Ecological Advancements and Developments of Agroforestry

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ARTICLE INFO	ABSTRACT
	Agroforestry is a conventional method of land use that could help to address agricultural environmental issues. In order to take advantage of the ensuing ecological and economic interactions, agroforestry is the technique of consciously integrating woody vegetation (trees or shrubs) with crop and/or animal systems. According to recent studies, the global agri-food industry may reach more sustainable methods of producing food and fiber by adopting agroforestry techniques and principles more widely. This would benefit farmers economically and would benefit society as a whole in terms of the environment. Agroforestry promotes eco-intensification based on resource efficiency and offers a wide range of provisioning, regulating, cultural, supporting ecosystem services, and environmental advantages. In this review, we discussed agroforestry with its advantages and developments.

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Introduction

Agroforestry is a land use pattern which includes intentional growing of woody perennials along with agricultural crops or animals on the same piece of land in spatial or temporal arrangement for economical or ecological benefits ensuring an interaction between woody and non-woody components (Torquebiau, 2000). The definition figures out some key points such as i) agroforestry involves more than one species of plant, ii) the cycle of this system is more than one year, iii) the system is complex in nature, iv) agroforestry ensures multiple outputs. Although it's not the perfect definition for the term agroforestry but it's the most widely accepted. All agroforestry system must possess three vital attributes. These are i) productivity: all agroforestry system should increase productivity of the land such as increased yield or increased soil fertility etc., ii) Sustainability: the system should be able to sustain the improvement of soil fertility and the environment, iii) adoptability: the system must be accepted by farmers (Nair,1993). Poplar-wheat intercropping was observed by (Kanzler et al. 2019) to considerably lower wind speed in the system, raise nighttime temperature, and decrease daytime temperature. Compared to sole-cropping, agroforestry systems can withstand more harsh climate events like temperature changes but significantly reduce light and throughfall (Niether et al., 2018). According to (Yang et al. 2021), PAR and temperature were lower in poplar with alfalfa and

jujube with wheat intercropping compared to monoculture. Farmers' desire to plant agroforestry systems is typically poor due to a lack of income information and suitable species-matching suggestions. However, the benefits of agroforestry systems in improving field microclimate have been well shown (Yang et al., 2021).

In this review, we discuss all aspects of agroforestry in brief. People can take an overall knowledge of its advantage and disadvantage from this review. We discussed how to spread agroforestry to make a sound environment.

History

The history of agroforestry is ancient. The practice started a few thousand years ago with human burning a piece of land followed by cultivating it. It is now known by slash and burn cultivation technique. However, the term 'Agroforestry' was first coined by John benny and his team in 1977 as a part of research of International Development Research Centre (IDRC) of Canada. This study paved the way of establishment of ICRAF (International Council for Research in Agroforestry). ICRAF played a vital role in conducting research on agroforestry worldwide and funding them. In 1991 the Council changed its name to International Centre for Research in Agroforestry. From 2002 ICRAF obtained the tag of "World Agroforestry"

indicating its leadership in the field of agroforestry research and development worldwide. Now a days ICRAF works for invention of modern technologies and disseminate them among farmers (King,1987; Nair 1993).

Classifications

Agroforestry system can be classified into five major categories according to dominance of its components. These are i) Agrosilviculture: in this system agricultural products are main component while woody plants are secondary component, ii) Silvoagriculture: Taungya or Shifting cultivation is the typical example of this system where woody components play major role and agricultural components are secondarily integrated, iii) Silvopasture: in this system trees are vital component and pastures are accessory component such as grazing forests, iv) Pastoral silviculture: grazing lands are suitable example for this system in which pastures are main element and woody plants are accompanying element, v) Agrosilvopasture: it is the summation of agricultural crops, woody plants and pastures where crops along with trees play authoritative role on pastures, vi) Silvoagropasture: in this system woody plants, agricultural component and pastures are pooled together where woody plants are prevalent component over other components (Atangana et al., 2014). According to the arrangement of components agroforestry system can be classified into two major categories i) spatial arrangement: It is the deliberate growing of trees with crops on same piece of land such as alley cropping, ii) Temporal arrangement: Shifting cultivation is a typical example of this. The land is cultivated for 2 to 4 years and then its left fallow for natural vegetation to regenerate.

Advantages of agroforestry

Agroforestry provide considerable advantage to environment as well as economy (Jose, 2019). As agroforestry includes trees and crops where leaves of trees fall to the ground and adds nutrients (Dossa et al.,2008). Many trees including agroforestry produce food for humans as well as animals (Table 1). The trees are deep rooted while the crops are usually shallow rooted. So, crops can utilize nutrients only from the top or upper portion of the soil column. But trees roots reach to the deep portion of soil column and uptake nutrients. These nutrients are recycled by litter fall and brought back to the surface soil (Nair, 2011). Agroforestry system including leguminous trees can add nitrogen to soil as leguminous plants can fix atmospheric nitrogen by symbiotic association with *Rhizobium* bacteria. In a study it was found that integration of poplar trees in agroforestry system has doubled the availability of nitrogen in soil by 7 kg N ha^{-1} $year^{-1}$ (Thevathasan & Gordon,2004). It has been scientifically proved that agroforestry can increase soil organic carbon (SOM). Extensive root system of woody plants serves as source for soil organic carbon in deeper layers of soil (Kell, 2012). Agroforestry system in cropland adds 3 to 1.5 times higher Carbon in soil through roots than shoots (Johnson et al.,2006).

A study conducted on soil plough depth (0-23 cm) in the presence of trees as an alley crop shows that SOM increased by 5300 kg ha^{-1} on an average (Pardon et al.,2017). Agroforestry also manifests to higher productivity. On the basis of the land equivalent ratio (LER) a few studies provide evidence to this phenomenon. A study conducted in Denmark shows that agroforestry systems requires 14-34% less input (light, water, nutrients etc.) than monoculture and the LER of the agroforestry system is 1.24-1.34 (XU et al.,2019). An experiment of silvoarable agroforestry system LER ranges from 1.3-1.6 (Lovell et al.,2018). Soil biota is very diverse including bacteria fungi, algae, protozoa, nematode etc. the abundance of these organisms depends on quality and quantity of litter, enzymatic activity, availability of nutrients (Lacombe et al.,2009). About 70% studies states positive relation between agroforestry system and soil microbial population while only 2 studies imply to negative association (Sollen et al.,2020). This establishes a positive role of agroforestry in increasing soil biodiversity. Microbes are known as decomposers. All kind of organic matter in soil is decomposed by microbial population of soil. Along with decomposition nutrients also releases and aids in nutrient cycling (Nair et al.,1999).

Table 1. Trees produce food for agroforestry systems.

Common Name	Species	Edibility	Principle Uses in Agroforestry
Cashew	*Anacardium occidentaIe*	Flowers, seeds	Garden, fence, pasture
Soursop	*Annona muricata*	Flowers	Garden, fence, pasture
Borassus-	*Borassus aethiopicum*	Multiple food uses	Garden, pasture
Pigeon Pea	*Cqjanis cajan*	Seed, leaves	Hills, nitrogen fixation, fuel, hedgerow
Papaya	*Carica papaya*	Flowers	Garden, quick shade
Chaya	*Cnidoscolus chayamansa*	Leaves	Rapid hedge
Coconut	*Cocos nucifera*	Multiple food uses	Pasture, roadside, construction
Coffee	*Coffea arabica*	Seeds (bean)	Hedges, hills, fuel
Mother of Cacao	*Gliricidia sepium*	Flowers	Living fence, feed, fuel
Leucaena	*Leucaena leucocephala*	Leaves	Hills, alley cropping, nitrogen fixation
Cassava	*Manihot esculenta*	Roots, leaves	Rapid hedge
Drumstick	*Moringa pterygosperma*	Leaves, flowers, pods	Fence, garden
Cocoa	*Theobrama cacao*	Pulp, seeds	Understory tree, pasture
Guava	*Psidium guajava*	Flowers	Pasture, fuel
Katuk	*Sauropus androgynus*	Leaves	Hedge, alley cropping
Izota	*Yucca elephantipes*	Flowers	Hedge
Jujube	*Ziszyphus mauritiana*	Flowers	Erosion control, fuel

Earthworms are known as natural plough as it stirs the soil and increases porosity. In agroforestry systems of France, the abundance of earthworms is considerably high than lands under monoculture (Barea et al., 2005). Agroforestry reduces soil erosion and increase soil water holding capacity by litter fall. The leaves of trees serve as mulching material and reduce evapotranspiration (Figure 1). Also, the leaves act as a physical barrier to run off water. Increased soil organic matters help to hold soil moisture (Sepúlveda & Carrillo,2015). Trees of agroforestry system also provide shading effect which increase humidity and reduce soil temperature as well as evapotranspiration (Schwendenmann et al.,2010). Today's one of burning topic is climate change and global warming. Agroforestry is a possible way of combating this global issue. Trees can be planted like border plants and this will help in reducing the amount of greenhouse gas like carbon dioxide (Toppo & Raj,2018).
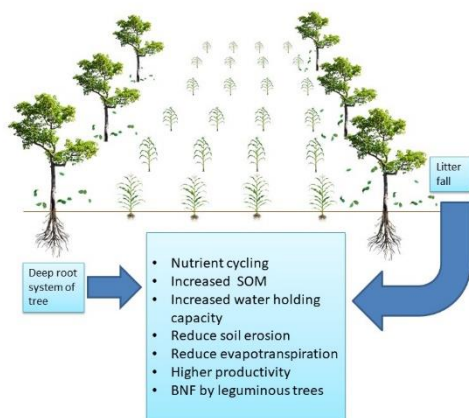

Figure 1. Role of agroforestry in agriculture and soil.

Disadvantages of agroforestry

There are some disadvantages of agroforestry too. The component of agroforestry like tree and crop affects growth of each other by interspecific competition. Tree and crops compete for light, nutrient, water etc. Through shading effect trees can reduce number of grains per spike up to 35% and grain weight up to 16% in durum wheat (Dufour et al.,2013). For nutrients, both components compete if the root system explores same depth of soil. Maize, red oak or black walnut plant's root extends up to 30 cm of soil in a dense manner. So, the yield of maize is reduced by 35% and yield of red oak or black walnut reduced by 33% as a result of nutrient competition between them (Jose et al.,2004). Allelopathic relation of many plants with crops can impose disadvantage. For example, black walnut, pecan, eucalyptus etc. secrete some kind of allelochemicals which inhibit the growth of any other plants near them (Devi, 2017).

Major challenges for today's Agroforestry are the adoption of agroforestry system by farmers. There are several reasons behind the low adoption rate of agroforestry over monoculture. Farmers do not want to pay higher amount of money for agroforestry purpose with a view to environmental benefits. In Germany 65.1% of the taxpayers are willing to invest in agroforestry while 82.1% believe it's the duty of government to take care of the environment (Otter & Langenberg,2020). So, it's easily understandable that there's a lack in public awareness in environmental conservation. Lack of capital, marketing facilities, technical knowledge among farmers are also vital reason for lower adaptability (Nouman et al.,2008). Implementation of new farming technologies comes with higher cost of production. Agroforestry system needs laborers which either cuts down manpower for crops or adds more money to production cost. In addition, Agroforestry products' profitability is still a big concern for growers (Graves et al.,2017). Research conducted on agroforestry is too limited and often there's a scarcity of data to prove hypotheses regarding the benefits of agroforestry.

Future works

The future work of agroforestry involves further research and practical implementation to solve the challenges. A study showed that community-level agroforestry adoption could be successful by conducting farmers' needs assessments and restoring farmers' confidence. It is necessary to focus on strengthening the capacity of farmers which greatly affect the adoption of agroforestry system. This may include involving the farmers in extension projects on farm-level plantation awareness campaigns and building their capacity through community engagement (Ullah et al., 2022).

The olive tree (Olea europaea L.), most widely-planted tree crop in Italy, which is covering an area of 1.16 million ha. For preventing soil erosion and soil degradation and to increase biodiversity green mulching in olive orchards has been increasingly recommended and adopted in recent decades. Preservation and the maintenance of attractive olive landscapes can play great roles in tourism. Growing alfaalfa in wide-spaced (i.e. 5 m x 10 m) olive orchards in Tuscany, it was observed that the nutritive value of the alfalfa was unaffected by the trees despite lower yields than in open field conditions.

Asparagus, a well-known perennial crop, can help reduce soil erosion by agroforestry system. By minimizing the administrative barriers associated with tree management on farm land adoption and maintenance of agroforestry can be promoted (Paris et al., 2019).

The naturally regenerating woodlots could be converted into high-value agroforestry systems by using conventional silvicultural practices. It gives supportive policies for selling farm-grown timber. Currently, the regulatory regime around the sale of farm-grown timber is highly expensive and difficult to navigate.

Tree selection is the most important factor in the agroforestry system. Such as high-density hedgerows of nitrogen-fixing trees have many benefits. Addressing terrace-based agroforestry can maximize the production of tree products on small landholdings. Research is needed to find the best way to arrange new species into existing terrace-based agroforestry.

To examine optimal spatial and temporal arrangement of trees, crops and livestock more research is needed including silviculture trials. It is necessary to pay attention on policy and regulatory barriers to the sale of farm-grown timber to remove disincentives in farm-tree growing (Cedamon et al., 2018).

The timely adoption of agroforestry is an important matter, that can improve the effectiveness of the agroforestry program. So, it is essential to motivate farmers for early adoption. Forestry extension agents can engage the less educated farmers in informal educational campaigns about the benefits of agroforestry in crop productivity. Village farmers can be motivated by establishing functional community-based organizations such as VDCs (Village Development Committees). The government could take necessary steps for the tenant farmers and establish a policy for them so tenure insecurity may not affect their timely adoption of agroforestry. Finally, the household head's age-related factors positively impact farmers' timely adoption of agroforestry. Thus, the government could ask the help of old farmers in the diffusion of agroforestry (Ullah et al., 2023).

The mulberry-dykes and fishponds agroforestry system (MFS), developed through the centuries as a result of a flood control system to protect Huzhou city from recurring floods. MFS is not only related to the cultural heritage or as an example of adaptation and mitigation, but also to it has great effect in reducing flood risk. To protect this unique agroforestry system development of adequate and specific planning instruments is necessary (Santoro et al., 2022).

Government of developing countries should provide incentives to farmers in order to encourage them for adopting agroforestry system. Extension services should introduce modern technologies among farmers. Research and studies of agroforestry should be encouraged by providing funds.

Conclusion

Agroforestry is the road to sustainable agriculture. Agroforestry provides a lot of benefits including nutrient recycling, carbon sequestration, soil conservation, better productivity any many more. Agroforestry encouragement is a relatively low-cost choice when it comes to enhancing rural living and mitigating the effects of climate change. By varying diets, agroforestry may improve food security in addition to its benefits for the environment. In this paper, we highlighted the overall of agroforestry with its advantages and disadvantages. Students can easily understand the purpose of agroforestry. We also talk about future initiatives in this area, which points to upcoming agroforestry research. It is high time for challenges in the path of agroforestry to be addressed.

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