General Article ________________________________ *Chapter -12*

Agroforestry: A strategy for sustainable Development

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Abstract

The World is facing numerous challenges in different aspects. The only way to address global challenges is to move forward with sustainability. Sustainable development is the major goal of present world and Sustainability is the primary goal of present agricultural practices. It is acknowledged that in order to achieve responsible and sustainable development, environmental, human, and economic capital should all be taken into account in every action or decision. To accomplish this, one of sustainable approach is through adoption and integration of agroforestry practices. Agroforestry is a distinctive approach to land management that combines agriculture farming, forestry, and or livestock or pasture on the same piece of land to increase production, profitability, and environmental stability. It meets roughly half of the demand for fire wood, 65 % of the demand for small timber, 70-80 % of the demand for plywood, 60 % of the demand for paper pulp, and 9-11 % of the demand for fodder, among other needs. This chapter discuss potential role of agroforestry practices in accomplishing Sustainable Development Goals (SDGs) through its numerous contributions to boosting agricultural yield and productivity, food and nutritional security, livestock production by increasing access to fodder, biomass energy generation, soil and water conservation, improvement in the physiochemical properties of soil, enhancing livelihood and employment opportunities, gender equality, halting biodiversity, carbon sequestration, and climate change mitigation. The organized research projects conducted over the previous three decades have amply demonstrated the potential of agroforestry in meeting Sustainable Development Goals (SDGs).

Key Words: Agroforestry, Biodiversity, Development, livelihood and Sustainability

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Introduction

The world is dealing with countless challenges such as climate change, extreme poverty and inequality, financial and economic crisis, food and nutritional crisis, water scarcity, energy crisis, population growth and demographic shift, health pandemics and infectious diseases and many more. Moving forward with sustainability is the only way to address these global issues. The main objective of the modern world is sustainable development. Numerous developments in the conversation about sustainable development have occurred over the past 50 years. More development has been seen in industrialized nations, but many developing nations have also realized the importance of pursuing sustainability. The World Commission on Environment and Development's Brundtland report, also known as Our Common Future, provided a definition of sustainable development. Sustainable development, according to this report, "meets the needs of the present generation without compromising the ability of the future generation to meet their own" (Burton, 1987). The 2030 Agenda for Sustainable Development, which was endorsed in 2015 by United Nations Member States, is centered around the 17 Sustainable Development Goals SDGs. This agenda seeks to forge an international alliance in order to address issues of social, economic, and environmental sustainability. To build a more sustainable world by the year 2030, deliberate policies will need to be developed and put into action with regard to issues of people and prosperity, the environment and partnership, and peace. Environmental, human, and economic capital should all be taken into account in every action or choice made in order to achieve Sustainable Development Goals (SDGs). Adoption and integration of agroforestry practices is one sustainable strategy for achieving this.

Agroforestry is a distinctive approach to land management that combines agriculture farming, forestry, and or livestock or pasture on the same piece of land to increase production, profitability, and environmental stability. The idea that technology might significantly contribute to economic progress, the eradication of poverty, and the improvement of the environment has generated through agroforestry. It has several tangible and intangible advantages that have a huge impact on the world economy. In fact, agroforestry holds out a lot of hope for attaining nearly all of the Sustainable Development Goals (SDGs) simultaneously. Agroforestry currently provides nearly half of the fuel wood required, two-thirds of the small timber required, 70-80% of the wood required for plywood, 60% of the raw materials required to make paper pulp, and 9-11% of the green feed required for livestock, in addition to meeting the daily needs of households for food, fruit, fibre, medicine, etc., (Dev et al., 2019). Agroforestry is also contributing significantly to the preservation of the resource base and an increase in overall productivity in rainfed areas, particularly in dry and semi-arid regions. Increasingly, agroforestry is being used to concentrate on reorienting priorities in fields including renewable energy, food and nutritional security, gender equality, employment creation, carbon sequestration, biodiversity restoration and farm productivity optimization. Around 1,023 mha are occupied by agroforestry systems and practices worldwide, which range from simple cattle and pastoral systems used for sustenance to shifting cultivation, backyard gardens, and alley cropping (Kumar et al., 2017). In India Agroforestry covers around 25.32 million ha, which is 8.2 % of the total geographic area (Dagar et al., 2014).

There is a significant opportunity to expand agroforestry in India to a total of 53.23 mha (17.5 % of the country), which will come from groves, fallows that can be farmed, cultivable fallows, degraded land, and wasteland (CAFRI, 2015).

Agroforestry for Food and Nutrition Security

Since the country's independence, its food output has multiplied many times, but recent advancements in the food supply have not been enough to meet the country's growing population's nutritional needs. One solution in this area is agroforestry, using the right combinations of tree, crop, and legumes. The various agroforestry systems offer the diversification options that are needed to boost food security and serve as a safety net against production declines that may occur during drought and other stressful conditions. Agroforestry also offers nutritional security due to its diverse production methods, which include, in addition to the farmers' usual food crops, fruit, vegetables, legumes, oilseed crops, medicinal and fragrant plants. Urbanization and economic expansion in the nation have grown quickly, providing farming communities with previously unheard-of opportunity to expand beyond subsistence farming and start delivering goods to the urban population. The subsistence needs of households are being gradually met by agroforestry goods like timber, fruit, food, fibre, fodder, medicine, and others, while also laying the groundwork for increased and sustained productivity. As a result, agroforestry systems give farmers the chance to boost farm output and diversify their sources of income. The findings of research conducted in the country's many agroclimatic areas indicate that, while agroforestry systems offer a wide range of financial returns, such returns are often substantially higher than those from continuously growing unfertilized food crops. Improved nutrition and health in the home are possible benefits of agroforestry, especially when women are the primary breadwinners. Crop diversification has been found to be aided by agroforestry. The communities' nutritional security might be guaranteed by the diversity of the fruits and vegetables produced by agroforestry systems. Agroforestry may have higher productivity because it captures more growing resources, such as light and water, or because the soil is more fertile. *Populus deltoides*, a common plant in agroforestry systems in the Upper Indo-Gangetic area, serves as the greatest illustration. Poplar was the greatest option since it grows quickly, gets along with other crops like wheat and has industrial uses. As a result, agroforestry based on poplar (Populus spp.) in northern India advanced quickly. Due to their huge market potential, woodlots of other quickly growing trees like *Eucalyptus species*, *Leucaena leucocephala, Casuarina equisetifolia, Acacia mangium,Acacia auriculiformis,* Ailanthus, teak, and *Melia dubia* are also growing in popularity among farmers in various parts of the nation (Ali et al., 2023).

Agroforestry for the Production of Fodder

In arid, semi-arid, and hill environments, trees and shrubs frequently give a significant amount of leaf fodder during the lean season through lopping/pruning of trees, also known as top feed. The production of leaf fodder is influenced by the species, beginning age, lopping frequency and intensity, and agroclimatic conditions. The silvipastoral system is the most suitable type of land use for degraded areas. In order to stabilize the vegetation and maintain rangelands' production, top feeds are also thought to be crucial **(**Dhyani, 2003). They are crucial for providing shade for grazing animals and acting as windbreaks. The two most significant are *Albizia lebbeck* and *Prosopis cineraria*. For desert and semi-arid areas, there are a variety of *Acacia species, Leucaena leucocephala, Dalbergia sissoo, Ailanthus excelsa, Azadirachta indica, Acacia leucopholea*, etc.; for hilly areas, there are Grewia optiva, Morus alba, Celtis australis, Albizia, Oaks, Ficus, etc. Feeding *Ficus religiosa* in combination with Panicum to the maximum extent possible can increase feed intake, weight gain, digestibility, and nutrient utilization. It can also be used in diet mixtures up to 75 % of the dry matter fed (Bamikole et al., 2003). *Prosopis juliflora*, *Acacia nilotica*, and *Tamarix articulata* are the most promising trees for silvipastoral systems on alkali soils, while *Leptochloa fusca*, *Chloris gayana*, and *Brachiaria mutica* are the most suitable grasses. In a four-year period without the use of fertiliser or amendments, *Leptochloa fusca* and *Prosopis juliflora* produced 46.5 t ha^{-1} green feed (Dagar et al., 2001).

Agroforestry for Soil and Water Conservation and Soil Improvement

One of the main sustainability concerns is maintaining the productivity of the soil resource, which is where agroforestry comes into play. Closely spaced trees on slopes prevent soil erosion by water in two ways: first, by acting as a physical barrier of stems, low branches, superficial roots, and leaf litter against flowing water; and second, by serving as locations where water infiltrates more quickly due to generally better soil structure under trees than on surrounding land. Agroforestry systems on arable lands envision growing trees and woody perennials on terrace risers, terrace edges, field bunds, as intercrops and as alley cropping in the shape of hedge row planting. Integrating trees on the fields acts as a natural sump for nutrients from deeper soil layers, adds bio-fertilizer, conserves moisture, and increases system productivity. The most popular method for producing mulch for moisture retention and nutrient recycling on field bunds has been alley cropping with leguminous trees like *Leucaena leucocephala. Leucaena leucocephala* was used as an alley crop to effectively reduce erosion on slopes of up to 30 %. By switching to contour hedge rows for tree management, crop yield loss might be reduced to a minimum. With a concomitant decrease in soil loss, the sediment deposition along the hedge and tree rows increased noticeably. Long term changes in the physical properties of the soil, such as its permeability, water holding capacity, aggregate stability, and soil-temperature regimes, can be achieved by incorporating trees and woody perennials on farmlands. Even though these advancements might be gradual, they ultimately lead to better soil conditions for plant growth. Experimental data paint a very clear picture of how agroforestry systems boost available nutrients and soil organic carbon when compared to planting a single tree or a single crop. One such example is the retention or planting of Khejri trees in grazing land to boost fodder production and to meet requirements for food, fodder, fuel, and small timber. This results in an increase in organic carbon, accessible N, P, and K content over time. After five years, it was also discovered that the soil organic carbon status of surface soil under *Acacia nilotica + Sacchram munja* and *Acacia nilotica + Eulaliopsis binata* had increased. *Acacia nilotica* and *Eulaliopsis binata* were discovered to be suitable for ecofriendly conservation and rehabilitation of degraded lands of the Shiwalik foothills of subtropical northern India. They are conservative but more productive and less competitive with trees. By implementing integrated land use planning with soil and water conservation measures on a watershed level, damaged forests can be restored by afforestation. In the Agrisilviculture growing of *Albizia procera* under various pruning regimes, CAFRI found that the soil's organic carbon grew by 13–16 % from its original values, which was five to six times higher than growing of either a solo tree or a sole crop. In the North Eastern Hill (NEH) region, agroforestry systems have been built using regional resources and conservation-based practices. With the aid of the region's natural resources, suitable alternative land use systems for agriculture, horticulture, forestry, and agroforestry have been developed for nearly identical hydrological behaviour as under the natural system. Runoff was reduced by 98 % under agrihorti-silvipastoral systems, while soil loss was decreased by 99 %. Terrace risers are stabilised and numerous outputs are produced when fine-root system grasses and legumes like *Stylosanthes guyanensis*, *Panicum maximum*, Setaria, and others are grown alongside deep root system fodder trees like alder (*Alnus nepalensis*). An in-depth analysis of the soil chemical properties of the traditional agroforestry system in the northeastern region revealed that, within 10 to 15 years of use, different agroforestry practices (AFP) significantly increased soil pH, OC, exchangeable Ca, Mg, and K, as well as the buildup of available P (Bray's P2 -P). Within 10 to 15 years of the practice of agroforestry, the exchangeable Al, a probable cause of infertility of these lands, completely vanished (Singh et al., 1994 & Dhyani et al., 1994). The use of trees as shelterbelts in places with strong winds or sand movement is a well-known illustration of how improving the microclimate led to better yields. Windbreaks and shelterbelts in India have been shown to increase agricultural output.

Agroforestry for Uplifting Livelihood and Opportunities for Employment

Due to the variety of possibilities and products, agroforestry systems offer prospects for the creation of jobs in rural areas. Agroforestry goods and environmental services play an important part in helping low-income households meet their basic needs while also establishing a foundation for the society's ability to live sustainably. In the recent past, the number of small scale enterprises dealing with wood and wood-based products has significantly increased as a result of the market's increased supply of wood. These businesses have greatly aided in the expansion of farm forestry and promoted agroforestry. Numerous business corporations, limited companies, including ITC, WIMCO, West Coast Paper Mills Ltd., Hindustan Paper Mills Ltd., JK paper Mills Ltd. and other institutions began agroforestry research with the focus on producing better planting material of the fast-growing species with the aim of satisfying the demand of wood based industries. In addition to the current agroforestry practices, there is a huge potential to create 943 million person days of work yearly from the 25.4 Mha of agroforestry land with better agroforestry systems (NRCAF, 2007). It was estimated that the Indian Himalayas alone could produce 5.763 million human days/year of employment and rural development benefits via agroforestry (Dhyani et al., 2005). Since ancient times, sericulture has been practiced in many regions of the nation. A dense Arjun plantation of one hectare can produce between 30,000 and 50,000 rupees in income from Tasar farming, according to information from the Sericulture Directorate of Uttar Pradesh. Agroforestry has room for Tasar sericulture. For the semi-arid Bundelkhand region, where palas (*Butea monosperma*) and ber trees are widely distributed, CAFRI designed a lac-based agroforestry system to help farmers improve their livelihood options. In the area, lac farming was successful during the Katki crop (rainy season). According to preliminary findings, there is a high chance to increase the region's ability to support livelihood through lac farming. Similar opportunities exist for farmers to increase their revenue by harvesting tree resin and gum. For development under agroforestry, CAFRI identified suitable trees for gum and resin in various agroclimatic areas.

Agroforestry for Carbon Sequestration and Mitigating Climate Change

Because of the potential for storing carbon in its diverse plant species and soil, as well as its applicability in agricultural lands and in reforestation, agroforestry is significant as a carbon sequestration approach. When it serves to lessen strain on natural forests, which are the main sinks of terrestrial Carbon, agroforestry can also have an indirect positive impact on Carbon sequestration. Using agroforestry techniques to conserve soil could improve the storage of carbon in trees and soils, which is another indirect method of carbon sequestration. Improved lopping and harvesting techniques, improved wood processing efficiency, improved fire protection and more effective use of burning in both forest and agricultural systems, increased use of biofuels, and increased conversion of wood biomass into durable wood products are all recommended for increasing the Carbon sequestration potential of agroforestry systems. As a result, agroforestry helps agriculture be more resilient by adjusting to and reducing the effects of climate change. Evidence that agroforestry systems in India are a potential land use strategy for increasing and preserving aboveground and soil carbon stocks to combat climate change is just now starting to emerge (Dhyani et al., 2009). Earlier estimates of the average sequestration potential in Indian agroforestry were 25 t C/ha across 96 Mha (Sathaye and Ravindranath, 1998). At the national level, current AFs are predicted to reduce 109.34 million tonnes of CO_2 annually, which may offset one-third (33%) of the entire GHG emissions from the agriculture sector (Ajit et al., 2016). However, the capacity of agroforestry systems as carbon sinks varies depending on the species composition, age of trees, location, local climate conditions, and management regimes (Dhyani et al., 2016).

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 and Van Noordwijk et al. 2004). 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 (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 N2 fixation efficiency suggests that planting of stem cuttings and flooding resulted in greater biological N2 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 litter fall, 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 (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-yearold 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.

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 house hold 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). 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. 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.

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 bioecological 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 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, evapo-transpiration, 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).

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 Promotion Challenges

Many agroforestry technologies have been developed and put to the test during the past three decades by various research organizations. But because of a lack of awareness, poor infrastructure, and lack of legislative backing, the majority of them have not yet reached the farmer's field. Therefore, in terms of technological adoption, the intended effect has not been seen. The primary cause of this is because the agroforestry sector, which contributes to the government sectors of agriculture, forestry, rural development, environment, and trade, is negatively impacted by unfavorable policies, legal restrictions, and a lack of coordination between them. A major obstacle is the lack of proper institutional and legislative frameworks that would offer farmers clear incentives to plant and safeguard trees that support both ecosystem function and rural livelihoods. The biggest barriers to falling, transporting, and marketing agroforestry products are currently existing rules and regulations, which differ from state to state. In order for poor farmers to access loans and other subsidies, agroforestry must be deemed equal to agriculture (Dhyani and Handa, 2013). In places where farmers received incentives in the form of high-quality planting material and a guaranteed market, such as in the case of Poplar, Leucaena, and Eucalyptus, agroforestry technologies have been effective. One of the main worries is the lack of good tree planting material, which needs to be addressed immediately.

Conclusion

The organized research projects conducted over the previous three decades have amply demonstrated the potential of agroforestry for resource conservation, environmental quality improvement, land rehabilitation, and the provision of multiple outputs to meet the daily needs of the rural population. Agroforestry gives potential to utilize synergies across Sustainable Development Goals (SDGs) and deal with the inescapable trade-offs as a platform for balancing agriculture and forestry in their interactions with landscapes, rural livelihoods, and urban lifestyles. Agroforestry has demonstrated its promise as a crucial path to success for millions of farm families, resulting in additional revenue, the creation of jobs, increased food and nutritional security, and the sustainable fulfilment of other basic human requirements. The conversion of barren grasslands and crop land to agroforestry is a huge opportunity as a technique to mitigate climate change and to restore degraded land since it aids in carbon sequestration, makes land productive, and prevents future soil degradation. 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.

References

Ajit. S. K. Dhyani . A. K. Handa . Ram Newaj . S. B. Chavan . Badre Alam . Rajendra Prasad . Asha Ram . R. H. Rizvi . Amit Kumar Jain . Uma . Dharmendra Tripathi . R. R. Shakhela . A. G. Patel . V. V. Dalvi . A. K. Saxena . A. K. S. Parihar . M. R. Backiyavathy . R. J. Sudhagar . C. Bandeswaran . S. Gunasekaran (2016). Estimating carbon sequestration potential of existing agroforestry systems in India. *Agroforest Syst*. DOI 10.1007/s10457-016-9986-z

Ali, S., Vasudev, L. and Tembhurne, B. V. (2023). Agroforestry: A Strategy for Sustainable Agriculture and Livelihood. Strategies for Sustainable Agriculture Edited book by Dr. Yuvraj A. Shinde, 190-196.

Bamikole M. A., Babayemi O. J., Arigbede O. M. and Ikhatua U. J. (2003). Nutritive value of Ficus religiosa in West African dwarf goats. *Animal Feed Science and Technology*., 105(1): 71-79.

Belsky, A.J., Mwonga, S.M. and Duxbury, J.M. (1993). Effects of widely spaced trees and livestock grazing on understory environments in tropical savannas. *Agrofor. Syst*., 24: 1-20.

Bridge, J. 1996. Nematode management in sustainable and subsistence agriculture. Annual Review of Phytopathology, 34: 201-225.

Burton, I., (1987). Report on reports: Our common future: The world commission on environment and development. *Environment: Science and Policy for Sustainable Development*. 29(5): 25-29.

CAFRI, (2015). Annual Report 2014-15. Jhansi. pp.39-45.

CAFRI. (2015). Vision 2050. Central Agroforestry Research Institute, Jhansi, India.

Cannell, M.G.R., Van Noordwijk, M. and Ong, C. K. (1996). The central agroforestry hypothesis: the trees must acquire resources that the crop would not otherwise acquire. *Agrofor. Syst*., 34: 27-31.

Dagar J. C., Sharma H. B. and Shukla Y. K. (2001). Raised and sunken bed technique for agroforestry on alkali soils of northwest India. *Land Degradation and Development*. 12: 107-118.

Dagar, J. C., Pandey, C. B., & Chaturvedi, C. S. (2014). Agroforestry: a way forward for sustaining fragile coastal and island agro-ecosystems. In Agroforestry systems in India: livelihood security & ecosystem services (pp. 185-232). *Springer*, New Delhi.

Das, D.K. and Chaturvedi, O.P. (2008). Root phyto mass recovery and rooting characteristics of five agroforestry tree species in Eastern India. *Journal of Tropical Forest Science*, 20(3): 156–166.

Dev I., Ram A., Bhaskar A. and Chaturvedi, O.P., (2019). Role of Agroforestry in Current Scenario. Agroforestry for Climate Resilience and Rural Livelihood. Scientific publisher (India), Jodhpur, pp.2-10.

Dhyani S. K. (2003). Role of watershed management in improving forage production. Sustainable Animal Production, Pointer Publ. Jaipur, India. Pp.173-207.

Dhyani S. K., Kareemulla K., Ajit and Handa A. K. (2009). Agroforestry potential and scope for development across agro-climatic zones in India. *Indian J. Forestry*. 32: 181-190.

Dhyani S. K., Ram A. and Dev I. (2016). Potential of agroforestry systems in carbon sequestration in India. *Indian J. Agricultural Sciences*. 86(9): 1103–12.

Dhyani S. K., Sharda V. N. and Samra J. S. (2005). Agroforestry for sustainable management of soil, water and environmental quality; looking back to think ahead. *Range Management and Agroforestry*. 26(1): 71-83.

Dhyani S. K., Singh B. P., Chauhan D. S. and Prasad R. N. (1994). Evaluation of MPTS for Agroforestry system to ameliorate infertility of degraded acid Alfisols on sloppy lands. Agroforestry systems for degraded lands, Oxford and IBH Publishing Co.Pvt. Ltd., New Delhi, I: pp.241- 247.

Dhyani, S. K. and Handa, A. K., (2013). Area under agroforestry in India: An assessment for present status and future perspective. *Indian Journal of Agroforestry*. 15(1):1-11.

Droppelmann, K. and Berliner, P. (2003). Runoff agroforestry-a technique to secure the livihood of pastoralists in the middle East. *Journal of Arid Environments*, 54: 571-577.

Epila, J.S.O. (1986). The case for insect pest management in agroforestry research. *Agricultural Systems*, 19: 37·54.

Jose, S. (2009). Agroforestry for ecosystem services and environmental benefits: An overview. *Agrofor. Syst*., 76(1): 1-10.

Kohli, A. and Saini, B.C. (2003). Microclimate modification and response of wheat planted under trees in a fan design in northern India. *Agrofor. Syst*., 58: 109-117.

Kumar, B.M., Nair, P.K.R. (2004). The enigma of tropical homegardens. *Agrofor. Syst*., 61: 135-152.

Kumar, Y., Thakur, T.K. and Thakur, A., (2017). Socio-cultural paradigm of agroforestry in India. *International Journal of Current Microbiology and Applied Sciences*. 6(6) :1371-1377.

Lal, R. 2008. Managing soil water to improve rainfed agriculture in India. Journal of Sustainable Agriculture, 32(1): 51-75.

Lin, B.B. (2007). Agroforestry management as an adaptive strategy against potential microclimate extremes in coffee agriculture. *Agroforestry and Forest Meteorology*, 144: 85-94.

Lin, B.B. (2010). The role of agroforestry in reducing water loss through soil evaporation and crop transpiration in coffee agroecosystems. *Agricultural and Forest Meteorology*, 150: 510-518.

McNeely, J.A. and Schroth, G. (2006). Agroforestry and biodiversity conservation-traditional practices, present dynamics, and lessons for the future. *Biodivers. Conserv.*, 15: 549-554.

Montagnini, F. (2006). Homegardens of Mesoamerica: biodiversity, food security, and nutrient management. In: Kumar B.M., Nair P.K.R. (eds.) Tropical homegardens: A Time-Tested Example of Sustainable Agroforestry. Advances in Agroforestry 3. Springer, Dordrecht, pp. 61-84.

Montagnini, F., Francesconi, W. and Rossi, E. (ed.). (2011). Agroforestry as a tool for landscape restoration. Nova Science, New York. Agroforestry As a Tool for Landscape Restoration. Nova Science, New York.

Nair, P.K.R. (2011). Agroforestry systems and environmental quality: introduction. *Journal of Environmental Quality*, 40(3): 784-790.

Narayana, V.V.D. and Rambabu (1983). Estimate of soil erosion. India. J. Irrigation & Drainage Engineering, ASCE, 19(4): 419-434.

Noble, I.R. and Dirzo, R. (1997). Forests as human-dominated ecosystems. *Science*, 277: 522-525.

NRCAF. (2007). NRCAF Perspective Plan Vision (2025). NRC for Agroforestry, Jhansi.

Pandey, C.B. and Sharma, D.K. (2003). Residual effect of nitrogen on rice productivity following tree removal of Acacia nilotica in a traditional agroforestry system in central India. *Agriculture, Ecosystem & Environment*, 96: 133-139.

Pandey, D.N. (2007). Multifunctional agroforestry systems in India. *Curr. Sci.*, 92(4): 455-463.

Patel, L.B., Sidhu, B.S. and Beri, V. (1996). Symbiotic efficiency of Sesbania rostrata and S. cannabina as affected by agronomic practices. *Biol. Fert. Soils*, 21: 149-151.

Rusch, A., Valantin-Morison, M., Sarthou, J. P. and Roger-Estrade, J. (2010). Biological Control of Insect Pests in Agroecosystems. *Advances in Agronomy*, 109:219-259.

Sathaye J. A. and Ravindranath N. H. (1998). Climate change mitigation in the energy and forestry sectors of developing countries. *Annual Review of Energy and Environment.* 23: 387-437.

Schroth, G. and Sinclair, F.L. (ed.). (2004). Trees, crops and soil fertility. CABI, Wallingford, UK.

Sharma, G., Sharma, R., Sharma, E. and Singh, K. K. (2002). Performance of an age series of alnus-cardamom plantations in the Sikkim Himalaya: nutrient dynamics. *Ann. Bot.*, 89: 273-282.

Singh B. P., Dhyani S. K., Chauhan D. S. and Prasad R. N. (1994). Effect of multipurpose tree species on chemical properties of acid Alfisols in Meghalaya. *Indian J. Agric. Sciences*. 65(5): 345-349.

Steffan-Dewenter, I., Kessler, M., Barkmann, J., Bos, M.M., Buchori, D., Erasmi, S., Faust, H., Gerold, G., Glenk, K., Gradstein, S.R. and Guhardja, E. (2007). Tradeoffs between income, biodiversity, and ecosystem functioning during tropical rainforest conversion and agroforestry intensification. *PNAS*, 104: 4973-4978.

Van Noordwijk, M., G. Cadish, and C.K. Ong (ed.) (2004). Below-ground interactions in tropical agroecosystems: concepts and models with multi-plant components. CABI, Wallingford, UK.

Walsh, M.J. (1999). Maximizing financial support for biodiversity in the emerging Kyoto protocol markets. *Science of Total Environment*, 240: 145-156.

Yadav, R.S., Yadav, B.L. and Chhipa, B.R. (2008). Litter dynamics and soil properties under different tree species in a semi-arid region of Rajasthan, India. *Agrofor. Syst*., 73(1): 1-12.

Yadav, R.S., Yadav, B.L., Chhipa, B.R., Dhyani, S.K. and Ram, M. (2011). Soil biological properties under different tree based traditional agroforestry systems in a semi-arid region of Rajasthan, India. *Agrofor. Syst*., 81(3): 195-202.