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REVIEW ARTICLE

Agroforestry: An ecosystem approach in farming for sustainability

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Abstract: Food security is achieved through the technological interventions; nevertheless, it is entailed with environment degradation. Often the practice of intensive agriculture at many instances is associated with ecosystem degeneration and thereby adversely affected sustainability. This, therefore, necessitated the need for redesigning farming systems which could increase production while conserving and improving ecosystem. Among the different land use systems, agroforestry - a combination of annual crops and perennial trees - due to improved vegetation diversity with economical and ecological functions found to help achieve the goals of sustainability and restoration of ecosystem besides diversified products. The ecosystem services such as soil fertility improvement, efficiency of natural resources, microclimate, biodiversity and carbon sequestration are also enhanced. Hence, tree-based land use system which mimic the natural vegetation to some extent could be considered as the preferred natural resource management strategy and it needs to be strengthened and expanded on farm through extensive research and extension activities.

Key words: Agriculture, Agroforestry, Biodiversity, Ecosystem services, Microclimate

Introduction

Agriculture is the major and largest land use system practiced on the planet covering around 40 per cent of the earth's surface (Foley *et al*., 2011). It is a source of livelihood for millions of poor people especially in under developed and developing countries in the world (Anon., 2009). Over the years, agriculture practice with advanced technologies has helped to meet the global food and fiber demand of large and galloping population. Nevertheless, significant expansion of area under agriculture and intensive farming have resulted in change in structure and function of the agroecosystem which in turn reduced the variety and levels of ecosystem services (Tscharntke *et al*., 2012) that are obtained from ecosystem which are beneficial to agriculture in particular and people in general. It was estimated that over the past 50 years 15 out 24 analyzed ecosystem services such as pollination, biological pest control, soil formation *etc.* were found to be decreased (Anon., 2005). Thus, modern agriculture with simplified system dominated by monoculture and high input use increased soil degradation, decline in biodiversity and water quality, deforestation, environmental pollution, and in some instances even declined productivity and farm income (Keating *et al*., 2010 and Flynn *et al*., 2009).

Further, intensified agriculture is not just most vulnerable to climate change but is also one of the elements for climate change because of higher usage of synthetic fertilizers and fossil fuels, and unscientific management (Le Quere *et al.,* 2009). Today agriculture is contributing around 14 per cent of the total GHGs emission responsible for climate change (Anon., 2007). It is estimated that the agriculture production has to be doubled by 2050 to meet the global population of 9 billion plus. As there is no opportunity to increase area under agriculture, increase in production has to come from increase in the productivity without endangering the ecosystem. This necessitated redesigning of present farming systems especially some of the traditional practices so as to recover the characteristics of ecosystem that have been degraded, damaged or destroyed due to anthropogenic activity (Maria *et al.,* 2015).

Farming system that conserves and increases the level of biodiversity and ecosystem services at farm environment is utmost important in achieving the sustainability. Evidences indicate close relationship between the levels of biodiversity and ecosystem services. For instance, a meta-analysis of 89 studies on restoration of major ecosystem types around the world indicated that increase in levels of biodiversity by an average of 44 per cent has increased ecosystem services by an average of 24 per cent (Rey Benayas *et al*., 2009). The biodiversity within agriculture comprising crops, trees, livestock, fishes, predators, parasites, pollinators, vertebrate and invertebrate soil organisms are generally recognized for their contribution in terms of sustainable production, livelihood and ecosystem health (Atta Krah *et al*., 2004). In this context among the different traditional land use systems, agroforestry is considered to be the most viable system as it contributes to agricultural biodiversity by having additional plant species (mainly woody perennial trees and shrubs) into agriculture which in turn diversifies small scale farm with economical and ecological functions and helps to achieve the goals of sustainability with restoring ecosystem characteristics.

Studies also indicated contribution of biodiversity by traditional agroforestry practices through *in situ* conservation of tree species on farm land, reduced pressure on forests, and provision of habitat for plant and animal species on farm land (Atta-Krah *et al*., 2004; Ouinsavi *et al*., 2005; Acharya, 2006 and McNeely and Schroth, 2006). Besides, tree based land use systems offer various economical goods and several ecosystem services (Chittapur and Doddabasawa, 2018) which prosper the farmer and benefit the agricultural practices through improvement in soil fertility, soil and water conservation, enhancement of water quality, carbon sequestration and biodiversity conservation (Leakey and Tchoundjeu, 2001; Djossa *et al*., 2008; Ouinsavi and Sokpon, 2008; Jose, 2009 and Chittapur and Patil, 2017). Agroforestry is known to mimic the natural vegetation system to some extent and, hence it is considered to be one of the best natural resource management strategies to achieve the goals of sustainability as well as climate resilience through synergetic action of adoption and mitigation strategies (Lasco and Pulhin, 2009 and Verchot *et al*., 2007). Therefore, it was considered as the clean development mechanism (CDM) under the Kyoto Protocol.

The practice of retaining trees on farm land is an age-old practice, as old as agriculture itself and often trees are purposefully grown on the farmland by the farmer to meet the multiple and diverse needs depending on the utility, economical product, compatibility and adoptability of species (Chittapur *et al.,* 2017). These traditional agroforestry systems comprise variety of species and planting pattern within every agro-ecological condition at regional and farm levels, encompassing different farm management strategies depending on economic condition of the farmer, availability of land, *etc*. (Giller *et al*., 2006). Therefore, different kinds of agroforestry systems are practiced in different parts of the globe.

Among the different agroforestry systems including alley cropping, wind breaks and systematic planting etc., traditionally most preferred agroforestry system under rainfed ecosystem is scattered planting which is also called as parkland system. Farmers prefer the trees on the bunds and farm boundaries with varying density of 15 to 40 trees per hectare in some instances (Doddabasava, 2017). The indigenous systems involving many different tree species were reported from many parts of the tropical countries of the world. *Faidherbia albida* in semi arid tropics in Western Africa (Vandenbelt and Williams, 1992), *Vitellaria paradoxa* and *Parkia biglobosa* in semiarid sub-Saharan Africa (Bremen and Kessler, 1995) and *Prosopis cineraria* with millets in Rajsthan (Tejwani, 1994) are some proven species. A few of the beneficial outcomes of the tree-based land use systems are narrated hereunder.

Soil fertility

Sustainability of agriculture depends on the fertility of the soil. Continuous cropping without leaving the land fallow for restoring the fertility that too in the absence of adequate manuring leads to the decrease in the productivity more so in tropics. While, application of synthetic fertilizer is an option to increase the productivity, exuberating prices increase the cost of cultivation and moreover it causes pollution of ground water and climate change. Nevertheless, maintenance and enhancement of soil fertility is important to achieve food security and environmental stability which needs to be addressed through appropriate site-specific management

Table 1. Soil fertility enhancement in multifunctional agroforestry systems in India

Region	Challenge	Changes observed due to Agroforestry
Himalaya (Kurukshetra)	Improvement of sodic soils enhanced nitrogen availability	Increase in microbial biomass, tree biomass and soil carbon:
Himalaya	Restoration of abandoned agricultural sites	Biomass accumulation (3.9 t ha^{-1} in agroforests compared to 1.1 t ha^{-1} in degraded forest) improvement in soil physico-chemical properties; carbon sequestration
Western Himalaya	Reducing soil and water loss in agroecosystems in steep slopes	Contour-tree-rows (hedge rows), reduced run-off and soil loss by 40 and 48 % respectively (in comparison to 344 mm run-off, 39 Mg ha^{-1} soil loss per year under 1000 mm rainfall conditions)
Sikkim Himalaya	Enhancing litter production and soil n utrient dynamics	Nitrogen fixing trees increase N and P cycling through increased production of litter and influence greater release of N and P, nitrogen fixing species help in marinating soil organic matter, with higher mineralization rates in agroforestry systems
Indo-Gangetic plains (UP)	Biomass production and nutrient dynamics in nutrient deficient and toxic soils	Biomass production (49 t ha^{-1} per decade)
Himalaya (Meghalaya)	Enhancing tree survival and crop yield	Crop yield did not decrease in proximity of *Albizzia* trees
Western India (Karnal)	Improvement of soil fertility of moderate alkaline soils	Microbial biomass C which was lower in rice-berseem crop (109.12 gg^{-1} soil); soil carbon increased by 11-52 per cent due to integration of trees and crops
Western India (Rajasthan)	Compatibility of trees and crops	Density of 417 trees per ha was found ideal for cropping with pulses
Central India (Raipur)	Biomass production in N and P stressed soils	*Azadiractha indica* trees were found to produce biomass in depleted soils
Central India	Soil improvement	Decline in proportion of soil sand particles, increase in soil organic C, N P and mineral N
Southern India (AP)	Optimality of fertilizer use	-
Southern India (Kerala)	Growing commercial crops and trees	Ginger in interspaces of *Ailanthus triphysa* (2500 trees ha^{-1}) helps in getting better rhizome of the former compared to sole cropping

practices. Among the land management practices agroforestry seems to be more promising in enhancing the soil fertility through the constant addition of organic matter, reduced nutrient leaching, more efficient nutrient cycling and reduced soil erosion According to Sanchez *et al*. (1997) there are four ways through which trees can contribute to the improved nutrient supply - increased nutrient inputs to the soil, enhanced internal cycling, decreased nutrient losses from the soil, and environmental benefits (Table1).

Efficient use of natural resources

Soil is considered to be non renewable resources because the formation of an inch of soil requires more than 1000 years. However, soil erosion has become an acute problem across the globe. The rate of soil erosion is much higher than natural soil formation and the rate of erosion was estimated to be in the range of 6 to 16 tonnes per hectare per year. However, Agroforestry systems having permanent cover play an important role in reducing the soil erosion and restoring the land degradation by improved rate of infiltration, reduced runoff and holding of soil through their deep-rooted system. The reduction in erosion also reduces the loss of nutrients from the system (Table 2, Penka *et al*., 2012).

TN- total nitrogen, NH_4-N ammonium nitrogen, NO_3-N nitrate nitrogen, TP total phosphorus PO_4-P phosphate phosphorus, G grass strip, G/W grass/ woody strip, F Forest buffer, ND not determined

There are several mechanisms whereby agroforestry may use available water more effectively than the annual crops. Firstly, unlike in annual systems where the land lies bare for extended periods, agroforestry systems with a perennial tree component can make use of the water remaining in the soil after harvest and the rainfall received outside the crop season. Secondly, agroforestry increases the productivity of rain water by capturing a larger proportion of the annual rainfall by reducing the runoff and by using the water stored in deep layers. Thirdly, the changes in microclimate (lower air temperature, wind speed and saturation deficit of crops) reduce the evaporative demand and make more water available for transpiration. In continuous maize cropping and improved fallow system in Malawi, Africa higher maize yield and rainfall use efficiency were observed in improved fallow system with *Sesbania sesben* as compared to the continuous maize cropping system (Mbow *et al.,* 2014). In another study, out of 1106 mm rainfall, runoff noticed was 782, 372 and 66 mm in bare soil, grass land and tree + grass cover, respectively and the remaining infiltrated in to the soil profile indicating the positive interactions of tree + crops in water conservation (Mishra *et al*., 1979)**.**

Favourable microclimate

Monteith *et al.* (1991) reported that trees on farm bring about favourable changes in the microclimatic conditions by influencing radiation flux, air temperature, wind speed, saturation deficit of under storey crops etc. all of which will have a significant impact on modifying the rate and duration of photosynthesis and subsequent plant growth, transpiration, and soil water use. For instance soil temperature under the baobab and *Acacia tortilis* trees in the semi-arid regions of Kenya at 5-10 cm depth were 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 and Williams, 1992). Significantly higher yield of both groundnut and sesame were recorded in alley cropping system as compared to the sole cropping system in the semi desert system in northern Sudan (Haider and Adam, 2008). Shelterbelts and wind breaks are extensively used agroforestry systems to reduce specifically wind velocity and soil erosion which also modify the microclimate through reduced wind velocity and soil moisture evaporation, and with proper design of planting and management of these systems protection on lee word side could be extend up to 25 times of the total height of the trees.

Diversity

Biodiversity within agriculture which contributes in sustainable production, livelihood and ecosystem health are gaining importance in recent days. Unlike monoculture agroforestry contributes biodiversity in agriculture by having additional perennial component on the farm land. Further integration of trees on farm land not only enhances the landscape diversity but these trees in turn also enhance various other organisms through providing habitat, creation of favorable microclimate condition, addition of organic matter etc. Thus, existence of trees on farm land could bring significant increase in components of agricultural diversity such as birds,

Table 2. Reduction (%) in sediment and nutrients loss with surface runoff in agroforestry buffer strips

System	Slope %	Sediment	Nutrients					References
			TN	NH_4-N	NO_3-N	TP	PO_4-P	
G	1-2	19	21	ND	24	8	ND	Udawatta *et al*. (2002)
G	1	94-100	ND	100	100	ND	100	Schoonover *et al.* (2005, 2006)
G	5	95	80	ND	62	78	58	Lee *et al.* (2003)
G/W	1-2	0	20	ND	37	17	ND	Udawatta *et al*. (2002)
G/W	5	97	94	ND	85	91	80	Lee *et al*. (2003)
G/W	4-15	80	50	20-50	50-90	60	50	Daniels and Gilliam (1996)
F	1	76-86	ND	68	97	ND	78	Schoonover *et al*. (2005, 2006)

TN- total nitrogen, NH_4-N ammonium nitrogen, NO_3-N nitrate nitrogen, TP total phosphorus PO_4-P phosphate phosphorus, G grass strip, G/W grass/ woody strip, F Forest buffer, ND not determined bats, pollinators, predators, macro and micro fauna in soils. Such increase in diversity due to existence of trees on the farm helps in enhancing the overall productivity of the farm. For instance, increase in soil organisms contributes to the sustainability of agroecosystem through their role in nutrient cycling, improvement of soil structure and water holding capacity, regulation of diseases and carbon sequestration (Atta Krah *et al*., 2004). In the context of this various researchers have examined the agroforestry for their contribution to biodiversity both in tropical and temperate region (Schroth *et al*., 2004; Harvey *et al.,* 2006). In study carried out in Costa Rica by Harvey and Gonzalez Villalobos (2007) noticed similar abundance of bird assemblage, species richness and diversity in agroforestry which were on par with natural forest. Similarly, Johnson and Beck (1988) studied the insect damage in shade coffee system in Jamaica and found reduced incidence of insect damage in shade coffee system due to attraction insect eating birds by complex vegetation. Further, quantum studies also indicated higher micro and macrofuanl diversity in agroforestry system (Moguel and Toledo 1999; Honnayya, 2018; Doddabasawa *et al*., 2018). In all the integration of trees not only conserve the plant species but also helps to conserve many other organisms which in turn helps to enhance the ecosystem services which benefits the agriculture

Climate change mitigation

A large proportion of the world's food is grown in tropical rainfed systems where climate variability may play an important role in productivity. Mean seasonal climate has been shown to have great influence on agricultural production across a range of crops, with extreme variations affecting crop development (Slingo *et al*., 2005). This suggests that there are thresholds above which crops become highly vulnerable to climate and weather extremes (Challinor *et al*., 2005).

In the face of increasing climate variability, it will be important to find sustainable and financially viable coping strategies for small farmers who have no access to technological improvements. The presence of trees in agriculture can have beneficial ecological functions on the agroecosystem through the mitigation of microclimate variability (Ewel, 1999; Gregory and Ingram, 2000). Agroforestry plays a critical role in modifying the microclimate by lowering soil temperature and reducing soil moisture evaporation through the combed effect of mulching and shading.

The shade trees are extensively used to protect the heat sensitive plantation crops like coffee, cacao, ginger, turmeric and cardamom from high temperature. Lin (2007) reported that the use of agroforestry systems is an economically feasible way to protect crop plants from extremes in microclimate and soil moisture and therefore these should be considered as a potential adaptive strategy in areas that will suffer from extremes in climate. Similarly, Beer *et al*. (1998) summarized that shade trees buffer high and low temperature extremes by as much as 5 °C.

Agroforestry is widely considered as a potential way and low cost method to sequester atmospheric carbon and, therefore, recognized as one of the strategies for climate change mitigation (Alavalapati and Nair, 2001). In agroforestry system, tree components are managed and pruned for reducing competition, and these pruned materials are generally non-timber products. Such materials are returned to soil to increase carbon biomass. The effectiveness of agroforestry systems in storing carbon depends on both environmental and socio-economic factors; in humid tropics, agroforestry systems have the potential to sequester over 70 Mg ha^{-1} in the top 20 cm of the soil (Nair *et al.*, 2009). The carbon storage capacity in agroforestry varies across species and geography (Albrecht and Kandji, 2003). Further, the amount of carbon in any agroforestry system depends on the structure and function of different components within the systems put into practice (Schroeder, 1993). The estimation of above ground carbon in stock in different traditional agroforestry systems under two contrasting ecosystem with different tree species in the Deccan plateau in India (Doddabasawa, 2017) revealed higher potential of standing carbon stock in agroforestry system which ranged from 4.64 to 14.96 t C/ha/yr in traditional agroforestry systems than the land use system without trees (Table 3).

Further, agroforestry systems can have indirect effects on carbon sequestration as it helps to decrease pressure on natural forests that are the largest sinks of terrestrial carbon. They also conserve soils and thus enhance carbon storage in trees and soils. Effects of agroforestry practices on the soil carbon pool indicated a rate of increase by 2-3 Mg C^{-1} $ha^{-1}yr^{-1}$ (Montagnini and Nair, 2004). Estimations of carbon sequestration potential in various studies ranged from 6.3GtC and 0.7-1.6 GtC (Indu *et al*., 2013).

Table 3. Carbon sequestration potential of different agroforestry systems under two contrasting ecosystems with different tree species

Agro-ecosystem	Tree based land use system	Mean No. of trees ha^{-1}	Agroforestry systems	Total carbon stock t ha^{-1}
Rainfed (25 years	Neem - pigeonpea	39.00	Boundary planting	7.46
old neem	Agroforestry system	26.75	Bund planting	5.54
		18.25	Scattered planting	4.64
		-	Sole pigeonpea	3.08
Irrigated	Teak - pigeonpea	123.25	Boundary planting	14.96
(15 years old teak)	Agroforestry system	97.75	Bund planting	13.57
	Block plantation	1600	Block plantation	71.84
	Silvihorti (Teak+Mango)	142	Silvihorti system	17.1
		-	Sole pigeon pea	4.46

Income and employment

Diverse outputs from agroforestry system such as timber, fuel wood, fertilizer, fodder, food and other non timber forest products enhance the income level of the farmer directly. Further, revenue spreads into short, medium and long terms and also reduces the risk of failure of income (Gold *et al.,* 2006). That apart, agroforestry also generates sustainable employment to the farming community. Further, agroforestry provides livelihood opportunities of subsidiary enterprises such as lac, apiculture, sericulture *etc*. apart from gum, resin and even medicines from some special tree species.

The level of income is also increased by reducing the cost of cultivation by lesser use of synthetic fertilizer or by enhancing the productivity of the field crop through enhanced, pollination, soil fertility, more efficient use of resources and creation of favourable microclimate. Thus, the livelihood of farmer is improved through diversified income from tree and enhanced productivity of the crop. Some of the studies indicated higher benefit cost ratio and land equivalent ratio in agroforestry systems (Sanchez *et al.,* 1997, Chittapur *et al*., 2017). Intercropping maize with coppicing legumes, for example, *G. sepium, Leucaena leucocephala* and *Calliandra calothyrsus* increased yields continuously for several years after establishment (Sanchez *et al.,* 1997; Garrity *et al.*, 2010). Analysis over a 5-year cycle indicated increased net profit from unfertilized maize to the tune of US$ 130 ha^{-1} compared to US$ 269 and US$ 309 ha^{-1} for maize intercropped with *Gliricidia* or in rotation with *Sesbania*, respectively. Further, benefit:cost ratios ranged from 2.77 to 3.13 for green fertilizer technologies, in contrast to 2.65 for subsidized fertilizers and 2.01 for non-fertilized fields (Ajayi *et al*., 2009).

Considering all these explicit benefits from agroforestry, could become a viable approach to restore the characteristics of ecosystem and also helps to achieve the goals of sustainability. Even though surprisingly adoption of these systems are very low which might be due to many of the benefits of agroforestry systems are intangible in nature and other deterrents in adoption of these systems are higher initial expenses, constraints of land and labor, poor knowledge of management of trees on the farm land, and poor extension programmes and demonstrative plots etc., Hence, special attention needs to be given in research and expansion of agroforestry systems for promotion of these eco-friendly land use system.

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