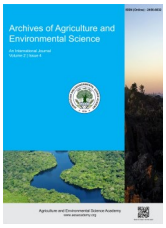
Archives of Agriculture and Environmental Science 6(1): 87-99 (2021)
https://doi.org/10.26832/24566632.2021.0601012

e-ISSN: 2456-6632

This content is available online at AESA

Archives of Agriculture and Environmental Science

Journal homepage: journals.aesacademy.org/index.php/aaes



REVIEW ARTICLE

Agroforestry for mountain development: Prospects, challenges and ways forward in Nepal

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ARTICLE HISTORY

Received: 11 January 2020
Revised received: 05 March 2021
Accepted: 19 March 2021

Keywords

Agroforestry system
Institution and policy
Land use
Livelihoods
Value chain

ABSTRACT

Most of the agroforestry systems (AFS) in Nepal are traditional, and deliberate management of trees, crops and livestock as an integrated and interactive agroecosystem, albeit its enormous socio-economic and ecological benefits, is limited. The objective of this review paper is to understand the prospects, analyze challenges and suggest practical solution for promoting agroforestry as a viable system balancing economic, social and environmental concerns. We develop this paper based on practical experience on the ground and an in-depth review of relevant literature and highlights the prospects, challenges and ways forward of AFS, both farm-based and forest-based, in Nepal. Nepal has enormous agroecological diversity, suitable land availability for agroforestry, traditional knowledge, skill and labor forces, and huge prospects of adapting new technologies and developing market systems, especially considering emerging markets for developing remunerative and environment friendly value chains. However, the prospective value chains of the mountain agroforestry products face many challenges, including i) socio-economic constraints of the farmers mainly because of high initial adoption costs, limited information on benefit-cost of agroforestry practices, limited knowledge on full benefits of agroforestry, and limited markets and marketing information; ii) institutional constraints because of unclear policy to support agroforestry, the lack of extension services and undefined administrative boundaries; and iii) inadequate scientific knowledge, expertise and technologies to address management complexity of agroforestry system. We therefore suggest having a scan of those challenges and find out solutions, especially for promoting growth and competitiveness of the sector with poverty reduction strategy ensuring availability of food, fuel, fodder and employment opportunity for local communities. The paper provides a few successful cases of AFS and finally suggests ways forward to promote AFS and a business model which could help achieve the untapped potentials for enhancing income and employment opportunity, achieving food and nutrition security, and building sustainable land use systems.

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Citation of this article: Atreya, K., Subedi, B.P., Ghimire, P.L., Khanal, S.C., Charmakar, S., & Adhikari, R. (2021). Agroforestry for mountain development: Prospects, challenges and ways forward in Nepal. *Archives of Agriculture and Environmental Science*, *6*(1), 87-99, https://dx.doi.org/10.26832/24566632.2021.0601012

INTRODUCTION

Agriculture is the backbone of the Nepalese economy. Over 60% of the population of the country depends on agriculture, resulting 27% of the gross domestic product (Dhakal, 2020) and it is quite obvious that the livelihood and household food

security of rural Nepalese farmers is highly dependent on farmers access to the trees and natural resources (Cedamon *et al.*, 2017; Khatiwada *et al.*, 2017). Farmers follow different farming practices according to traditional knowledge, land suitability and configuration of holdings, existing infrastructure (e.g., irrigation facilities, road networks), and cultural and household needs. The combinations of these factors make complexity of the farming systems and integrated agricultural practices with the management practices of adjacent forested lands. Planting trees on farmland is a tradition for Nepalese farmers, especially hills and mountains, and because of this, many land-use systems and associated practices are present. Farmers combine the management of woody perennials (e.g., trees, shrubs, bamboos) on the same management unit as agricultural crops and/or animal husbandry. Nepalese farmers maintained the number of trees per farm on an average 15 in the eastern hills, and 53 in the western hills (Amatya and Newman, 1993). Variations occur in terms of spatial arrangement or temporal sequence. These practices are grouped and identified as agroforestry systems, and characterized by various ecological and economical interactions between the components. Agroforestry systems and practices differ by the socio-economic conditions of farmers and ecology (Subedi *et al.*, 2018). This includes variations in culture, elevation, aspect, soil type and slope, which have a powerful influence on the system practiced. The direct benefits derived from the various agroforestry systems include timber, fodder, fruit, livestock, non-timber forest products (NTFPs), and agricultural crops. There are also indirect ecological benefits and the beneficiaries' range from local to global.

There is some evidence that agroforestry systems, under certain circumstances, are more profitable than forestry or agriculture alone, and efforts are being made to develop suitable agroforestry technologies (Lehmann *et al.*, 2020; Liu *et al.*, 2018). These have helped farmers to improve their livelihoods options. Unfortunately, there are no specific plans to encourage agroforestry research and development in the mountains of Nepal. Similarly, although there are many examples of ecologically and economically promising agroforestry practices, these practices have not yet sufficiently documented for dissemination among potential beneficiaries. Present efforts are unfocused on the needs of local farmers and other stakeholders. This is despite the existence of government legislation, policy statements and strategic plans including Master Plan for Forestry Sector (1989), Agriculture Development Strategy (2015-2035), the Agriculture Policy (2004), the Forest Act (1993), the Forest Regulation (1995), Forest Strategy (2016), Forest Policy (2019), National Agroforestry Policy (2019) and the periodic plans, which have emphasized rural development through sustainable natural resources management, agroforestry interventions, and the domestication and promotion of non-timber forest products (NTFPs) for enterprise development. We have observed very little effort in implementing programs that promote and replicate good agroforestry practices. In 2019, Nepal government has endorsed National Agroforestry Policy and Nepal became the second country globally after India having the national policy on agroforestry (Connell, 2020).

Asia Network for Sustainable Agriculture and Bioresources (ANSAB) has also been actively working for promoting agroforestry in Nepal and the South Asia region. It has closely worked with International Council for Research in Agroforestry (ICRAF) and the Government of Nepal for the development of Agroforestry Policy in Nepal, and with SAARC Agroforestry Center and other regional institutions for development of regional level programs. It includes the promulgation of Kathmandu Declaration on Agroforestry (2015) and SAARC Resolution on Agroforestry (2016) to develop a regional program on Agroforestry for SAARC countries, and launching of the National Agroforestry Policy of Nepal. ANSAB also had accomplished some projects that explored existing agroforestry systems, and identified the most promising practices in Nepal. Most of the agroforestry systems identified are traditional, and we found minimum progress on the deliberate management of trees, crops and livestock as an integrated and interactive agroecosystem. Agroforestry, although an ancient practice of land use, Association of Temperate Agroforestry (re) defined it as the *intentional* combinations of trees with crops and/or livestock that involve intensive management of the interactions between the components of integrated agroecosystems.

Through in-depth review of literature and ANSAB's own experiences, this paper briefly highlights the prospects and challenges of agroforestry systems in Nepal. It also provides a few cases of successful agroforestry systems and finally suggests ways forward for the progress of agroforestry systems in Nepal, which could help to reduce poverty through better employment opportunity and livelihoods security and build sustainable land use systems. The study would help to advance agroforestry research and development through achieving the untapped potentials of agroforestry systems and enhance livelihoods generating income and employment opportunity, securing food and nutrition, and building sustainable land use systems. There are several land-use problems in the countries around the world (Figure 1), and agroforestry can play a significant role to minimize those problems. However, it needs emphasis that despite agroforestry's role in addressing the major land-use problems and issues in developing and industrialized regions, the relative importance of the issues in the two major regions are in somewhat opposite directions (Nair and Garrity, 2012).

Significance of agroforestry

The establishment of International Council for Research in Agroforestry (ICRAF) in 1977, which is at present known as World Agroforestry and the launch of the international peer-reviewed journal—Agroforestry Systems–in March 1982 show the importance of agroforestry as an accepted discipline of scientific study on 'land use crisis' (Lundgren, 1982). There are many benefits of agroforestry (Figure 2). Significant numbers of literature on the importance of agroforestry are available in both the tropical and temperate regions.In 2014, the journal—Current Opinion in Environmental Sustainability (Volume 6)—devoted a special issue on agroforestry systems' sustainability

with a focus on Africa. Likewise, another journal—Agriculture for Development (Volume 28, 2016)–published by Tropical Agriculture Association also devoted a special issue on agroforestry. We can group global literature on the benefits of agroforestry systems into two: ecological benefits and socio-economic benefits. Ecological benefits of agroforestry systems included are carbon sequestration, biodiversity conservation, soil enrichment, and maintenance of clean air and water quality (Jose, 2009; Santoro *et al.*, 2020). For example, meta-analysis of global agroforestry systems observed the capacity of tree roots on the reduction of chemical fertilizer residues in soil by 20% to 100% and that of chemical pesticides leaching and runoff by 90% (Pavlidis and Tsihrintzis, 2018).

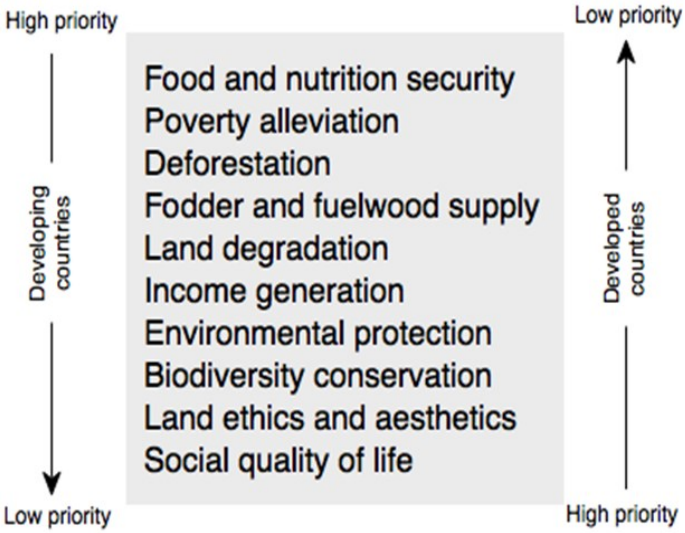

Figure 1. *The major land-use problems in developing and developed world (Modified: Nair and Garrity, 2012).*

Similarly, another global review of 86 papers (Feliciano *et al.*, 2018) on the carbon sequestration potential of agroforestry systems found the highest annual carbon sequestration rate for transition from grassland to silvopastoral system (4.38 tC/ha), followed by transition from underutilized land to home garden (3.8 tC/ha); however we found varied estimates with climate, and time since the land use change and the previous land use.

Likewise, enhanced livelihood security and employment opportunity through agroforestry systems are a few examples of the socio-economic benefits. Livelihood is a function of employment, trading of material, sale of labor, home garden, food processing, livestock production, and cultivation or use of natural property resources. The adoption of agroforestry practices in Nepal have shown increased households' income. For example, Neupane and Thapa (2001) estimated higher returns (US$1582/ha) from adopting agroforestry practices compared to non-adopting households (US$804/ha). Tree-based agroforestry practices also bring opportunities for rural development through promoting agroindustry and improving local economies by reducing unemployment. For example, local community especially women group, in Malakheti village, Kailali district allocated land for cultivation of lemongrass within the community forest and each household had received NPR 3500 annually by selling the lemongrass to the nearby distillation plant (ANSAB, 2008). The adoption of agroforestry practices thus has multifold benefits that improve the quality of local livelihood, ecosystem services and build local farmers resilient to climate change. These benefits and services provided by agroforestry systems occur over a range of spatial and temporal scales-farm scale to landscape scale to global scale so that diverse society can enjoy the benefits of agroforestry systems (Jose, 2009).

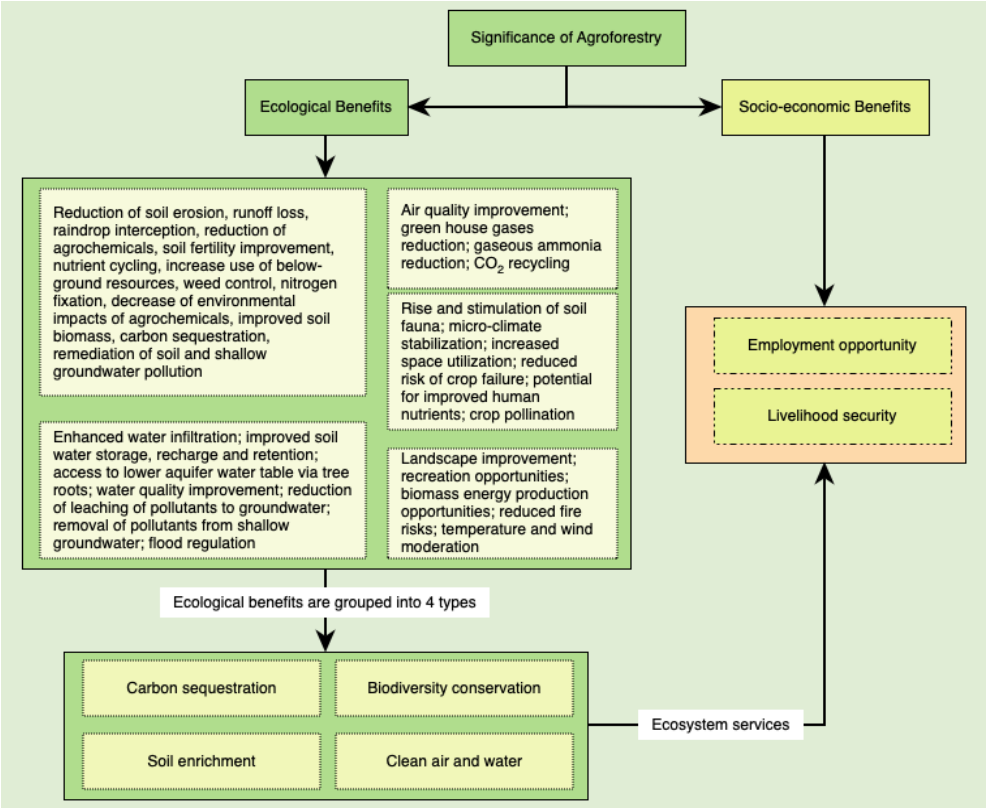

Figure 2. *Benefits of agroforestry in mountain sustainability.*

Existing agroforestry systems

Although we see a complexity in the classification of agroforestry systems, most of the classification approaches are for the identification of different types of agroforestry, grouping them based on the similar characteristics and arrange the information about respective agroforestry for efficient communication (Sinclair, 1999). However, there is no clear-cut agroforestry classification system that fulfill all the ongoing agroforestry practices in all ecological regions of the globe (Nair, 1987). Various classification systems have been emerged and basis of those classification was mainly dependent upon the objectives of the agroforestry practices. At present, most of the classification of agroforestry systems are based on the structural component - where the arrangement of agroforestry components is the main focus; and functional - where the roles or outputs of the agroforestry components are the main focus. In some cases, specific systems are also designed based on environmental adaptability and agroecological zonation as well as socio-economic and management level. Amatya *et al.* (2018) has provided a comprehensive categories of agroforestry system mainly developed based upon the traditional classification (Figure 3).

Prospects of agroforestry system in Nepal

Availability of land and resource base

Table 1 provides the land use and land cover dynamics of Nepal over the years. The area of cropland changes over the years is minimal, however forest cover change dynamics over the past 50 years was dramatic. As the country has a large portion of farmland, forestland, abandoned, barren land, and non-forested shrub land (Table 1) suitable for agroforestry practices; we see a tremendous prospect of agroforestry system in Nepal. National forest cover was 38% of the total area of Nepal in the 1970s, but rapidly reduced to 29% in the 1990s (Paudel *et al.*, 2016) and recovered recently. Though the estimates differ by studies, the coverage of forest was in between 39-46% (Chen *et al.*, 2014; Lei *et al.*, 2017; Uddin *et al.*, 2015) in the year 2010; and 43.1% in the year 2014 (Reddy *et al.*, 2018). The recent national level forest resource assessment by the Department of Forest Research and Survey under the Ministry of Forests and Environment has estimated 40.36% of forests cover and additional 4.38% of other wooded land (canopy cover 5-10%) cover, totaling 44.47% of the total land area of Nepal (DFRS, 2015). Approximately 83% of the total forest are outside the Protected Areas. The forest cover is maximum in the Middle Mountains (37.80%), followed by High Mountains and High Himal (32.25%), Siwalik (23.04%), and Terai (6.90%) (DFRS, 2015). Land degradation because of fragile geographical structure, deforestation, overgrazing, unsustainable agricultural practices, industrialization is a major challenge in Nepal. The extent of land degradation in Nepal is very high (Table 2). Nearly 10% of cropland, 36% of forest and 37% of rangeland are in degraded condition (MoEST, 2008; Devraj *et al.*, 2019; Chalise *et al.*, 2019). Approximately 46% of the total land area is prone to water erosion, 4% is prone to wind erosion, and 2% is prone to chemical and physical degradation (Acharya and Kafle, 2009); and agroforestry systems, especially planting native and naturalized tree species such as *Prunus cerasoides* (Paiyu), *Choerospondias axillaris* (Lapsi) and *Melia azedarach* (Bakaino) could restore the ecology of the degraded land in the mid-hills of Nepal (Jha, 2016).

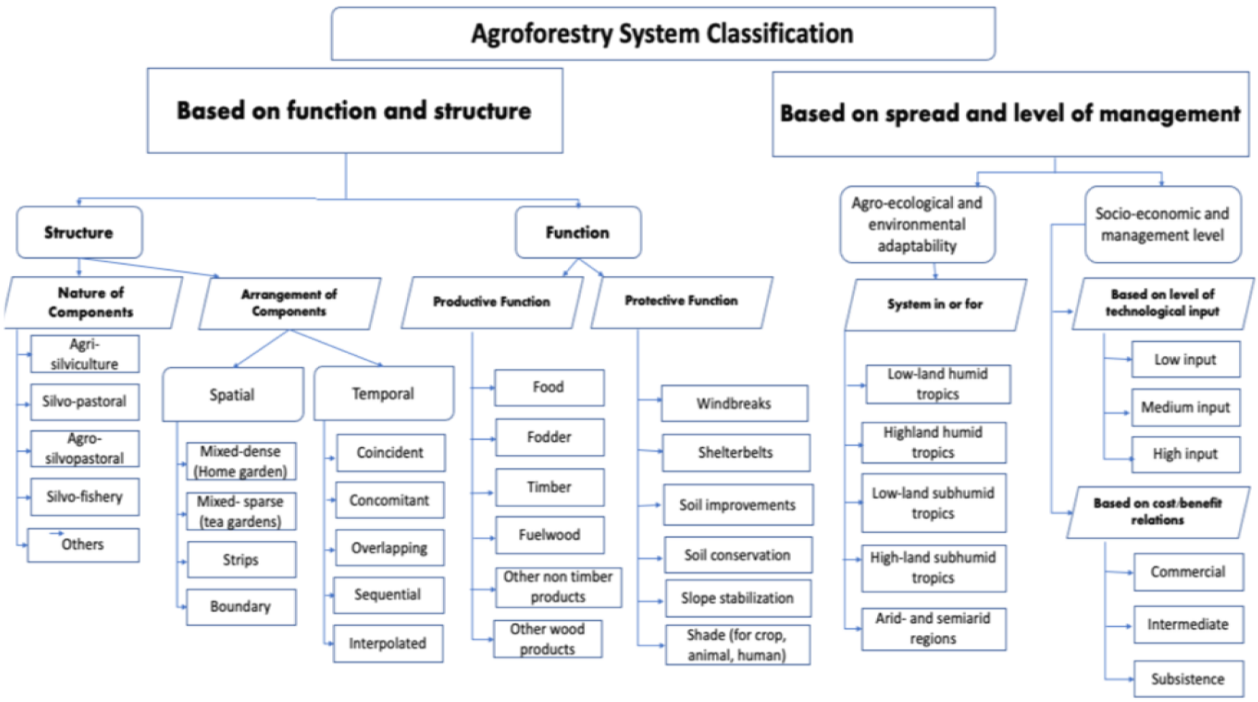

Figure 3. *Classification of agroforestry system (Source: Amatya et al., 2018).*

Table 1. Land use and land cover statistics of Nepal.

Land use	Changes in the land use and land covers of Nepal during 2010 and 2014 (%)				
	Year 1978/79 (LRMP, 1986)	Year 2010			Year 2014 Reddy *et al.* (2018)
		Uddin *et al.* (2015)	Lei *et al.* (2017)	Chen *et al.* (2015)	
Forest land	38.01	39.1	40.66	45.63	43.1*
Cropland	27.19	29.83	25.01	30.64	28.2
Grassland	11.54	7.90	10.77	18.01	9.1
Snow/glacier cover	3.59	8.20	5.53	3.64	7.9
Other land use (urban land, shrub land)	19.67	14.97	18.03+	2.08	11.7**
Total	100	100	100	100	100

+ Sum of shrub land (8.68%), barren land (7%), wetland (2%), and artificial surface (0.35%); * Sum of core forest area [land >1ha, and >10% canopy cover (26.8%)], plantation (5.7%), tropical scrub (2.0%), subtropical scrub (2.7%), temperate scrub (2.1%) and alpine scrub (3.8%); ** Sum of barren land (10.7%), water bodies (0.6%), and settlement (0.5%).

Table 2. Land area under degradation in Nepal.

Land use category	Degraded area (million ha)	Total land area (million ha)	% of degraded land
Forest (poorly managed)	2.1	5.828	36.02
Agriculture (poorly managed sloping terraces)	0.290	2.969	10
Pasture and rangeland	0.647	1.75	37
Flood and landslides damaged area (1984-2003)	0.106	11.551	0.92
Forest encroachment	0.119	5.828	2.04
Nepal	3.262	11.551	28.24

Source: MoEST (2008)

Agroecological diversity

Nepal is the 'micro-museum' of world climate, ranging from subtropical to arctic within a short 150 to 250 km north-south distance; and there is a great variety of micro-climate - both resulted diverse land use and agroecological diversity. Nepal has three ecological regions: the terai, the hills and the mountains and 12 agroecosystems (Joshi *et al.*, 2020). Despite such climatic diversity, agriculture largely based on traditional practices, and in such case adoption of agroforestry may provide high returns.

Rich in traditional knowledge and skills

For many years, the national agricultural and forestry plans had been less supportive for the promotion of agroforestry in the country. Farmers through long-term experience with nature, over centuries, with trial and error, have developed indigenous knowledge and local practices maintaining crop-tree-animal interaction (Thapa *et al.*, 1995; Thapa *et al.*, 1997; Jacobi *et al.*, 2016). Applying such traditional knowledge and skills, farmers have adopted climatic and geographically suitable tree species in the agricultural land to meet their basic needs of food including milk, fodder and fuelwood since ancient time. Traditional knowledge and practices are being recently recognized in the conservation and management of natural resources, governing socio-ecological resilience against the changing climate, and local adaptive management (Berkes *et al.*, 2000; Tengö *et al.*, 2014; MoSTE, 2015). Nepal Government also observed the importance of traditional knowledge and practices (MoSTE, 2015) and thus emphasized the use of community-based traditional skills, knowledge and practices at local level planning and development, especially in the local adaptation plan for actions (LAPA).

Increasing domestic and international markets for specialty products

Opportunities exist by establishing the national/international market linkages to enable specialty products of the agroforestry systems for selling more readily and at competitive prices. However, the levels of logistic requirements, quality assurance, price premium and competition differ according to the markets. Not only government has now favored these markets through policy changes, also a few innovative farmers (for example, Prem Lama, Ashapuri Organic Farm, crop-based agroforestry system) and community forest user groups (example - handmade paper, Dolakha, forest-based NTFPs) have already started cultivating such products and selling into those market segments. Many enterprises are emerging in forest-based agroforestry systems in Nepal. Agroforestry systems can provide raw materials for such small-scale enterprises such as saw milling, carpentry, wood carving, basket-making, handmade-paper, medicinal plants, essential oils, and bio-briquette. In addition, there is a possibility to incorporate value chain and landscape approaches into agroforestry systems because, not only climatic factors such as temperature and precipitation but also market may determine the opportunity for agroforestry systems.

For example, in 1964, because of increased demand and premium prices for cardamom, farmers in the eastern hills of Nepal started cardamom-based agroforestry practices. Himalayan Alder (Utis – *Alnus spp.*) is the chief shade providing trees used in large cardamom (*Amomum subulatum* Roxb.) - based traditional agroforestry systems. Both Alder and cardamom grow well on moist and degraded land, and do not compete with other crops for land use. The most favorable environmental conditions for *A. nepalensis* exist in central Nepal in the north-west facing slopes; whereas for *A. nitida* they are in western Nepal (Rana *et al.*, 2018). Future distribution of these species determined by the precipitation during the warmest quarter (for *A. nepalesis*) and the driest quarter (for *A. nitida*). At present, about 24% of the total area of Nepal is suitable for the species—the central region is the most suitable, whereas the western region has a dispersed distribution suitability. The future species distribution in the hilly region will remain unchanged and most favored along the river valleys, however predicted a northward shift under the future climate change (Rana *et al.*, 2018). Such data on the *Alnus* species is essential for adaptive responses and preventive measures for the sustainable management of agroforestry tree species; however, there is a lack of data on the future distribution of the cardamom species. The *queen of spices* or *black gold*, the cardamom is the world's third-most expensive spice crop, which comprises 7% of agricultural exports from Nepal, and nearly 70% of the world market (cited in DiCarlo *et al.*, 2018). Despite lower productivity compared to other countries, it fetches a higher price grown in the hilly region. About 67,000 households are engaged in cardamom farming nationwide. The annual production is about 6600 metric tons contributing over US $20 million to the national economy.

We see many international companies to buy specialty products; however, all value chain actors have to comply with a set of standards conserving landscape and improving local livelihoods. For them, trust, authenticity, and quality are more important (Gold *et al.*, 2004). We can achieve this through third party certification. Organic certification of the farm and forest land, Forest Stewardship Certification (FSC) of the community forest, Certified Wildlife Friendly to protect rare, threatened and endangered wildlife species has already been in operation in the country. In Nepal, over 80 community forests (12,282 ha) have already received FSC-certification (Bhattarai *et al.*, 2020) and the area under certification is increasing. Nepal government has recently (March 2020) endorsed FSC National Forest Stewardship Standard, that has encouraged the value chain actors for specialty products. Likewise, 9,361 hectares of agricultural land (0.2% of total agricultural land) and 24,422 ha wild collection and beekeeping areas have been organic certified. Similarly, 398 ha (15.2%) coffee farm of 2618 ha of total coffee area is under organic certification (Willer *et al.*, 2020).

Specialty coffee-based agroforestry system is one of the most potential systems in Nepal, which can contribute to the national goal of social and environment friendly growth with poverty reduction strategy. There is a huge potential of extra income from practicing inter-crops at coffee farm. In a study, inter-cropping ginger in the coffee farm resulted in higher annual net returns (NPR 51,683 from inter-cropping vs. 34,190 from only coffee) per hectare. Similarly, coffee and banana proved to be the best among tested inter-crops that resulted to net returns of NPR 61,774 per hectare. Similarly, shade trees in the coffee farm can also provide extra incomes if they belong to fruit trees, leguminous species, or ecosystem services (for example, increased soil fertility). In the coffee-based agroforestry system, only coffee gets the premium at present, and other inter-crops which are normal commodity, if organically certified, can also get premium. There is a tremendous scope to cultivate inter-crops and shade trees and make them available to the specialized market niches.

Increasing consumer awareness and demand of organic vegetables

Over the past decade, the demand of organic vegetables is increasing in Nepal, mostly in major cities, with increased public awareness on health, however, field level adoption of organic farming practices is so far limited (Bhatta *et al.*, 2009; Pokhrel and Pant, 2009; Bhattarai, 2019). Regarding growing vegetables and fruits and fodder trees on farmland, home garden-based agroforestry system has a great value to local environment and people's livelihoods (Gautam *et al.*, 2009; Rana *et al.*, 2018; Sunwar *et al.*, 2006). This farming practice occurs near to the homestead and provides farmers with increased diversity in their food crops. In Nepal, 72% of households have traditional home gardens. However, they are small (<11% of agricultural landholdings), and we found limited policy favoring home gardens. Home garden-based agroforestry system contributes to about 44 to 60% of the vegetables and fruits demands of the total meal in a household in Nepal (Sthapit *et al.*, 2006). It is also a climate-resilient practice that increase crop diversification of nutritious food, increase income, and enhance micronutrients intake and reduce poverty (Ferdous *et al.*, 2016; Galhena *et al.*, 2013; Talukder *et al.*, 2014). We see a great possibility of transforming traditional home garden to a more systematic home garden-based agroforestry system, including structural characteristics, functions, ecosystem services and biodiversity in rural areas of Nepal for enhancing the resilience of the system against not only to the climate change but also to the rapid changes in the modern technology and global economy. In addition, there is an opportunity exists to grow vegetables as inter-crops within the certified coffee and tea farm and fetch the premium national and international markets.

Possibility of NTFPs cultivation in the forests land

The plantation of NTFPs in forest stands is a recently started agroforestry system, and it has a significant potential in Nepal. This practice came into commercial level through USAID/BDS-MaPS project (where ANSAB was responsible for cultivation and sustainable management of NTFPs), especially in western Terai from 2004, which facilitated the cultivation of lemon grass, citronella and palmarosa; and Chiraito (*Swertia chirayita),* Lokta (*Daphne bholua*) and Argeli (*Edgeworthia gardneri)* in mid-hills and mountains, in open areas of community forests; and

large cardamom (*Amomum subulatum*) in the moist area under *Alnus nepalensis* forests in community-managed forests in the hills. Mostly landless poor communities are benefiting from the practice, which focuses on generating income opportunities. For example, in Baitadi district, the contribution of NTFPs income on the total household incomes was up to 90% (Bista and Webb, 2006). This practice has not only helped to increase employment but also to conserve forests, since local people are vigilant in guarding against illegal activities. Although the practice (tree species and NTFPs) has not yet proven successful on a large scale, there is an expectation that it will play a significant role in the generation of income for the poor and landless people of rural communities. Ingram *et al.* (2016) mentioned that NTFPs are critical to the livelihoods of approximately 1.4 billion poor people, contributing about 20-25% of annual household income of people living in and near forests in developing countries. In Nepal, studies had estimated significant share of income from NTFPs especially for the poor and marginalized households. About 80 % of the rural population depend on the NTFPs for their livelihood, and NTFPs have commercial, socioeconomic and environmental values in rural communities in Nepal. Out of 700 recognized NTFPs in Nepal, 150 species are commonly used in international trade (Shrestha *et al*., 2020). However, there are raised concerns on the unsustainable harvesting and management of NTFPs and their depletion (Pandit and Thapa, 2004). We see the possibility of cultivation of NTFPs in the community forests without tree cover that can address poverty and conservation issues.

Multipurpose high value trees species for timber, human nutrition, and fruits

We found the management of multipurpose trees and shrubs on farmland to be the most common practice in the hill areas. The utilization of multipurpose trees, like *Alnus nepalensis*, serves to enhance the organic content of the soil and to fix nitrogen. Different *Ficus* species provide fodder for livestock. Farmers have been planting some fodder trees on their land to meet their fodder demand. There are possibilities of generating additional income by identifying and promoting fast growing and high value crop and tree species. This emphasizes primarily on the tree production as the first choice, and secondarily on the inter-crops or livestock production. The multipurpose high value tree species found in Nepal in the agroforestry systems are, for example, *Ficus* spp., *D. sissoo*, *Bauhinia* spp., *Acacia catechu*, *Artocarpus lakoocha*, *Cassia siamea* and *Albizia lebbeck* in the Terai region; and *Bauhinia spp. Albizia procera*, and *Alnus nepalensis* in the hills. We see tremendous opportunity (high social acceptance and favorable climate) of integrating high value tree species into the existing traditional agroforestry system especially for enhancing livestock nutrition, human nutrition, and timber and fruits harvest. Most times, the focus of traditional agroforestry systems was on introducing trees on arable land, however, we see the developmental possibility of introducing inter-crops under high value tree systems such as apple orchards, tea and coffee plantation, community forests and other private forest plantation.

Challenges for the development of agroforestry system in Nepal

Dhakal (2013) suggested a range of factors including social, biophysical, demographic and institutional, and policy influencing the adoption of agroforestry intervention. Pattanayak *et al.* (2003) documented 21 variables explaining adoption of various types of agroforestry practices are in use at different geographic locations and grouped them into five broad categories: preferences, resource endowments, market incentives, biophysical factors and risk. Despite a brighter prospect of agroforestry systems, Neupane *et al.* (2002) and Dhakal and Rai (2020) found minimum adoption rate in Nepal. There are many challenges for this, but broadly we explained the challenges for the development of agroforestry system in Nepal in the following sub-headings: (i) socio-economic constraints of the farmers, (ii) policy and institutional constraints, and (iii) management complexity of agroforestry system itself.

Socio-economic constraints of the farmers

The socio-economic status of a household/farmer determines the adoption of agroforestry practices. The initial high adoption costs of agroforestry system, limited information on the benefit-cost of the agroforestry practices, unawareness of the farmers on the full benefits of agroforestry systems, and limited markets and market information on the agroforestry-based products are a few bottlenecks hindering the adoption of agroforestry systems in Nepal.

High adoption costs of agroforestry system

The initial cost to introduce suitable agroforestry practices is higher because it needs technical knowledge, quality planting materials, and other infrastructure according to land size, geographical condition and existing and potential market demand. Interestingly, so far in Nepal, the agroforestry initiatives have targeted resource-poor farmers who are most vulnerable to food shortages (Dhakal, 2013) and have a limited resource base. To grow the agroforestry products a sizable quantity, the small size of the land per household is also a challenge. A recent research in Nepal (Dhakal and Rai, 2020) on adoption of agroforestry practices found that farmers having extra income from off-farm activities are positively associated with the adoption decision of the agroforestry system.

Lack of benefit-cost analysis of agroforestry practices

Lack of benefit costs analysis of the agroforestry practices results in minimum confidence of farmers to adopt the technology, thus we observed low adoption rate. When deciding on adopting new technology, the adopters often look into the costs and returns associated with the new technology. Agroforestry practices are available with limited associated cost and expected returns. A few studies estimated costs and benefits of agroforestry system; however, those are more biased towards estimating cost-benefits of 'with projects' vs "without project'

rather than specific agroforestry practices. For example, Neupane and Thapa (2001) estimated returns from project promoted agroforestry system—a combination of adopting multiple agroforestry species - ipil ipil (*Leucaena leucocephala* and *Leucaena diversifolia*) and calliandra (*Calliandra calothyrsus*), bhatmase (*Flemingia congesta*), mulberry (*Morus alba*), gauzuma (*Gauzuma ulmiformis*), NB 21 (*Pennisetum* sp.), napier (*Pen nisetum purpureum*) and stylo (*Stylosanthes guianensis*); and the study failed to calculate cost and benefit of adopting single species, for example. We find no convincing cost-benefit analysis for different agroforestry practices which we thought is the key to build confidence of poor farmers to adopt suitable agroforestry model in Nepal. Farmers are more concerned with profitability of such intervention over the existing practices and discard the less profitable one however there is no proper information on quality planting materials production, plantation, harvesting and post harvesting technology, and cost and benefit of adopting various agroforestry models. Likewise, there are serious access and equity problems along with tenure and use rights to follow widely the agroforestry practices and receive the multiple benefits from foods to carbon sequestration benefits to marginalized and poor farmers.

Low level of awareness among farmers on the benefits of agroforestry systems

Agroforestry system in Nepal, although traditional and ancient practice, farmers are still unaware of the 'modern' agroforestry system. The agroforestry systems deliver several forest products, agriculture products and ecosystem services which may enhance social well-being of the local farmers, national and global community. The poor, small and marginal farmers are almost unaware of the scientific importance (economic and environmental aspects) of agroforestry, short- and long-term benefits, and technical requirements. There is a lack of activities to increase awareness and to educate farmers on the benefits of 'modern' agroforestry systems.

Lack of organized markets for agroforestry products

Although a few niche markets for the specialty products are emerging in Nepal, most of the farmers are not access to those segments. Agroforestry enterprises make up multi-product, multiyear activities often requiring several years before we derive income streams (Gold *et al.*, 2004). Market size, structure and value chain of agroforestry-based products depend on the demand and supply characteristics of the products and their beneficiaries, thus market information is important for value addition and devising investment strategies for the related enterprises (Millard, 2011; Uprety *et al.*, 2016). Marketing of agroforestry products is unique because many products lack marketing institutions, market information, and grade or quality standards.

Institutional constraints

Lack of supporting institutions and undefined administrative boundaries of the concerned authority hinder the development of agroforestry system in Nepal.

Administrative constraints

We noticed private and agroforestry sub-division under community forest division in the Department of Forests and Soil Conservation, however there was no dedicated program and human resources to promote agroforestry in the country. We also see little integration between agriculture and forestry in the countries' policy and administration, and their enforcement was poor by the concerned ministries. Recently, Nepal government has approved National Agroforestry Policy 2019 with the provision of formulating inter-ministerial agroforestry coordination committee at federal level; and develop agroforestry plan, budget, and coordination, monitoring and evaluation system at all levels of government including federal, provincial and local - which we wait to implement in the real ground.

Financial constraint

Several rural farmers based upon subsistence farming for their livelihoods. As these farmers need initial adoption costs in bearing the high risk of changing their land use system, those poor farmers may need financial support, which is lacking at the local level. The micro-finance institutions are available in the rural areas. However, the high interest and low volume of lending limit the ability of farmers to access micro-finance. Institutional finance and insurance coverage in agroforestry has not yet started. Carbon credit may be one of the best options to the farmers to reward on promoting agroforestry, however, there is no definite policy and standards to access the carbon market, awareness among the farmers on it, and method to fulfill the international requirements.

Management complexity of the system itself

The agroforestry system itself is very complex, which results in the lack of scientific knowledge and experts within the country, lack of improved technology, and finally raised concern on its sustainability.

Lack of knowledge and experts

Agroforestry is a complex system and thus highly technical as it combines shrubs and trees in agricultural and forestry systems to create more diverse land-use systems. The agroforestry practices existed since ancient time in Nepal in a subsistence form, which lacks the commercial aspect of agroforestry. There are a few institutions promoting agroforestry, for example, Nepal Agriculture Research Council (NARC), Department of Forestry Research and Survey (DFRS), Department of Plant Resources (DPR), universities, and non-governmental organizations such as Asia Network for Sustainable Agriculture and Bioresources (ANSAB), Nepal Agroforestry Foundation (NAF), and Local Initiatives for Biodiversity, Research and Development (LIBIRD). They altogether have made some efforts in agroforestry and fodder production, tree improvement, utilization of forest products such as bamboo and rattan, and estimation of volume and biomass for various forest products. However, there is a lack of

knowledge and sufficient expert personal in the field to conduct agroforestry research and development. There is also limited university curriculum and graduates in the field. Demonstration plots of the best agroforestry practices with their scientific merits are almost none.

Technological constraints

The selection of technology is critical to the success of agroforestry interventions. A few projects have promoted agroforestry practices in the country by introducing exotic tree species and technologies, undermining local species, traditional knowledge and practices. There are two major risks of introducing exotic species–the first, unacceptable at the farmers' level; and the second, ecologically erroneous (for example, introduction of *Dalbergia sissoo* in low land, and die-back problem). Likewise, there is a shortage of quality planting material and improved seed varieties; simple to complex machinery, and no proper treatment practices of diseases in tree species (Subedi *et al.*, 2014).

Sustainability issues

No sufficient scientific evidences existed for the sustainability of the agroforestry system in Nepal, thus policy makers and politician may raise concerns on the database relating to the social, economic and environmental benefits of different agroforestry practices, long-term research results, to plan specific policy and institution. Statistics on agriculture and forest exist, albeit limited; but not existed for agroforestry systems.

Ways forward

Overall, the country is bestowed with agroecological diversity and suitable land available for agroforestry, traditional knowledge, skill and labor forces, which can be combined with the prospects of adapting new technologies and developing market systems especially considering emerging markets to develop remunerative and environment friendly value chains. However, the prospective value chains face serious challenges related to enabling environment, especially related to investment friendly climate that supports to increase returns and reduce risk of the value chain actors. We therefore suggest having a scan of those challenges and find out solutions, especially for promoting growth and competitiveness of the sector with poverty reduction strategy ensuring availability of food, fuel, fodder and employment for local communities. Policymakers and other stakeholders should know that not all the agroforestry systems and practices are suitable for everywhere in the country, the current state of scientific knowledge offers little guidance on what agroforestry systems and practices work which agroecosystems and social context under what conditions. The following are the recommendations made for the future development of agroforestry systems in Nepal.

Increase investment to encourage and educate farmers

Increase in investment to encourage and educate farmers about the science in agroforestry and the diverse ecosystem services provided by the shade trees is one of the utmost importance. We should give the following science behind the agroforestry systems priority while educating farmers.

- Food and non-food sources of the agroforestry systems that a household can achieve through agroforestry systems;
- Agroforestry systems as the nutrient safety net and soil nutrient provider;
- Agroforestry systems stimulate organic matter decomposition, nutrient recycling, and provide erosion control;
- Agroforestry systems increase carbon storage and reduce GHG emissions, mitigate climate change effects;
- Agroforestry systems enhance functional biodiversity of the landscape; and
- Ultimately, the agroforestry system helps to increase overall farm productivity and higher income to the farmers in a long run.

Incorporate market system development approach for the agroforestry products

Facilitate the development of agroforestry-based multiple enterprises fulfilling environmental, market and legal requirements through *market system development approach*. For this to happen, there is an urgent need for identifying prioritized agroforestry-based products by ecological regions and their respective value chains to connect producers with market, along with supporting and linking up market actors. The global market for agroforestry-based products is growing; henceforth, it is worthwhile to provide economic opportunities for rural poor communities by linking them to national and international markets for the products. We see a better future of production of highly marketable and highly nutritive agroforestry-based specialty products. In Nepal, revisiting the agroforestry system through the lens of markets and building resilient communities is emerging (Aryal *et al.*, 2019; Cedamon *et al.*, 2019; Nuberg *et al.*, 2019; Nuberg *et al.*, 2018; Pandit *et al.*, 2019), and a recent study showed an increase of income of the households (37-48% over the baseline) who adopted such practices (Pandit *et al.*, 2019).

Incorporate traditional knowledge as adaptive management in the local level planning

We need incorporation of traditional knowledge of agroforestry systems into the modern sciences. Some literature, for example Atreya *et al.* (2018) and Nepal Government (MoSTE, 2015), have already suggested doing so for the betterment of humanity through enhancing environmental services. While doing so, establishing its relationships with socio-ecological resilience and adaptive management should be of top priority. The existing ecosystems at a particular area results from a close interaction between local people and their environment, termed as social-ecological systems, dealing which must consider both ecological

and social issues of the area. We need to embrace the complexity of the agroforestry systems - which is an alignment of the best of farmers' traditional knowledge with empirical scientific evaluation. Agroforestry is a shining example of this approach, merging centuries-old knowledge with modern science (Steiner, 2012). It is better to acknowledge the best of the farmers' traditional knowledge and complement it with scientific study. In addition, domestication of the local tree species along with acknowledging local knowledge on the production practices and uses could establish novel food products for the local, regional or even international markets; however, for this to happen there is a need of collaboration between agroforestry specialists and the food industry to establish desirable traits and characteristics of potentially novel food products (Leakey, 1999). There are several wild indigenous trees and fruits species available in Nepal. A study in Dolakha district (Shrestha and Dhillion, 2006) observed 80% of the 62 wild food plants have multiple benefits, henceforth domestication of those species into the existing agroforestry systems could diversify the income sources.

Show the best agroforestry systems and (re) orient it as a sustainable land use system

Demonstration and replication of the best agroforestry systems at landscape levels as per the local needs assessment (social and biophysical acceptance, goals and configuration by land use systems) - for example apple orchard; coffee/tea plantation; Alnus and cardamom-based agroforestry systems and declaration of agroforestry super zones are necessary. Let farmers know the best agroforestry systems suitable for the local conditions that provide the greatest benefits to them. As there are limited reliable and easily generated statistics existed on agroforestry systems in Nepal, the demonstration of the good examples of the best existing agroforestry practices and its replication into new agroecological regions, particularly degraded land could be the best way to generate scientific data for the systems. National government should support developing or (re) orienting agroforestry systems as a sustainable land use system for Nepal.

Carbon markets for extra economic and ecological benefits

As we observed a contribution of agroforestry systems in carbon sequestration, we see the possibility of extra economic benefits through payment for ecosystem services (PES) and farm/forest certification - but we felt urgently a need of reducing monitoring and evaluation costs of certifications. Also required is to estimate carbon sequestration rate (Pandit *et al.*, 2013) of the various agroforestry systems at national level as most of the past studies in the country are more focused towards soil fertility and livelihoods improvement (Neupane *et al.*, 2002; Neupane and Thapa, 2001); and the estimates on soil carbon sequestration in the forest ecosystems are many (see, for example, Upadhyay *et al.*, 2005; Pandit *et al.*, 2017; Sharma *et al.*, 2017), such studies are inadequate in agroforestry systems, however emerging (Bajracharya *et al.*, 2015; Pandit *et al.*, 2013). A study in Nepal stated that a household can benefit from agroforestry systems about NPR 45,490 per hectare in 20 years from carbon sequestration if we introduced a payment scheme (Gahatraj, 2017).

More collaboration, research and extension

The government institutions: the Forest Research and Training Center (FRTC), Department of Forests and Soil Conservation (DFSC), Tribhuvan University, Institute of Forestry, Agriculture and Forestry University, Faculty of Forestry, Nepal Agricultural Research Council; and non-government organizations (NGOs): Forest Action, Nepal Agroforestry Foundation, ANSAB; and International NGOs (INGOs): International Center for Integrated Mountain Development (ICIMOD), IUCN are being involved in the agroforestry research and development in Nepal. However, the collaboration among these institutions and coordinated efforts for integrated research and development of the agroforestry system are rare.

More collaborative agroecosystems-based research (long-term and entire systems perspective), agroforestry education at different levels (farmers education to university graduates) and favorable policies (landscape and value chain perspective; and well setup dedicated agroforestry division under FRTC, NARC and DFSC in federal level; the same under Ministry of Forestry and Environment and Ministry of Agriculture and Cooperatives at provincial level; and dedicated agroforestry officer at divisional forest office and Agriculture Knowledge Center (AKC) and Agriculture Development Office (ADO) are necessary to develop agroforestry systems in Nepal to offer practical benefits to agriculture, the environment, and in the extension, the human health and welfare. There is a lack of scientific information, particularly at the level of experimental observations, henceforth we need further research and observations in parallel to policy implementation. It is worthwhile to develop/collect data on agroforestry systems to provide support in developing a common climatic classification of the agroforestry systems available in Nepal.

Conclusion

Despite the several encoring scope and potentiality of agroforestry in Nepal, agroforestry practices are following very traditional approaches. Site- or region-specific agroforestry system identification based on the sound scientific trails and testing of the systems are lacking. Till now, we only focused our research on natural systems of agroforestry practices. Awareness of the short- and long-term benefits of agroforestry systems should be disseminated not only to the poor and subsistence farmers but also to the business-oriented entrepreneurs who are almost unknown of its benefits as an industry. This will also address the key challenge of high adoption cost of adopting agroforestry system by subsistence farmers in the rural communities. In addition, agroforestry-based industries would also be promoted if we can convince key businessmen in the agroforestry-based industries. Traditional knowledge is the root of agroforestry.

Hence, we can use agroforestry systems as an adaptive management of the local level planning. However, doing so socio-ecological integrity should be of high priority. Agroforestry should merge ages long knowledge with modern science which would be a sustainable solution for food security, ecosystem services and socio-ecological resilience of the intervention area. Because of the low confidence on the adoption of the agroforestry practices, responsible organization (Nepal Government) should develop best agroforestry system in a specific region by doing rigorous research and demonstration. By doing so, farming communities would convince for the implementation of the recommended agroforestry system in their location. In addition to this, proper land use system could also be established which is more sustainable. Lastly, the emerging global issues such as GHG emission, climate change and their possible mitigating measures as carbon marketing for extra economic and ecological benefits of agroforestry system is proven strategy but still not getting attention in wider level. Hence, more collaboration, research and dissemination of the agroforestry systems are needed among the universities, research organizations, respective ministries, NGOs/INGOs and farming communities.

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