THE CURRENT ROLE AND IMPORTANCE OF AGROFORESTRY – A REVIEW ARTICLE

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Abstract. Agroforestry has recently gained attention as it is capable of having multiple outlooks in both economic as well as product- oriented ways, also with its full potential can result in a sustainable life. Agroforestry nowadays can also be called as Integrated Farming System (IFS) as it combines all the systems altogether viz agriculture, horticulture, forestry, animal husbandry, apiculture, pisciculture etc. In recent days the problem of climate change and carbon sequestration, declining food security, improper nutrient cycling in the soils, soil conservation, livelihood improvement of the farmers, biodiversity enhancement all gain utmost priority. But, altogether cannot be solved in a single stretch except Agroforestry. The reason behind this is Agroforestry with its four dimensions namely regulating services, supporting services, cultural services and provisioning services has the potential to solve all these problems at a single stroke. The current area under agroforestry in India is estimated as 25.32 m ha, or 8.2% of the total geographical area of the country which should be increased to meet all the above-mentioned recommendations. The benefits which we get from agroforestry are innumerable. Additionally, substantial extent of areas of unproductive crop, grass, and forest lands as well as degraded lands could be brought under agroforestry. The places which are under the government but not used to its full potential has to be brought under agroforestry for the purpose of not only utilizing the land but also to derive some of the environmental and ecological benefits which it provides. Our knowledge on these issues is unfortunately rudimentary. Until such problems and negotiations are surmounted, the full potential and environmental benefit of the agroforestry will continue to be underappreciated and underexploited.

Keywords: *agroforestry, carbon sequestration, livelihood improvement, food security, nutrient cycling, soil productivity, biodiversity enhancement*

Introduction

Scientifically, growing trees and agricultural crops on the same land, including waste areas, is known as agro-forestry. It modifies the simultaneous production of food, fodder, fuel, timber, and fruit by combining forestry and agriculture. The National Agroforestry Policy (2014) defines agroforestry as a combination of land-use systems which combines trees and shrubs on farmlands and rural landscapes with or without livestock to enhance productivity, profitability, diversity, and ecosystem sustainability. Agroforestry is a collective name for land-use systems and technologies where woody perennials (trees, shrubs, palms, bamboos, etc.) are deliberately used on the same land-management units as agricultural crops and/or animals, in some form of spatial arrangement or temporal sequence.

There are three main types of agroforestry systems:

Agrisilvicultural systems are a combination of crops and trees, such as alley cropping or home gardens.

Silvopastoral systems combine forestry and grazing of domesticated animals on pastures, rangelands or on-farm.

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The three elements, namely trees, animals and crops, can be integrated in what are called agrosilvopastoral systems and are illustrated by home gardens involving animals as well as scattered trees on croplands used for grazing after harvests (*Figs. 1* and *2*).

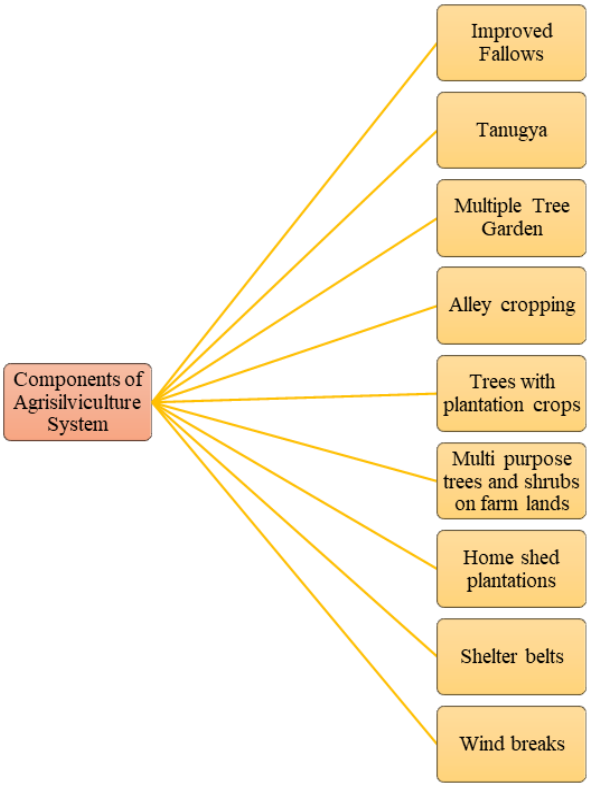

Figure 1. *Components of agri-silviculture system*

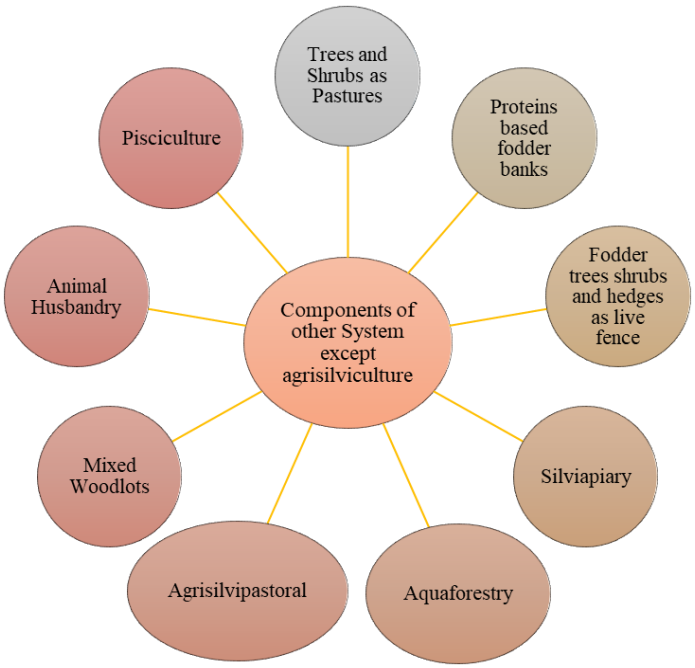

Figure 2. *Components of agroforestry other than agri-silviculture system*

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Agroforestry also plays a very important role in various aspects which gained its potential after the implementation of the third national forest policy in the year 1988, which clearly indicates the all the industries should produce their own raw material. At the same time, it is also clearly defined that 33% of the land area should be under forests. To achieve this mandate, agroforestry is of utmost importance.

In principle, Agroforestry adheres to and promotes most of the agroecological elements as defined by the FAO which can be redefined as shown in *Table 1*.

Table 1. *Agroecological elements which in turn defines agroforestry*

COMPONENTS	COVERAGE
Variety	With trees that support and preserve biodiversity in the agroecosystems, agroforestry increases the diversity of crops and livestock
Co-production and information exchange	Over time, the nation's local agroforestry expertise has grown, and it is mostly recognized for its ethno-forestry techniques and native knowledge systems for cultivating a wide variety of tree species. The goal of recent efforts is to mobilize scientific information about agroforestry systems
Synchronization	Combinations of crops, animals, and trees make for synergistic land-use practices in terms of efficient resource use, nutrient cycling, and the potential to coordinate efforts to mitigate and adapt to climate change. This happens by storing carbon and assisting farmers in managing the risks associated with climate change
Effectiveness	Compared to other agricultural systems, agroforestry has the potential to result in a more closed nutrient cycle, which maximizes nutrient utilization. In comparison to monoculture systems, these systems also exploit solar energy more effectively
Re-pleasing	Nutrient recovery, recycling, and efficient usage are all possible with agroforestry, especially when nitrogen-fixing trees or symbiotic fixers are employed
Fortitude	Agroforestry is an integrated agricultural strategy that improves ecosystem health and biodiversity while diversifying production and income for farmers, strengthening their socioeconomic resilience against climate change
Human and communal ideals	Because of its ecological, social, and economic benefits, agroforestry has been deeply ingrained in human and social ideals for ages. Because it provides fuel wood, fodder, and a close-by food source, women find it alluring because it lessens the need for them to trek far and supports their livelihoods
Customs related to culture and cuisine	Agroforestry increases crop and livestock diversity by utilizing trees that support and preserve biodiversity in agro ecosystems

Materials and methods

The article mainly based on a systematic review about the agroforestry and its components as well as the contributions made by the agroforestry and its components and the impact made by those in the years together. This review pooled together and analyzed information from all the national and international research papers in various journals to extract the comprehensive understanding and qualitative as well as quantitative approach in the field of agroforestry. Last 25 years research papers with

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regards to agroforestry has been used for this review writing in which the important extracts have been taken and oriented in a systematic way for easy understanding of agroforestry and its impacts.

State-wise area coverage of agroforestry

In India, forestry and agroforestry land are about 69.79 (FSI, 2013) and 25 Mha (Dhanya et al., 2013) respectively, out of the total existing geographical area of 305.60 Mha. Agroforestry facilitates the amount of carbon stocking is 532.5 Mt. half of the C stock found in forests is secured by agroforestry, and current research indicates that India's agroforestry area will grow dramatically in the next years. (NRCAF, 2006). Numerous research revealed that the agroforestry system is an incredible method of sequestering carbon, with its effective role being the above-ground storage of carbon biomass (Mukherjee et al., 2015) and also for storing the carbon biomass even in the below the ground (Nair et al., 2010). Although agroforestry has a lot of potential in India, adoption rates are currently slow due to obstacles that prevent it from realizing its full potential. These include inadequate market infrastructure, a lack of high-quality planting materials, transportation and processing of wood, inadequate research, and onerous and frustrating laws pertaining to trees (Sharma et al., 2017). By increasing the amount of green cover and providing the necessary raw materials, the agroforestry system is the main factor reducing the pressure on natural forests. Greater potential for improving the local community's environmental and financial returns for substantial agricultural distribution that provides food, fodder, lumber, fuel wood, and fiber for the growing socioeconomic status (Bijalwan et al., 2011). Because tree roots enhance the quality of water absorption and increase beneficial microorganisms, which in turn improve soil nutrient richness, agroforestry systems are land management techniques (Murthy et al., 2013) (*Fig. 3*).

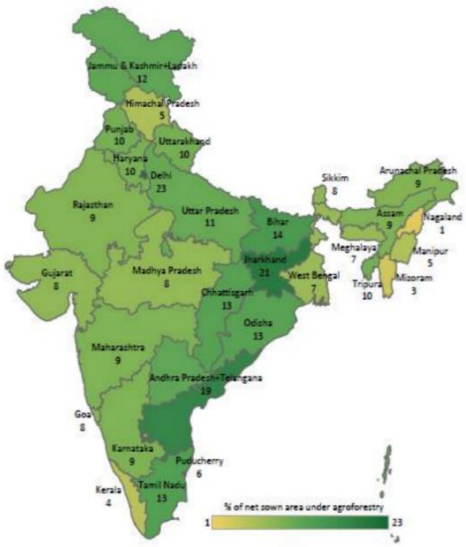

Figure 3. *The state-wise area coverage of agroforestry in India (Source: Newaj et al., 2017)*

Benefits of agroforestry systems

Agroforestry may be able to provide benefits for the environment and the economy. The next section discusses some of the main advantages of keeping agroforestry

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systems in place. Multiple harvests at different times of the year are made possible by the various agroforestry system components. Additionally, it improves the availability of fuel wood, raises food output and hence ensures food security, enhances soil fertility, enhances biodiversity, and benefits animals and ecosystems, among other benefits. Consequently, it lowers the chance of crop failure and guarantees farmers have other sources of income (Pandey, 2007).

Results and discussion

Agroforestry for nutrient cycling and soil productivity

The cycle is made up of system transfers or internal turnover, output from losses, and inputs into gains (World Kisan, 2017). The types of trees and intercrops used in agroforestry, as well as the methods used for management, determine the characteristics of the soil. In addition to offering food, fuel, lumber, fodder, building supplies, raw materials for small-scale forest-based businesses, and other cottage industries, trees can occasionally supplement soil with vital nutrients (Ghosh et al., 2011). In addition to helping to combat climate change and global warming, planting trees and crops can assist to increase or sequester the soil's carbon content. This increased soil carbon can also serve as a significant carbon sink. Problematic soils can also be reclaimed with the aid of agroforestry. According to Jhariya et al. (2013), every type of microbial activity in soil supports the cycling of nutrients and other ecosystem services. The movement of nutrients from one component of a soil ecosystem to another, known as "nutrient cycling," leads to an increase in soil productivity through a variety of microbiological and biological processes. Because of the influence of the trees, the deposition of organic matter, the presence of root exudates, and the varied litter quality, agroforestry improves the microbial activity associated to the soil (Fahad et al., 2022). Using agroforestry techniques to plant trees on farms may be the most effective way to increase soil fertility (Octavia et al., 2023). Rainfall, biological nitrogen fixation, fertilizer application, and residues from outside the system can all contribute to the addition or gain of nutrients. The removal of crops, soil erosion, leaching, volatilization, and other activities can result in nutrient decreases or losses. A system's internal recycling of nutrients, litterfall, root rot, and other processes can all result in nutrient transfers. By increasing the amount of nutrients available to crops, lowering the amount of nutrients lost from the system through leaching and erosion, and increasing the amount of nutrients in the crop root zone, trees in agroforestry moderate the cycle of nutrients (Nair et al., 1979). With the assistance of tree roots, some nutrients that are inaccessible to agricultural crops because they are found in the lower soil depth may be made available to crops at the top layer. Thus, the most significant advantage that trees can have for the soil is an increase in the availability of nutrients and an improvement in soil structure. Because their roots are usually deep and spreading, trees can access and absorb water and nutrients from the deep soil layers, often in areas that are inaccessible to other herbaceous crops or farms. The term "Nutrient Pumping" refers to the process by which the trees in agroforestry systems draw nutrients up from the deeper soil profile and finally deposit them on the surface layers through litter fall and other mechanisms. Compared to high moisture soils, trees in low moisture content soils have deeper root systems and aid in water and nutrient pumping (Makumba et al., 2009; Schroth and Sinclair, 2003; Schroth, 1999). Numerous legumes also establish a symbiotic relationship with the actinomycetes, a group of non-leguminous nitrogen-fixing

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organisms. Free-living soil organisms have an impact on non-symbiotic fixation, which can be important in natural ecosystems with relatively low nitrogen requirements from external sources (Nair, 1993). The soil structure and texture have to be further studied in future to know the effectiveness of the nutrient cycling and the improvement in soil productivity and fertility status.

Agroforestry for carbon sequestration

The net removal of carbon dioxide from the atmosphere and storage of it in the long-lasting pools of trees is known as agroforestry-based carbon sequestration. Both above-ground and below-ground biomass may be found in these ponds. Compared to pastures or field crops, agroforestry systems are thought to have a greater capacity to sequester carbon (Sanchez, 2000; Roshetko et al., 2002; Sharrow and Ismail, 2004; Kirby and Potvin, 2007). This hypothesis is predicated on the idea that adding trees to pastures and croplands would increase both the net amount of carbon sequestered above and below ground (Palm et al., 2004; Haile et al., 2008). Agroforestry systems in India have the potential to sequester an estimated 0.5 to 20 and 0.01 to 0.50 mg of carbon per hectare for crop components and tree cover, respectively, each year. This helps to increase the quality of the yield produced on the same area (Singh et al., 2021). Agroforestry systems, which come in various kinds and are used in various parts of the world, are incredibly effective at counteracting negative impact of climate change by broadening the variety of tree crops, which increases the capacity for sequestering carbon dioxide more than when only one type of crop is grown (Toppo and Raj, 2018).

When compared to non-agroforestry systems, conversion to agroforestry systems produced a much higher C sequestration (+25.34%). Agrihorticulture had the largest mean soil C stock (38.11 Mg C ha^{-1}), + 31.64% greater than in conventional systems (Kumara et al., 2023).

The premise that between 45% and 50% of branches and 30% of foliage dry weight is carbon is the basis for estimates of aboveground carbon sequestration potential (CSP) (Shepherd and Montagnini, 2001; Schroth et al., 2002). There are two ways that carbon can be sequestered in soils: directly and indirectly, according to the Soil Science Society of America (SSSA) (Soil Science Society of America, 2001). Inorganic chemical processes that transform carbon dioxide into soil inorganic carbon molecules like calcium and magnesium carbonates are the direct source of soil carbon sequestration. When plants photosynthesize atmospheric carbon dioxide into plant biomass, indirect plant carbon sequestration takes place. The quality of organic matter is closely related to the turnover of soil organic carbon (SOC) (Agren et al., 1996; Martens, 2000). Based on the amount of soil organic carbon (SOC), the land use systems can be arranged as follows: forests, agroforestry, tree plantations, and arable crops. Due to its ability to store carbon in its many plant species and soil, agroforestry has great promise as a climate change mitigation method (Albrecht and Kandji, 2003; ICAR, 2006). In semi-arid, sub-humid, humid, and temperate climates, the typical carbon absorbed by these activities has been calculated to be 9, 21, 50, and 63 Mg C ha^{-1}. As a result, it can be a practical method for storing carbon in the tropics for small agroforestry systems, where it has been reported to range from 1.5 to 3.5 Mg C ha^{-1} yr^{-1} (Roshetko et al., 2007; Montagnini and Nair, 2004). Agroforestry techniques have been shown to boost top soil carbon stores in degraded subhumid tropical soils by up to 1.6 Mg C ha^{-1} yr^{-1} (Mutuo et al., 2005). The planning and maintenance of agro-forests is crucial to the effectiveness of carbon sinks. The below ground biomass also to be considered very important as

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equal to that of above ground biomass for the calculation of net amount of carbon sequestered in the agroforestry components.

Agroforestry for biodiversity enrichment

Agroforestry systems, which integrate trees into livestock or crop farming operations, have the potential to improve carbon sequestration and mitigate the continuous loss of biodiversity (Pantera et al., 2021). According to Plieninger et al. (2019), farming systems should be acknowledged from the perspectives of regulation and cultural services in addition to the crop production aspect. Indeed, their contribution to soil enrichment, carbon sequestration, biodiversity protection, and landscape beauty has been highlighted in a number of studies (e.g., Santos et al., 2019; Liu et al., 2020). One of the main approaches for meeting the growing demand for high-quality agricultural products while optimizing ecosystem services and minimizing negative environmental effects is agroforestry (Torralba et al., 2016; Arosa et al., 2017; Den Herder et al., 2017; de Jalón et al., 2018; Moreno et al., 2018). Agroforestry has been found to be crucial for both the protection of endangered species and the reduction of species loss in agricultural settings (e.g., Mosquera-Losada et al., 2009; Torralba et al., 2016; Udawatta et al., 2019). One goal of resource efficiency is biodiversity conservation, which supports a variety of functions that are beneficial to human well-being, such as the provision of food and fiber as well as regulating and cultural services.

By boosting habitat and landscape variability, increasing structural complexity, and elevating the overall aesthetic value and vision of the landscape, agroforestry can help conserve biodiversity in agricultural landscapes. The enhancement of biodiversity in upcoming days play a very major role in the conservation of Rare, Endangered and Threatened (RET) species in any agroforestry systems as it is the need of the hour.

Agroforestry for food production

One of the main issues of days is food security. In addition to other interventions, a variety of interconnected agricultural approaches are needed to solve the issue of food and nutritional security. These approaches include bio-fortifying staples, increasing the productivity of staple crops, and cultivating a wider range of edible plants that can produce fruits, nuts, vegetables, and other edibles for a wider variety of diets (Frison et al., 2011). Possibility of expanding the crop portfolio to include staple crops and micronutrient-, fiber-, and protein-rich varieties. Raising yields is crucial when cultivating wild trees because, if native trees are thought to be rather unproductive, staple crops would probably take precedence over other crops in deforested areas, which will decrease agrobiodiversity (Sunderland, 2011). Increased vegetable yields, when combined with fruit, provide diversified and nutritionally balanced diets as opposed to diets based solely on calories (Susila et al., 2012). Agroforests play a critical part in this process. In difficult climates, trees can alter the microclimate for garden vegetables and provide support for climbing plants like yams (Maliki et al., 2012). By combining agriculture, horticulture, floriculture, forestry, and livestock in one unit area, agroforestry has enormous potential to produce food and provide farmers with a variety of food items made from different components. By growing cash crops, vegetable crops, agriculture crops, and forestry trees in combination, this may also give the farmers food on a regular, weekly, monthly, and annual basis, sustaining the overall food supply and boosting food production.

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Quantification of agroforestry services

In the summer, lower the air temperature by 1.5°C to 2°C. Capable of storing 2.33 tons of carbon from 133 trees that carry oil seeds and 245 multipurpose trees and shrubs. (Soil and climatic regulations) as per the practice followed.

Capable of generating 5.92 tons of oxygen on 0.75 acres, 37 kinds of butterflies, 44 varieties of birds and 5 species of animals were observed in the multifunctional agroforestry area. (Floral and faunal diversity) as per the agroforestry practiced in Tamil Nadu (*Fig. 4*).

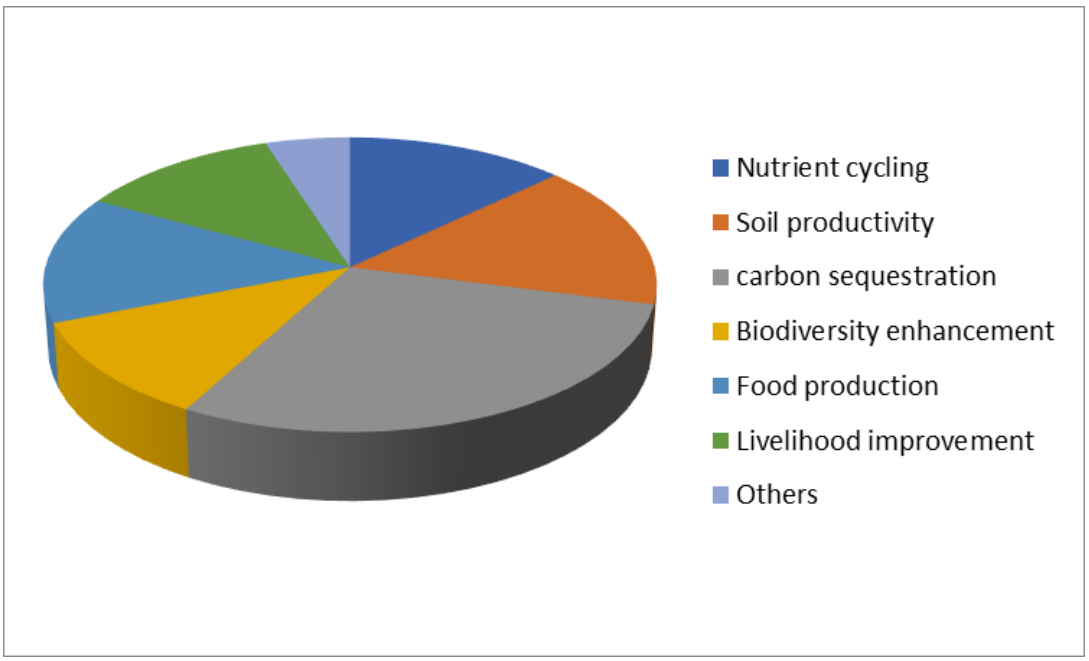

Figure 4. *Contribution of agroforestry systems*

Conclusion

Agroforestry is a scientifically enhanced technique to the farmers to improve the ecological, economic, environmental as well as social status of the community as a whole. The carbon sequestration done in the agroforestry systems cannot be altogether overcome by either planting agriculture or forest trees solely in the field which in turns intensifies the importance of agroforestry in the area of carbon sequestration and mitigating climate change in the future years to come. The food production at the same time is also satisfied by the agroforestry practices where the total or the entire crop failure is nullified and in turn it increases food production to a greater extent. The livelihood status of the farmers also gets increased due to its intermittent income which may be either in the form of daily, weekly, monthly or yearly basis. The soil productivity, fertility and the nutrient cycling also gets very well improved due to the deep-rooted trees present in the agroforestry system which is not at all possible in the either of the systems other than forestry-based farming. The biodiversity also enriches to a very much extent which invites various types of birds, butterflies and animals and serves as a species richness area. The only way forward for agroforestry is that is the awareness, its management techniques and suitable planting materials which should be provided to the farming community (*Fig. 5*).

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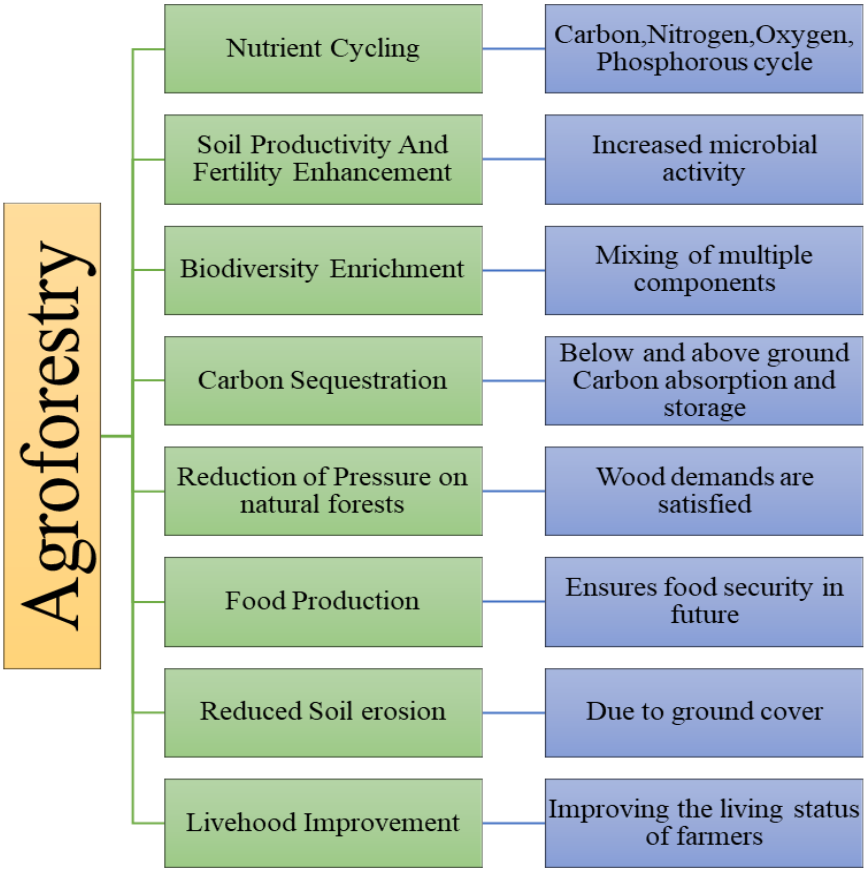

Figure 5. *The primary and secondary roles of agroforestry systems and its positive impacts*

REFERENCES

[1] Agren, G. I., Bosatta, E., Balesdent, J. (1996): Isotope discrimination during decomposition of organic matter: a theoretical analysis. – Soil Sci. Soc. Am. J. 60: 1121-1126.

[2] Albrecht, A., Kandji, S. T. (2003): Carbon sequestration in tropical agroforestry systems. – Agriculture, Ecosystems and Environment 99: 15-27.

[3] Arosa, M. L., Bastos, R., Cabral, J. A., Freitas, H., Costa, S. R., Santos, M. (2017): Long-term sustainability of cork oak agro-forests in the Iberian Peninsula: a model-based approach aimed at supporting the best management options for the Montado Conservation. – Ecol. Model. 343: 68-79.

[4] Bijalwan, A., Sharma, C. M., Kediyal, V. K. (2011): Socioeconomic status and livelihood support through traditional agroforestry systems in hill and mountain agro-ecosystems of Garhwal Himalaya. – Indian For. 1423-1431.

[5] De Jalón, S. G., Graves, A., Palma, J. H., Williams, A., Upson, M., Burgess, P. J. (2018): Modelling and valuing the environmental impacts of arable, forestry and agroforestry systems: a case study. – Agrofor. Syst. 92: 1059-1073. doi: 10.1007/s10457-017-0128-z.

[6] Den Herder, M., Moreno, G., Mosquera-Losada, R. M., Palma, J. H., Sidiropoulou, A., Freijanes, J. J. S., et al. (2017): Current extent and stratification of agroforestry in the European Union. – Agric. Ecosyst. Environ. 241: 121-132.

[7] Dhanya, B., Viswanath, S., Purushothaman. S. (2013b): Decomposition and nutrient release dynamics of Ficus benghalensis L.—litter in traditional agroforestry systems of Karnataka, southern India. – International Scholarly Research Notices. https://doi.org/10.1155/2013/524679.

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DOI: http://dx.doi.org/10.15666/aeer/2205_39073918

[8] Fahad, S., Chavan, S. B., Chichaghare, A. R., Uthappa, A. R., Kumar, M., Kakade, V., Pradhan, A., Jinger, D., Rawale, G., Yadav, D. K., Kumar, V. (2022): Agroforestry systems for soil health improvement and maintenance. – Sustainability 14(22): 14877.
[9] Frison, E. A., Cherfas, J., Hodgkin, T. (2011): Agricultural biodiversity is essential for a sustainable improvement in food and nutrition security. – Sustainability 3: 238-253.
[10] FSI (2013): State of Forest Report. – Forest Survey of India, Ministry of Environment, Dehradun, India.
[11] Ghosh, S. R., Wadud, M. A., Mondol, M. A., Rahman, G. M. M. (2011): Optimization of plant density of Akashmoni (Acacia auriculiformis) for production of fuel wood in the bunds of crop land. – J. Agrofor. Environ 5(2): 1-6.
[12] Haile, S. G., Nair, P. K. R., Nair, V. D. (2008): Carbon storage of different soil-size fractions in Florida silvopastoral systems. – J. Environ. Qual. 37: 1789-1797.
[13] ICAR (2006): Handbook of Agriculture. 5th Ed. – Indian Council of Agricultural Research, New Delhi.
[14] Jhariya, M. K., Raj, A., Sahu, K. P., Paikra, P. R. (2013): Neem—a tree for solving global problem. – Indian Journal of Applied Research 3(10): 66-68.
[15] Kirby, K. R., Potvin, C. (2007): Variation in carbon storage among tree species: implications for the management of a small-scale carbon sink project. – For. Ecol. Manage. 246: 208-221.
[16] Kumara, K., Pal, S., Chand, P., Kandpal, A. (2023): Carbon sequestration potential of agroforestry systems in Indian agricultural landscape: a meta-analysis. – Ecosystem Services 62: 101537.
[17] Liu, X., Bakshi, B.R., Rugani, B., de Souza, D.M., Bare, J., Johnston, J.M., Laurent, A. and Verones, F., 2020. Quantification and valuation of ecosystem services in life cycle assessment: Application of the cascade framework to rice farming systems. *Science of the Total Environment*, *747*, p.141278. DOI: 10.1016/j.scitotenv.2020.141278.
[18] Makumba, W., Akinnifesi, F. K., Janssen, B. H. (2009): Spatial rooting patterns of gliricidia, pigeon pea and maize intercrops and effect on profile soil N and P distribution in southern Malawi. – African Journal of Agricultural Research 4(4): 278-288.
[19] Maliki, R., Cornet, D., Floquet, A., Sinsin, B. (2012): Agronomic and economic performance of yam-based systems with shrubby and herbaceous legumes adapted by smallholders. – Outlook on Agriculture 41: 171-178.
[20] Martens, D. A. (2000): Plant residue biochemistry regulates soil carbon cycling and carbon sequestration. – Soil Biol. Biochem. 32: 361-369.
[21] Montagnini, F., Nair, P. K. R. (2004): Carbon sequestration: an underexploited environmental benefit of agroforestry systems. – Agroforestry Systems 61: 281-295.
[22] Moreno, G., Aviron, S., Berg, S., Crous-Duran, J., Franca, A., de Jalón, S.G., Hartel, T., Mirck, J., Pantera, A., Palma, J.H. and Paulo, J.A., 2018. Agroforestry systems of high nature and cultural value in Europe: provision of commercial goods and other ecosystem services. Agroforestry systems, 92, pp.877-891. doi: 10.1007/s10457-017-0126-1.
[23] Mosquera-Losada, M. R., McAdam, J. H., Romero-Franco, R., Santiago-Freijanes, J. J., Rigueiro-Rodróguez, A. (2009): Definitions and Components of Agroforestry Practices in Europe. – In: Rigueiro-Rodróguez, A., McAdam, J., Mosquera-Losada, M. R. (eds.) Agroforestry in Europe. Springer, Dordrecht, pp. 3-19. DOI: 10.1007/978-1-4020-8272-6_1.
[24] Mosquera-Losada, M.R., Santiago-Freijanes, J.J., Rois-DíAz, M., Moreno, G., den Herder, M., Aldrey-Vázquez, J.A., Ferreiro-DoMínguez, N., PAnTerA, A., PisAnelli, A. and Rigueiro-Rodríguez, A., 2018. Agroforestry in Europe: A land management policy tool to combat climate change. Land use policy, 78, pp.603-613. doi: 10.1016/j.landusepol.2018.06.052.
[25] Mukherjee, A., Banerjee, S., Nanda, M. K., Sarkar, S. (2015): Microclimate study under agroforestry system and its impact on performance of tea. – J. Agrometeorol. 10(1): 99-105.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2205_39073918

[26] Murthy, I. K., Gupta, M., Tomar, S., Munsi, M., Tiwari, R., Hegde, G. T., Ravindranath, N. H. (2013): Carbon sequestration potential of agroforestry systems in India. – J. Earth Sci. Clim. Change 4(1): 1-7.
[27] Mutuo, P. K., Cadisch, G., Albrecht, P. C. A., Verchot, L. (2005): Potential of agroforestry for carbon sequestration and mitigation of greenhouse gas emissions from soils in the tropics. – Nutrient Cycling in Agroecosystems 71: 43-54.
[28] Nair, P. K. R. (1979): Agro forestry research: a retrospective and prospective appraisal Proc. – Int. Conf. International Cooperation in Agro Forestry. ICRAF Nairobi, pp. 275-296.
[29] Nair, P. K. R. (1993): An Introduction to Agroforestry. – Kluwer Academic Publishers. Netherlands.
[30] Nair, P. K. R., Kumar, B. M., Nair, V. D. (2010): Agroforestry as a strategy for carbon sequestration. – J. Plant Nutr. Soil Sci. 172: 10-23.
[31] Newaj, R., Rizvi, R.H., Chaturvedi, O.P., Alam, B., Prasad, R., Kumar, D. and Handa, A.K., 2017. A country level assessment of area under agroforestry and its carbon sequestration potential. Technical bulletin, 2(2017), pp.1-48. ICAR-Central Agroforestry Research Institute, Jhansi.
[32] NRCAF (2006): Perspective Plan-Vision 2025. – NRCAF, Jhansi.
[33] Octavia, D., Murniati, Suharti, S., Hani, A., Mindawati, N., Suratman, Swestiani, D., Junaedi, A., Undaharta, N. K. E., Santosa, P. B., Wahyuningtyas, R. S. (2023): Smart agroforestry for sustaining soil fertility and community livelihood. – Forest Science and Technology 19(4): 315-328.
[34] Palm, C. A., Tomich, T., van Noordwijk, M., Vosti, S., Alegre, J., Gockowski, J., Verchot, L. (2004): Mitigating GHG emissions in the humid tropics: case studies from the alternatives to Slash-and-Burn Program (ASB). – Environ. Dev. Sust. 6: 145-162.
[35] Pandey, D. N. (2007): Multifunctional agroforestry systems in India. – Current Science 92: 455-463.
[36] Pantera, A., Mosquera-Losada, M. R., Herzog, F., Den Herder, M. (2021): Agroforestry and the environment. – Agroforestry Systems 95(5): 767-774.
[37] Plieninger, T., Torralba, M., Hartel, T., Fagerholm, N. (2019): Perceived ecosystem services synergies, trade-offs, and bundles in European high nature value farming landscapes. – Landsc. Ecol. 34: 1565-1581. DOI: 10.1007/s10980-019-00775-1.
[38] Roshetko, J. M., Lasco, R. D., Angeles, M. S. D. (2007): Small holder agroforestry systems for carbon storage. – Mitigation and Adaptation Strategies for Global Change 12: 219-242.
[39] Roshetko, M., Delaney, M., Hairiah, K., Purnomosidhi, P. (2002): Carbon stocks in Indonesian homegarden systems: CAN smallholder systems be targeted for increased carbon storage? – Am. J. Alt. Agr. 17: 125-137.
[40] Sanchez, P. A. (2000): Linking climate change research with food security and poverty reduction in the tropics. – Agric. Ecosyst. Environ. 82: 371-383.
[41] Santos, M., Carvalho, D., Luis, A., Bastos, R., Hughes, S. J., Cabral, J. A. (2019): Can recreational ecosystem services be inferred by integrating non-parametric scale estimators within a modelling framework? The birdwatching potential index as a case study. – Ecol. Indic. 103: 395-409. DOI: 10.1016/j.ecolind.2019.04.026.
[42] Schroth, G. (1999): A review of belowground interactions in agroforestry, focusing on mechanisms and management options. – Agroforestry Systems 43: 5-34.
[43] Schroth, G., Sinclair, F. L. (2003): Trees, Crops and Soil Fertility Concepts and Research Methods. – CABI Publishing. UK, USA.
[44] Schroth, G., D'Angelo, S. A., Teixeira, W. G., Haag, D., Lieberei, R. (2002): Conversion of secondary forest into agroforestry and monoculture plantations in Amazonia: consequences for biomass, litter and soil carbon stocks after 7 years. – For. Ecol. Manage. 163: 131-150.

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DOI: http://dx.doi.org/10.15666/aeer/2205_39073918

[45] Sharma, P., Singh, M. K., Tiwari, P., Verma, K. (2017): Agroforestry systems: opportunities and challenges in India. – J. Pharmacog. Phytochem. SP-1: 953-957.
[46] Sharrow, S. H., Ismail, S. (2004): Carbon and nitrogen storage in agroforests, tree plantations, and pastures in western Oregon, USA. – Agroforest. Syst. 60: 123-130.
[47] Shepherd, D., Montagnini, F. (2001): Carbon sequestration potential in mixed and pure tree plantations in the humid tropics. – J. Trop. For. Sci. 13: 450-459.
[48] Singh, V., Johar, V., Kumar, R., Chaudhary, M. (2021): Socio-economic and environmental assets sustainability by agroforestry systems: a review. – Int. J. Ag. Env. Biotech. 14(4): 521-533.
[49] Soil Science Society of America (2001): Carbon Sequestration: Position of the Soil Science Society of America (SSSA). – SSSA, Madison, WI. www.soils.org/pdf/pos_paper_carb_seq.pdf (accessed: Jan 20, 2008).
[50] Sunderland, T. C. H. (2011): Food security: why is biodiversity important? – International Forestry Review 13: 265-274.
[51] Susila, A.D., Purwoko, B.S., Reyes, M.R. and Palada, M.C., 2011. Vegetable agroforestry systems in Indonesia (No. Indonesian TMPEGS SANREM-CRSP 2009). Bogor Agricultural University.
[52] Toppo, P., Raj, A. (2018): Role of agroforestry in climate change mitigation. – J. Pharmacog. Phytochem. 7(2): 241-243.
[53] Torralba, M., Fagerholm, N., Burgess, P. J., Moreno, G., Plieninger, T. (2016): Do European agroforestry systems enhance biodiversity and ecosystem services? A meta-analysis. – Agric. Ecosyst. Environ. 230: 150-161.
[54] Udawatta, P. R., Rankoth, L., Jose, S. (2019): Agroforestry and biodiversity. – Sustainability 11: 2879.

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DOI: http://dx.doi.org/10.15666/aeer/2205_39073918