 to 30%, but the reduction effect (Puri et al. 1995) was only up to a distance of 3 m. Interestingly, 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.

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 (Swaminathan 2001). Eucalyptus was incompatible with mango and sapota. 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 (Kumar et al. 1999).

BENEFITS FROM AGROFORESTRY

Environment benefits: Combining trees with food crops on cropland farms yield certain important environmental benefits, both general ecological benefits and specific on-site benefits. The general ecological benefits include:

1. Reduction of pressure on forest.
2. More efficient recycling of nutrients by deep-rooted trees on the site.
3. Better protection of ecological systems.
4. Reduction of surface run-off, nutrient leaching and soil erosion through impending effect of tree roots and stems

of these processes.

5. Improvement of microclimate, such as lowering of soil surface temperature and reduction of evaporation of soil moisture through a combination of mulching and shading.
6. Increment in soil nutrients through addition and decomposition of litter-fall.
7. Improvement of soil structure through the constant addition of organic matter from decomposed litter.

***Economic benefits*:** Agroforestry systems on croplands/ farmlands bring significant economic benefits to the farmer, the community, the region or the nation. Such benefits may include:

1. Increment in maintenance of outputs of food, fuel wood, fodder, fertilizer and timber.
2. Reduction in incidence of total crop failure, common to single-cropping or monoculture system.
3. Increase in levels of farm incomes due to improved and sustained productivity.

Social benefits: Besides the economic benefits, social benefits occur from increase in crop and tree product yields and in the sustainability of these products. These benefits include:

1. Improvement in rural living standards from sustained employment and incomes.
2. Improvement in nutrition and health due to increased quality and diversity of food outputs.
3. Stabilization and improvement of upland communities through elimination of the need to shift sites of farm activities.

CONCLUSION

Nowadays climate change is well known to all due to its impact on environment and people. The increased levels of GHGs can be reduced by integration of trees with agriculture. Therefore, agroforestry has a critical role to play in the evergreen agriculture that not only underpins food security, but also provides ecosystems services that can make human life secure. In order to use agroforestry systems as an important option for livelihoods improvement, climate change mitigation and adaptation, and sustainable development of the country, research, policy and practices 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. There is a need to build a bridge between adaptation and mitigation measures for creating environmental secure options of carbon sequestration with multifunctional benefits from agroforestry.

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