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Agroforestry: A Way Forward for Sustainable Development

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ABSTRACT

Understanding the role of agroforestry in present agricultural practices in subject to increase in production as well as its beneficial contribution towards environment and income. As climate change, soil degradation, water scarcity and increase in price of agricultural raw materials leads agricultural more crucial but when agroforestry practices came into existence, the productivity and sustainability increase. Increase in population and its effect towards land-use competition welcomes agroforestry in revolution basis. This practice relies more on sustainability with low input and diversified income. Agroforestry is considered as smart way of farming which fulfill various aspects for farmers and environment. It helps mostly the small scale land holders to satisfy their economical needs along with food security. After analysis of many research paper it is found that this system have many components with different key elements. The adaptation of this practice is influenced by several characteristics of that particular area. However there are many benefits in practicing agroforestry, they are crucial in initial stages in field landscape designing. After detailed study of many research works, this review paper gives overall outline of contribution of agroforestry in farm diversification and income, food security, role in environment etc. now agroforestry is playing important role in self resilience, fullfilling basic needs with socio-economic and environmental benefits.

Key words: *Sustainability, Diversification, Ffood security, Climate change and carbon sequestration.*

Introduction

In India 1950's, Green Revolution began with increased productivity of monocultures, however it has not solved the problem of food security of the indigenous people, which encouraged them for sustainable development to ensure food security. Traditional communities started following the agroforestry practices to grow more resilient, self-sufficient and to preserve bio-diversity(Goncalves *et al.,* 2021). Further, the rise in the term ' Agroforestry ' was a form of ancient practices, where the trees were only the integral part of the farming system, the primary motive of these practices was food production not tree production (Nair, 1993). The term ' Agroforestry ' refers to cultivation of forest trees in combination with agricultural crops/livestock's or both with the beneficial effect of ecosystem. Agroforestry implies that where there is involvement of two or more species of plants/trees, animals and woody perennials (Nair, 1993). Agroforestry is majorly considered as a potential way of improving environmental sustainability and socio-economy in both tropics and temperate zones. Researches proven that there is significant association of agroforestry system with environmental services such as carbon sequestration, biodiversity, soil erosion and improvement of water quality (Alavalapati *et al.,* 2004).

As population increases, there is increase in pressure on food security paves the way for sustainable agricultural practices. Considering these realization in agricultural land use management along with better income, agroforestry came into existence (Rigueiro-Rodríguez *et al.,* 2008). Then small land holders started reconsidering agroforestry as a dynamic, ecological and economical with the intention of developing sustainability along withimproved farm productivity as well as welfare of their rural community (MacDicken and Vergara, 1990). Unlike, other agricultural practices agroforestry are more knowledge intensive practice when compared to modern agricultural practices. Improved quality of seeds with good varieties, chemicals and various mechanical inputs are more considered in agroforestry practices (Mercer, 2004). Agroforestry is a multidisciplinary approach which involves the requirement of agronomist, soil scientist, forester, plant pathologist, economist social scientist, extension and further research departments (Dhyani, 2009).

After many researches and ages agroforestry system receives much attention in India from the researchers/scientists side as well as policy makers side for its perceived ability of contribution in significant economic growth and environment quality. So that nowadays agroforestry system is most important part of ' Evergreen Revolution ' in India (Puri and Nair, 2004). Agroforestry connects the global policy of environment by few productive land use methods, that contributes directly and significantly to all key elements of sustainable development of the country (Garrity, 2006).As per (National Forest Policy, 1988) , it is suggested to maintain ecological balance because according to wood based need of the country (as day by day needs of wood and timber are increasing), there is a need to maintain forest under one-third of the country. In such case it is found that agroforestry is the only feasible option to maintain the demand of food and wood as well as to conserve ecosystem.

Characteristics and components of agroforestry

Agroforestry system is a system which requires low input cost with less maintenance yet still generates higher recycling rate which makes more preferable for low income farmers with more profitability (Jezeer *et al.,* 2018). Generally, agroforestry exists around the world in various forms such as silvoarable system, silvopastoral system, agrosilvopastoral system, multipurpose trees, riparian buffer, improve fallow (Mosquera-Losada *et al.,* 2009). Based on major practices covered in survey by IITA are alley farming, improved fallows, live fencing, apiculture and cut and carry fodder systems (Nkamleu and Manyong, 2005). The main theme of agroforestry centers sustainability in terms of economics: productivity and profitability; ecology: resource conservation and environment; social issues: food safety and security which makes an unparallel land use system (Pandey, 2007).

Profitability, sustainability, competition and complexity are the four major key elements to be considered in agroforestry(Sanchez, 1995). Agroforestry has more than two components, which provides farm diversification, it reduces the risk of crop failure due to natural calamities. Farmers are combiningvarious components like perennial tree

Table 1. Outline of different practices of agro forestry systems in several countries

S.No	Practices	Description
1	Silvopastoral	Combination of tree with forage crops and animal production. Comprises forest grazing and open forest trees.
2	Silvoarable	Trees intercropped with annual and perennial crops which has alley cropping system, scattered trees and line belts.
3	Agro-Silvopastoral	Combining trees with annual crops and livestock production but the arable and livestock components are temporally and spatially distinct.
4	Multipurpose trees	Fruits and other trees are plant in cropland with pasture for purpose of fruit, fuel wood, timber etc.
5	Improve fallow	Plantation of leguminous woody species to improve soil fertility
6	Riparian buffer	Strips of perennial vegetation naturally or planted between land or water sources to protect water availability and quality.

(Mosquera-Losada *et al.*, 2009)

(Table 2), apiculture, pisciculture, livestock's etc. which depend upon their ecological conditions and resource (Hymavathi *et al.,* 2010). Farm production in agroforestry system increased through various beneficial process like biological nitrogen fixation, nutrient cycling, nutrient pumping, improving soil physical and chemical properties, weed and post control and increase in moistures availability of soil (Sahoo and Wani, 2020). The main objectives of agroforestry production are to diversify production, control shifting cultivation, increase soil organic matter, fix atmospheric nitrogen, recycling nutrients, modify microclimate and optimize system productivity (Somarriba, 1992).

Trees and shrubs are dominant mainly overstorey plants, this is one of key factor in agroforestry (Huxley, 1983). Interaction of agroforestry system can be classified into above-ground and below-ground process (Schroth, 1995).

Productive function of agroforestry

Agroforestry for sustainable development

Nowadays agricultural production are declining with response to constrains of natural resources, Climate change and land-demand competition. Thus, agroforestry considered as major potential way to maximize productivity, yield and assured food security along with diversified farm income in resilience to climate change (Kiptot *et al.,* 2014). Agroforestry have the opportunities for prevention or land degradation especially in humid tropics (cooper *et al.,* 1996). Several benefits in agroforestry are (1) it conserves soil from protects against erosion (2) it maintains and improves soil fertility (3) it helps in more productive use of water and water conservation (4) it helps in environmental function which requires for sustainability (Ong and Swallow, 2003).

Economic analysis of agroforestry

In agroforestry system, the cost of cultivation of the intercrop is inversely proportion to the age of plantation (*Populus deltoids)*, which means when age of plantation increases the cost and returns from the intercrops deceases. In agroforestry system for example sugarcane intercropping, found that cost of intercropping amount in first year was 45,858 and in second year it was decreased to 39,750. The gross returns of sugarcane decreased from 71,150 to 55,111 per acre of cultivation. The net returns declined from 25,952 during first year 15,321 in second year. The same trends recorded in wheat, as the net returns decreased due to increase in poplar canopy which shows that in agroforestry system returns from intercrop is inversely related to age of the plantation (Karemulla *et al.,* 2005).

Agroforestry in farm diversification and income

Agroforestry system performs the function of farm diversification (occurs when more species of the plants/trees or animal breeds added in single given farm or farming community) which contributes in term of economy of the farm (Raj *et al.,* 2019). The agroforestry systems are more likely to have more productive functions, i.e produce from trees and crops as well as output from livestock's (Rigueiro-Rodríguez *et al.,* 2008). Agroforestry system used to diversify the farm with the integration of timber

Table 2. Classification of productive function of agroforestry

Function	Description	Example
Production	Creation of biomass for further use	Trees: Fruits, oils, timber, cork, firewood, nuts etc.Crops: Grains and seed production, soft vegetables and fruits, bio fuel and fodder (Eichhorn *et al*., 2006).
Habitat	Provides habitat for conservation and maintenance of biological diversity	Animals: Meat production, provides habitat diversity, species diversity, shelter for animals, poultries etc. (Sánchez, 2005).
Regulation	Regulates and maintenance of essential environmental and life supporting system	Involves in soil and eater conservation, reduces risk of soil erosion, nutrient leaching and takes part in carbon sequestration (Palma *et al*., 2007).
Cultural	Opportunities for cognitive development and recreation	It also takes part in land enhancement, recreation (Bell, 2000)and cultural heritage (Rigueiro-Rodríguez *et al.,* 2008)

trees with high productivity and profitable rate of agricultural crops/livestock's which involves the capture and maximization of inter-specific genetic diversity with benefit of both production and environment (Leakey, 1999). Agroforestry and farm diversification approaches are compared in terms of economic efficiency. Increase in land-use efficiency results in land-use system in way which reconcile agricultural provisioning with multiple ecosystem services, which includes climate change, better farm income, carbon sequestration, land-use efficiency etc. (Paul *et al.,* 2017).

The study in Ethiopia results that agroforestry and farm diversification activities enhances the sustainability of land management which maximize the farm household economic return from these diversified practices (Kassie, 2018). The study of farm diversification and income of 300 rubber agroforestry farms under many diversifications with more than 300 farmers cultivation of monocultures, rubber- food crops, rubber- fruit plants, rubber- non-edible crops. The data shows that more net income gained in agroforestry combination other than rubber monoculture (Huang, *et al.,* 2022). Research at Hisar, India, a related to doubling farmer's income through *Populus deltoides* based agroforestry system in northwestern India with economic analysis results that diversification in cropping system are more profitable with spacing of 10×2M than traditional cropping system (Chavan and Dhillon, 2019). ABM demonstrated that by connecting individual farmers decision with ecological process, agroforestry maintains native forestswhile improving live hood, income of the rural households which stimulates and engages the farmers to include agro forest for diversification and increased income (Nöldeke *et al.,* 2021). It is found that agricultural crops like (wheat, ginger, turmeric, colacasia, cabbage, spinach, potato, mustard, garlic etc), fruit crops (citrus, mango, guava, pomegranate etc.) can get more benefit when it grown along with poplar but some crops like sugarcane, soyabean, mentha, sorgham.can be grown only in two initial years (Sharma, 1996). Nowadays, popular (*Populus deltoids*) has become a most preferable cash crop in northwestern part of India because which plays an important role in socio-economy, commercial and environmental concerns of the people (Pandey *et al.,* 2020).

Examples for agroforestry cropping pattern

Role of agroforestry in food security

Agroforestry comprises the growing of nutritious fruit and food crops which increases the health and nutrition of rural people. As per researches agroforestry plays a important role in child nutrition (Sahoo and Wani, 2020). Agroforestry has important role in increase in production of vegetables and fruits that provides higher nutrients and vitamins rather than calories. Small holders achieved a typical increase in milk yield to raise extra revenue from milk sales more than USD 100 per cow per yearand provides milk more efficiently to urban consumers (Jamnadass *et al.,* 2013). Establishment of agroforestry where there is less tree cover has identified as one of the most useful strategy for enhancing food production without additional deforestation (Garrity, 2010).

In early 2000's research held in Philippines outlined that eradication of hunger through establishment of agroforestry practices which also improves soil fertility, land regeneration, poverty eradication and generated incomes in the disadvantaged areas (Magcale-Macandog *et al.,* 2010). Researches in many countries of Africa shows that agroforestry system contributes food security by different ways such as increased milk production and indigenous fruit production for improved human health and farm income; fertilizer trees for increased crop production (Kiptot *et al.,* 2014). According to research in Yayu, the agroforestry system contribute in a complementary manner to fulfill the various demands of the households. Farmlands surrounded by trees produce the major food supply of the households, which sometimes may also produce supplementary income (Jemal and Callo-Concha, 2017).

Agroforestry and soil health:

Agroforestry improves the soil health by enriching soil organic matter availability than mono-cropping system, improves soil nutrient availability and soil fertility due to presence of trees in this system and enriches soil microbial health which positively influence the soil health (Dollinger and Jose, 2018). In 90's research held in Nepal explained that the soil nutrients/parameters like amount of Soil Organic Matter (SOM), Nitrogen (N), Phosphorous (P), Potassium (K) levels are significant in agroforestry system when compared to conventional farming. The benefit-cost analysis of agroforestry system are more profitable than conventional farming system. In results the study shows that agroforestry has potential for enhancing food production and farmer economic condition with positive effects of soil fertility and soil erosion in sustainable manner (Neupane and Thapa, 2001). Agroforestry system contributes in litter addition, litter decomposition and nutrient release, nutrient addition through root biomass, nutrient pumping and erosion control (Sarvade, 2014). Alley cropping and silvopasture vegetation and their dynamics strongly influence biodiversity with improved soil porosity, water dynamics and nutrient cycling efficiency with maximum plant growth and minimum leaching of soil nutrients (Udawatta, 2021). A study in Brazil reported that in soil erosion, the mobilized amount of mercury, calcium, magnesium and potassium were similar in two year old agroforest system and mature forest system were significantly lower compared to continuous cropping system (Widianto *et al.,* 2004).

Agroforestry help in decreasing soil erosion via litterfall and pruning in this system act as a physical barrier and soil cover during erosion, along with interception of trees (Atangana *et al.,* 2014). *Ficus bengalensis* based agroforestry system is highly based on litter mass dedecomposition (Singh *et al.,* 2021) In agroforestry system (When compared to monoculture system agroforestry system improves 75% infiltration rates and 57% lower runoff rates (Muchane *et al.,* 2020). Research in agroforestry established that potential of many salt tolerant trees and bushes in biological amelioration and in rehabilitation of salt affected soil (CSSRI, 2010). A study in southern United States shows that soil organic matter content and microbial biomass is high in pecan and cotton (*Gossipium hirusitumm*) then compared to monoculture cotton (Lee and Jose, 2003). A combine study regarding agroforestry buffer in improving the soil porosity at mid-west region of United States found that average pore paths in grass and agroforestry buffer strips were three and five times respectively grater than soil of maize-soyabean rotation (Udawatta *et al.*, 2008a). Further study showed the improved soil aggregate stability, soil carbon, and nitrogen, enzyme activities under row crops compared to agroforestry buffers (Udawatta *et al.*, 2008b). A experiment on Oregon demonstrated the use of N- fixing red alder in maize alley cropping system. They used 15N injection technology, 38-58% of total N in maize obtained from N fixed by red alder and the same nitrogen transfer increased with decrease in tree and crop distance (Seiter *et al.,*1995)

Agroforestry and water conservation

Agroforestry isone of the most useful approach in watershed management to promote sustainable use

Table 3. Examples of trees and crops suitable in agroforestry system

Age	Popular (*Populus spp.)*	*Eucalyptus spp.*	Dek (*Melia azedarach)*
1	Mentha (*Mentha spp.*), Mung (*Vigna radiata*), Maize (*Zea mays*), Sorghum (*sorghum bicolor*), Arvi (*Colocasia esculenta*)	Wheat (*Triticum* aestivum), Mustard (*Brassica juncea L.*), Potato (*Solanum tuberosum*), Marigold (*Tagetes spp.*).	Wheat (*Triticum* aestivum, Mustard, Turmeric (C*urcuma longa)*, Sugarcane (*Saccharum officinarum*)
2	Mentha (*Mentha spp.*), Mung (*Vigna radiata*), Bajra (*Pennisetum glaucum*), Sorghum (*sorghum bicolor*), Cowpea (*Vigna unguiculata*), Arvi (*Colocasia esculenta*)	Wheat (*Triticum aestivum*, Mustard (*Brassica juncea L.*), Potato (*Solanum tuberosum*), Berseem (*trifolium alexandrinum*), Oats (*Avena sativa*), Marigold (*Tagetes spp.*).	Potato (*Solanum tuberosum)*, Berseem, Oats (*Avena sativa*), Turmeric (C*urcuma longa)*, Sugarcane (*Saccharum officinarum*)
3	Bajra (*Pennisetum glaucum*), Cowpea (*Vigna unguiculata*), Arvi (*Colocasia esculenta*)	Wheat (*Triticum aestivum*, Mustard (*Brassica juncea L.*), Potato (*Solanum tuberosum*), Berseem (*trifolium alexandrinum*), Oats (*Avena sativa*), Marigold (*Tagetes spp.*)	Turmeric (*Curcuma longa)*
4-6	This stage is not economical to grow crops	Wheat (*Triticum aestivum*, Mustard (*Brassica juncea L.*), Potato (*Solanum tuberosum*), Berseem (*trifolium alexandrinum)*, Oats (*Avena sativa*), Marigold (*Tagetes spp.*).	

(Gill, 2016)

of water resource (Khan and Tewari, 2009). The presence of shade trees in the field reduces the evaporative rate of soil evaporation and transpiration of crops (Lin, 2010). In China, from agroforestry system, an evaluation based on water balance and water competition in alley cropping system consists of deciduous wild trees like Jujube and Peanut, which shows that alley cropping, water budget components and water use patterns were increased significantly (Zhao *et al.*, 2012). Primarily, agroforestry system with perennial trees can make use of remaining water in the soil after harvest from the rainfall got outside of crop season. Secondly, agroforestry increase the productivity of capturing rainwater in larger proportion by reducing runoff by using water stored in deep layers (Kamugisha *et al.*, 2022).

Agroforestry and climate change

There is recent understanding of the scenario of climate change and its issues with challenges provides an in-depth analysis of agroforestry system which is potential towards climate change mitigation and adaptation. Agroforestry system provides variety of ecofriendly methods which being employed to mitigate climate change, suggest to build harmony between agroforestry and climate change as well as maintaining sustainability of the ecosystem (Jhariya *et al.*, 2019). In agroforestry system the crops will get the beneficial effect of microclimate in various ways (Khan and Tewari, 2009). Agroforestry indulge in changes in microclimate by lowering air temperature, wind speed and saturation deficit of crops which reduces the evaporation demand which make more water available for transpiration (Kamugisha *et al.*, 2022). According to researches Agroforestry is considered as a Climate Smart Agriculture which promising adaptation option for small landholders (Colin, 2013).

Agroforestry and carbon sequestration

Carbon sequestration is the process of removing carbon from the atmosphere and depositing it in reservoir (Berner, 2003). Agroforestry system have the potential to store carbon and remove atmospheric carbon dioxide through enhanced growth of trees and shrubs (Pandey, 2002). In agroforestry system trees, shrubs etc. are incorporated together in which the amount of carbon sequestered is high compared to monoculture (Garrett and McGraw, 2000). In agroforestry system the carbon can sequestered through different ways, i.e carbon sequestered in tree biomass, soil organic carbon enhancement, carbon stored in block and boundary plantation (Murthy *et al.*, 2013). Unlike other forest/tree culture or monoculture system agroforestry system likely to have unique advantage in carbon sequestration process because agroforestry can arguably store C due to their fast growth and adaptability with high productivity which allows food crops to grow in faster rates (Montagnini and Nair, 2004).

Researchers found that carbon sequestration potential on arid, semi – arid and degraded soils are low as compared to humid fertile sites; as well as temperature agroforestry has lower carbon sequestration potential than tropical agroforestry and the potential of agroforestry system to store carbon varies according to the type of the system, age of the component species, species composition, environ-

Table 4. Physical and chemical characterization of soil of 0-40cm in semi-arid region ofCeara´, Brazil with treatments of Agrosilvopasture(AGP), Silvopasture (SILV), Traditional Agrosilvopasture (TRAG), Intensive cropping (IC), Native Forest (NC)

Attributes	AGP	SILV	TRAG	IC	NC
Clay (g kg^{-1})	113.9	113.4	164.4	139.7	168.4
Coarse sandy (g kg^{-1})	265.7	461.6	308.6	318.4	321.6
Fine sandy (g kg^{-1})	364.7	216.2	293.1	305.0	233.3
Silt (g kg^{-1})	255.7	208.8	233.9	236.9	276.7
Bulk density (g cm^{-3})	1.59	1.65	1.68	1.64	1.63
Ca^{2+}(Cmol$_c$ dm^{-3})	21.8	6.3	16.9	14.4	22.1
Mg^{2+}(Cmol$_c$$dm^{-3}$)	4.3	3.0	5.5	3.7	9.7
K^+(Cmol$_c$$dm^{-3}$)	0.9	0.85	1.2	0.7	1.3
Na^+(Cmol$_c$ dm^{-3})	0.20	0.08	0.2	0.15	0.2
CEC(Cmol$_c$ dm^{-3})	28.0	12.71	26.1	20.7	35.6
pH in H_2O	7.0	6.37	6.8	6.8	6.8

(Maia *et. al.*, 2007)

mental factors geographical locations, management practices etc. (Nair *et al.*, 2009). An estimate done by (IPCC, 2000), advised that improving the current management practices in existing agroforestry practices (better management of trees and crop lands) could sequester 17000 Mg C y^{-1} by 2040 from 12000 Mg C y^{-1}. Further additional unproductive cropland and grassland approximately 630 million ha can be converted to agroforestry, provides carbon sequestration potential of 586000 Mg C y^{-1}. According to (Nair *et al.,* 2009) quantified caron sequestration potential of agroforestry estimated that land area under 1023 million ha are under agroforestry. Using media carbon sequestration potential of (Dixon, 1995) 94 Mg ha^{-1}, the land area of 1023 million ha represents 1.9 Pg of carbon sequestration potential over 50 years.

Agroforestry and biodiversity

The agroforestry system can contribute to bio-diversity in various ways as explained by many authors (Schroth *et al*. 2004; McNeely 2004; Harvey *et al.* 2006) mainly agroforestry plays five major roles in bio-diversity conservation (1) agro forest can provide habitat (refer Table 2) which can tolerate up to certain level of disturbance (2) it helps is to preserve sensitive species germplasm (3) it plays a productive and sustainable role in minimizing conversion rate of clearing natural habitat into traditional agriculture (4) it makes a connectivity of remnants habitat conservation by integrity of remnants and conserving of sensitive flora and fauna (5) it provides ecological services like preserving soil from erosion, water conservation, climate mitigation etc.

Constrains

Despite of considerable uses lack of research, education and extension services with shortage of knowledge regarding agroforestry in several parts of the country are there (Guyassa and Raj, 2013).

Allelopathy effect

Allelopathy (organism produce one or more biochemical that influence the germination, growth, survival and reproduction of others) is the term which is applicable in agroforestry system. Allelopathy effect have some beneficial effects like effects on *Parthenium hysteroporus* by *Eucaluptus sp.*on its germination and growth (Patel, 2011) through reduced emergence of weeds, bit the scope of selective elimination of weeds without making any adverse effect on crop has not been investigated (Rao *et al.,* 1997). But there are major gains to improve the resolution of agroforestry because they have similar underlying ecology and prospect for management to fully encompass people's use of tree resources and natural vegetation (Sinclair, 1999).

Landscape designs

Designing of agroforestry system in farm contains broader diagnostic scope which deals with sole land-use system with specific attention to trees and crops (Raintree, 1987). Farmers facing the issues are discussed that identifying, designing and implementing are major constrains (Arnold, 1983).

Root competition

Root characteristics and its process are important factor to be considered for the success of agroforestry system. However root contributes in regeneration of soil fertility but they are also important in competition with crops (Schroth, 1995).

Conclusion

Agroforestry is considered as sustainable and profitable with positive in most of the aspects of environment. After reviewing many research works agroforestry practices are considered as most diversified system of cropping which generates higher income. This practice not only focus on farm income but also it works mainly towards the food security of the community. Further, the beneficial effects of agroforestry system in climate change, carbon sequestration, water conservation are more considerable than profitability rate. Considering the above mentioned reviews the practice are crucial in the initial stages after there will be sustainable processes with beneficial effects. Moreover the positive effects, the allelopathy effects on weeds are beneficial but still its effect on crops are under research. Nowadays the agroforestry system are mostly encouraged by small land holders for their sustainable development. Agroforestry also have several constrains which is not permanent but the research works undergoing to overcome them.

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