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Review

Transforming agroforestry in contested landscapes: A win-win solution to trade-offs in ecosystem services in Nepal

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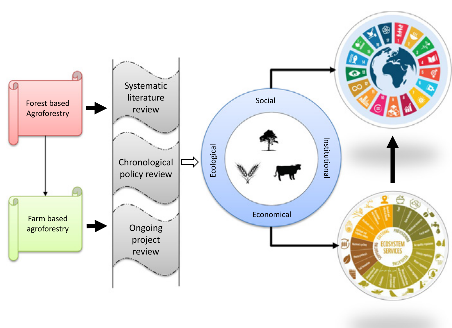
HIGHLIGHTS

- Farm-based agroforestry is becoming popular than forest-based agroforestry.
- Agroforestry can supply 13 types of ecosystem services, supporting 10 SDGs.
- Socio-economic, ecological, and institutional factors of interventions are crucial.
- Integrated agroforestry is vital in minimizing trade-offs among ecosystem services.

GRAPHICAL ABSTRACT



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ABSTRACT

Trade-offs in ecosystem services (ES) is increasingly becoming a pressing issue in sustainability science, to deal with supply constraints of landscape and divergence in demand from local and global stakeholders. Agroforestry is a well acknowledged and established management practice to minimize the trade-offs, and to sustainably manage the contested landscapes while satisfying the growing demands of both local and global ecosystem beneficiaries. However, various facets of agroforestry, its management modality, institutional arrangements, and implementation outcomes are inadequately understood. This paper aims to scrutinize major agroforestry practices through the methods of systematic review of literature, government policies, and project reports. Taking a case of Nepal, this paper presents agroforestry transition from forest-based agroforestry (i.e., shifting cultivation) to farm-based integrated approach to agroforestry in Nepal. This paper reveals that integrated agro-forestry approach is crucial in creating win-win scenarios among various stakeholders by minimizing trade-offs and maximizing synergies among ES, especially food, fibre, and other ES (i.e., biodiversity, soil functioning, water, and climate regulation). Analysing socio-economic, ecological, and institutional factors that are affecting agroforestry for the last fifty years, we further suggest an integrated model of agroforestry which is replicable in other countries with similar socio-economic status, practicing subsistence farming system. The findings of the paper are crucial in awakening scholars, policy makers and landscape managers for up-scaling and out-scaling of integrated approach to agroforestry for ecosystem management and attainment of various sustainable development goals such as, no poverty (#1), zero hunger (#2), climate action (#13), and life on land (#15).

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Contents

1. Introduction

The concept of ecosystem services (ES) has been popularly used in the recent years to manage contested landscapes for sustainable development (Wood et al., 2018). ES are the features and functions of nature that benefits human which are based on inbuilt as well as induced interactions between human and nature, at different time and space (Costanza et al., 1997; MEA, 2005). ES are also the dynamic processes that depends on supply (ecological limits) and demand (human value) of various provisioning and non-provisioning (i.e., regulating and cultural) ES (Kroll et al., 2012; Rau et al., 2018; Snäll et al., 2021). ES are thus mainstreamed in sustainability science, considering its biophysical and socio-economic associations and interactions across various spatial and temporal scale (Balvanera et al., 2022; Cavender-Bares et al., 2015; Schröter et al., 2017). To illustrate, UN Sustainable Development Goals (SDGs-2030), Post-2020 Global Biodiversity Framework, and UN Decade on Ecosystem Restoration (2021 – 2030) have embraced ES for sustainable development.

Allotment and supply of ES are based on the configuration of ecosystem assets (i.e., forestland, grassland, wetlands, cropland, and others) which is further dependent on different land use practices (W. Chen et al., 2019; Hasan et al., 2020). Some ES are mutually exclusive while others have some sorts of relationship/interaction which can be explained through synergy and trade-offs (Bennett et al., 2009; Lin et al., 2018; Vallet et al., 2018). Trade-offs in ES (i.e., increase in one ES leading to decrease of the others) are the major concerns for optimal management of landscape to address wide range ecosystem demands, being within the productive capacity of the landscape (Cavender-Bares et al., 2015; King et al., 2015). Trade-offs in ES are prominent especially between the supply of provisioning services and non-provisioning services (Macchi et al., 2020). Trade-offs exist even within the provisioning ES such as between agricultural products and forest products, especially under the land sparing scenarios (Aryal et al., 2022).

Agroforestry — a land use system that deliberately introduce woody perennials and livestock in the agricultural lands (Nair, 1993; Nair et al., 2021a)—has been increasingly realized as the potential measure to address the emerging challenges of competing land use practices and ES (Kuyah et al., 2019). Agroforestry, in a multifunctional working landscape, support the provisioning of wood and crops, along with the other environmental benefits such as, soil retention, biodiversity conservation, and carbon sequestration (Jose, 2009; Maraseni et al., 2012). Nonetheless, agroforestry can also cause undesirable loss in forest cover and biodiversity in the tropics if it is derived from forested landscapes (Martin et al., 2020). Accordingly, various farm-based and forest-based agroforests are being practiced which have diverse implications to the landscape and supply of ES.

Agroforestry has been studied in the past from various perspectives such as, role of agroforestry in food security (Duffy et al., 2021; Kiptot et al., 2014; Phimmavong et al., 2019), livelihood and building climate resilient communities (Aryal et al., 2019; Quandt et al., 2019), environmental benefits (Jose, 2009; Sobola et al., 2015), flood and drought resilience (Quandt et al., 2017) and carbon sequestration (Dhyani et al., 2020; Murthy, 2013) among others. Further, meta-analysis of agroforestry has been done focusing on land use history (Martin et al., 2020), supply of ES in African countries (Kuyah et al., 2019), biodiversity conservation in European countries (Torralba et al., 2016), and soil carbon in China (Hübner et al., 2021). However, no study has been done to understand the role of agroforestry in minimizing trade-offs in ES in contested landscapes in the tropics, including Nepal. Moreover, there exist a clear knowledge gap about how agroforestry transition has been happening in developing countries including various forms of agroforestry, its management modality, and institutional arrangement. Likewise, the long-term observation of the factors affecting agroforestry have not been critically observed in the past which is crucial to understand the agroforestry transition in recent days. Realizing this knowledge gap, this study is aimed at scrutinizing major agroforestry practices in terms of its form of origin, implementation arrangement, management interventions, supply of ES, and its contribution to SDGs. Further, we aim to diagnose factors affecting agroforestry development through systematic review of literature. Taking a case of a package-based agroforestry practices of Super Zone Development Program (SZDP) in Nepal, we demonstrate a linkage of integrated approach to agroforestry with balanced supply of ES and achievement of SDGs.

2. Conceptual framework and methods

2.1. Integrated management approach

Sectoral approach to nature conservation is becoming inefficient in managing complex yet uncertain socio-ecological processes because of divergence in interests of multiple stakeholders, ambiguity in issues prioritization, and changing global context in managing ES (Dewulf et al., 2005; Sacchelli and Bernetti, 2019). Integrated management approach has emerged so as to overcome the deficiency of sectoral approaches, such as poor understanding of wicked problems, lack of proper operationalization of social and ecological phenomena, and biased planning and management at the landscape level (X.-L. Chen et al., 2019; Cuong et al., 2017). For example, sectoral emphasis on accelerated food production to overcome extreme poverty in a short-run might degrade water quality and soil productivity, implying land degradation and productivity loss in the long-run (Barrera et al., 2012; Muller et al., 2017; Prăvălie et al., 2021). The purpose of integration in the past at the organization level was to avoid duplication in implementation of intended management activities (Bleischwitz et al., 2018; Mitchell et al., 2015; Thomson, 2003). Similarly, integrated management approach was adopted to ensure that the essential components are mainstreamed in comprehensive planning and development (Al-Jawad et al., 2019; Bamisile et al., 2020; Malmir et al., 2022). In the late 2000, the concept of integrated management was used to balance the environment conservation with human development (Alpert, 1996). In landscape conservation and biodiversity management, the concept of integrated management was also used to embrace the broader components rather than site-based sectoral approach to conservation and ecosystem management (Cuong et al., 2017; Wang et al., 2013). In recent years, integrated management is aimed to buffer the negative impact of one action/intervention to other, and to accelerate synergy among various sets of conservation and development actions (Sacchelli and Bernetti, 2019; Thomson et al., 2019; Wang et al., 2013).

Agroforestry, itself, is an old-age practice of integrating agriculture and forestry, addressing the concerns of wood, food, energy and water, simultaneously (de Mendonça et al., 2022; Elagib and Al-Saidi, 2020). Various forms of agroforestry systems are being practiced worldwide, focusing on the major components of tree, crop, and livestock (de Mendonça et al., 2022; Parodi et al., 2022). However, the level of integration in agroforestry is largely confined within the ecological domain of vegetative and agronomic practices (Aryal et al., 2019). Because the success or failure of agroforestry practices is attributed to various land use practices, government policy and program structures, institutional arrangement for implementing agroforestry practices, socio-economic condition of farmers, vegetation structure, soil quality, and local climatic conditions (Amatya et al., 2018; Aryal et al., 2019; Gebru et al., 2019; Guillerme et al., 2011). The integration of activities should also be directed towards creating an enabling environment for agroforestry development by incorporating various social, ecological, economical, and institutional factors in program planning and implementation (Coe et al., 2014). Nevertheless, the activities can be categorized and prioritized as the core programs, complementary programs, and supplementary programs. In this regard, integrated agroforestry is the holistic approach to agroforestry, comprising various socio-economic, ecological, institutional, and managerial aspects, to support sustainable development goals through the supply of multiple ES (Buck et al., 2020; Kuyah et al., 2019; van Noordwijk, 2020; Waldron et al., 2017).

2.2. Methodological approach

We adopted systematic literature review (SLR) and review of government policies and project reports for this study. SLR is an evidence based formal framework to build new knowledge based on a thorough analysis of previously published articles (Fagerholm et al., 2016). SLR overcomes the drawbacks of traditional approach to literature review, which suffers from biases (Haddaway et al., 2020). The review protocol was set according to the research objectives. After settling the research aims and review protocol, we defined the search string based on the keywords of the research as: [("agroforestry" OR "agro-forestry" OR "farm-forestry" OR "farm forestry") AND "Nepal"]. To avoid the biases in selection of articles, we used generic words such as agroforestry and farm-forestry. Inclusion of other keywords (such as, home gardens, shifting cultivation, horticulture, and others) might collect more literatures but it might predominate numerous other forms of agroforestry. We selected Nepal in our review analysis because: (1) Nepal is one of the agrarian based countries (i.e., two-thirds of the population depend on agriculture) yet about half of the land area (i.e., 45 %) is covered by forest, which can best explain the agriculture and forestry interface, (2) it represents developing countries in the global south striving to minimize deforestation and forest degradation while one-fifth of the population is under absolute poverty line (combating poverty and hunger), (3) agroforestry is an integral part of subsistence farming in Nepal which has been practicing for ages, and (4) Nepal is dedicated to intervene in land-use practices based on various global commitments such as Convention on Biological Diversity, SDGs, and UN Decade on Ecosystem Restoration (Laudari et al., 2022).

We searched for articles in electronic database 'Scopus' and 'Web of Science Core Collection' in December 2021. We found a total of 161 records (83 from Scopus and 78 from Web of Science Core Collection) based on our search string. After the removal of duplicate records, 102 articles were selected for screening. Title and abstract screening were carried out through which the articles that were not focused on at least one form of agroforestry and not based in Nepal were removed. From the total records, 73 articles were selected for full-text screening. During the full text screening, 22 articles were removed from full-text reading, and the remaining 51 articles were selected (*see supplementary file*) for data extraction based on full-text reading. We developed a data collection framework (*in MS Excel spreadsheets*) to collect the data from the selected literature. The framework was inspired by various systematic literature review done in the past (Aryal et al., 2022; Bhattarai et al., 2022; Haddaway et al., 2020), and structured through experts' consultation. The data collection framework was finalized after rigorous discussions among the authors. During the data extraction, the articles were screened against the pre-determined data framework such as, form of agroforestry, physiographic zone of study, managerial and funding mechanisms, major management interventions, supply of ES, and contribution to SDGs. Further, the articles were screened against the required information about what factors are affecting agroforestry development and why agroforestry can be considered as a policy alternative to address trade-offs in ES. A flowchart of the methods of the study is presented in Fig. 1.

Besides, to understand the chronological development of agroforestry and its structural transformation, we reviewed major policies, legislations, and regulations regarding agroforestry, including but not limited to agroforestry policy (2019), forest policy (2019), land use policy (2015), agriculture development strategy (2014), and other legislative as well as project documents about agroforestry. In addition to literature review and review of the policy documents, we also reviewed a project which has been implemented since 2016 by the government of Nepal as the Prime Minister Agriculture Modernization Project. A detailed review of project outcomes in terms of its agroforestry component was done. This project was selected for review because it has embraced the most recent form of agroforestry that is being practiced at wider scale throughout Nepal. The project has been implemented in 16 districts of Nepal, covering an area of about 40,000 ha, to make transformational changes in the agricultural sector and farming system in the country (MoALD, 2021; MoALD, 2017). It has aimed to create >25 thousand full time and >700 thousands seasonal employment in agriculture sector (Devkota, 2021). Among the four major components of the project, SZDP embraced a package-based integrated agroforestry program. SZDP is being implemented in 16 districts of Nepal, representing various physiographic region. In SZDP, one product (i.e., coffee in Gulmi district, orange-based horticulture in Syangja district, aquaculture in Bara district, and vegetables in Kaski district) is focused on the centre for commercialization, and various other activities are implemented to support soil and water conservation, land productivity enhancement, and livelihood support activities (MoALD, 2021). A review of the SZDP is important in ascertaining the factors that are responsible to integrated and successful agroforestry program development. Moreover, review of this project is also crucial in learning lessons for integrated agroforestry which is suitable for Nepal and other developing countries. Thus, implementation mechanisms, program configuration and intermediate outcomes of SZDP is also reviewed and discussed in this paper. Quantitative analysis, such as frequency of records of the literature are presented in appropriate tables and charts, using R software (R Core team, 2021). Thematic analysis and configurative synthesis of qualitative data were carried out to interpret and discuss various facets of agroforestry in supplying ES and serving SDGs (Aryal et al., 2022).

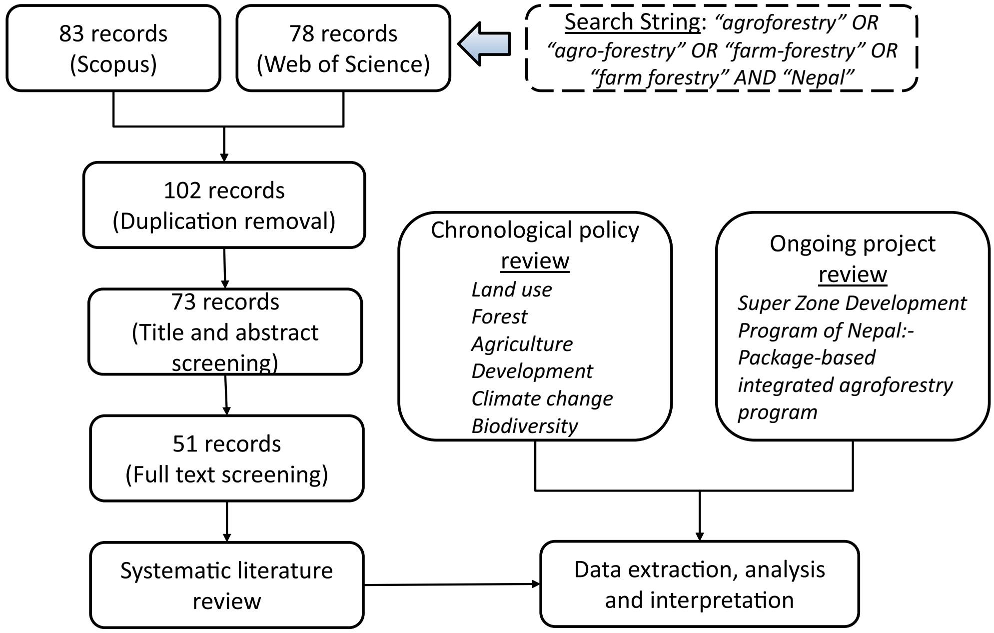

Fig. 1. Flowchart of systematic literature review and data extraction.

3. Results

3.1. Development of agroforestry practices

Agroforestry is an age-old practice in Nepal's farming system which has been practicing in the forms of on-farm tree plantation, fodder tree plantation, and agricultural practices with livestock husbandry. Shifting cultivation used to be a common forest-based agroforestry practice in Nepal. However, the formal program of planting trees in farmlands has been practised since 1970s. The chronological development of agroforestry practices in Nepal is presented in Table 1.

Starting from the site-based intervention to halt forest encroachment in 1972, Nepal has embraced the potentials of agroforestry through the promulgation of National Agroforestry Policy in 2019. During the last half century, the practice of agroforestry has been shifted from forest-based agroforestry (i.e., Taungya and shifting cultivation) to farm-based agroforestry (i.e., agri-silviculture, horticulture, home garden and hedge-row intercropping). Along with the populated discourse on agroforestry, various government and non-government organizations have also been involved in the development and implementation of agroforestry programs. The Ministry of Agriculture and Livestock Development (MoALD) and Ministry of Forest and Environment (MoFE) are the major government authorities involved in agroforestry development along with other partners such as, International Centre for Integrated Mountain Development - ICIMOD, Asia Network for Sustainable Agriculture and Bioresources - ANSAB, Nepal Agroforestry Foundation-NAF, Local Initiatives for Biodiversity, Research and Development - LiBiRD, Academic institutions (i.e., Institute of Forestry, Agriculture and Forestry University), Climate Technology Centre and Network, National Agriculture Research Council, and World Agroforestry. Further, the scope of agroforestry has not only been restricted to support fodder and fuelwood demand of the farmers, but it has now been discussed as an approach to multi-functional landscape management to deliver multiple ES.

3.2. Dominant agroforestry practices and its management modalities

Based on our search string and review protocol, we found that the first Nepal-based agroforestry specific paper was published in 1990. However, the number of articles were very low until 2010 (<25 %) (Fig. 2). Various forms of agroforestry have been documented in the published literature, including both forest-based and farm-based.

Although agroforestry practices are classified based on its elements of integration, they are not mutually exclusive, such as agri-silviculture which may also contain the components of home garden, sloping agricultural land technology, and others. But our result is based on how the author referred to that agroforestry practice. In general, farm-based agroforestry were highly populated in the literature as compared to the forest-based agroforestry. Agri-silviculture was the most popularly documented (i.e., >60 %), which denotes the deliberate introduction or retention of already existing of trees within croplands (Fig. 3). Plantation and/or retention of trees around (i.e., boundaries/dykes) agricultural lands was the second popular form of agroforestry, followed by non-timber forest products-based agroforestry. Alley cropping, especially sloping agricultural land technology, was covered by only <10 % of the selected literature.

Regarding the physiographic region, most of the articles were based on mid-hills (>70 %), followed by lowland (<14 %), and only one article covered the agroforestry practice in the high-hills of Nepal. >80 % of the articles were based on the agroforestry practices that were managed by individual farmers, while about 14 % articles covered community managed agroforestry, and the remaining 6 % were representatives of agroforestry managed by non-government and research institutes. Similarly, about 78 % of the papers indicated that agroforestry was managed through private investment while the remaining 22 % were either project supported, or community and other research institutes supported.

Management interventions under agroforestry were basically observed as: (1) tree based: i.e., plantation of multipurpose trees and non-timber forest products, retaining trees in farmlands, exotic tree plantation, tree pruning and management; (2) crop based: i.e., terrace farming, minimum soil tillage, climate smart cropping, and irrigation management; (3) livestock based: i.e., fodder and grass plantation; and (4) others including fruit tree cultivation, coffee plantation, aquaculture based interventions, and capacity building programs. Among others, multipurpose tree plantation was referred in one third of the literature, followed by plantation of fodder species (27 %), and intercropping (22 %). Other activities, such as water source conservation, irrigation management, fishing ponds, and climate smart cropping were referred only once in the selected literature.

Table 1
Chronological development of agroforestry practices in Nepal.

Milestones	Policy/program/project	Approach and focus
1972	Taungya agroforestry system introduced in Tamagadhi of Bara	• Encroached forest area by the hill migrants were given to them for tree plantation in encroached area, to protect from further encroachment
1978	Sagarnath Forestry Development Project	• Plantation of fast-growing tree (i.e., *Eucalyptus*) species.
1983	Terai Community Forestry Development Project	• Poor farmers were given plantation areas (about 1 ha per family) for 4–5 years to grow crops without damaging planted trees • Introduced *Dalbergia Sissoo* and *Cassia Siamea* in Terai
1983	Farm Forestry Project by Tribhuvan University with the support from The International Development Research Centre of Canada	• Planting trees in own lands of small-scale farmers to satisfy their need of fuelwood, fodder, green manure, and timber • Develop simple propagation technique by selecting promising tree species • Protection techniques by planting live fences
1993	Forest Act	• Agroforestry in leasehold forests for poverty reduction and protection of degraded forests
1993	Nepal Agroforestry Foundation (NAF)	• Promoting agroforestry programs and activities • Fodder tree plantation and production in mid-hills (i.e., Dhading)
1998	Terai Private Forest Development Association with support from NAF	• Agroforestry based farming system in few VDCs of Terai district
2000	Revised Forest Policy	• Fruit tree intercropping and promotion of medicinal and aromatic plants in farming system
2002	Leasehold Forest Policy	• Leasing of forestland for agroforestry development
2004	National Workshop on Home Gardens in Nepal	• Capacity building and extension about home gardens for food, income, biodiversity, and ecosystem services
2011	Climate Change Policy	• Agroforestry development for adapting and mitigating the impacts of climate change
2014	Agriculture Development Strategy	• Agroforestry to increase production and productivity of croplands through integrated management
2014	Nepal Biodiversity Strategy and Action Plan	• Allocating public lands for agroforestry development and biodiversity conservation
2015	Land Use Policy	• Provisioning of green belt and river-bank protection
2015	The Kathmandu Declaration on Agroforestry	• Mainstreaming agroforestry in national conservation and development programs
2016	Prime Minister Agriculture Modernization Project	• Development and implementation of package-based integrated agroforestry development programs (i.e., Super Zone Development Program)
2019	Forest Policy	• Focused research and development of various agroforestry system and extension programs
2019	National Agroforestry Policy	• Dedicated national policy for agroforestry development, including multipurpose use of lands, climate resilience ecosystem, livelihoods and income, investment and economy, and research and development in agroforestry

3.3. Supply of ecosystem services and development goals from agroforestry

We found that agroforestry program could supply various ES, ranging from provisioning to cultural ES (Fig. 4). Almost all forms of agroforestry were reported to supply provisioning services for food and fibre (i.e., forest products) availability, simultaneously. Soil conservation is the 3rd most reported ES from agroforestry which is reported by >30 % of the selected articles, followed by carbon and climate services, biodiversity and habitat support, meat and milk production, land productivity enhancement, water yield and others. Further, agroforestry practices also contribute to supplying cultural ES (i.e., religious value and landscape aesthetic).

Regarding the contribution of agroforestry in achieving SDGs, we found that four goals are substantially addressed by agroforestry, such as, zero hunger (#2), life on land (#15), no poverty (#1), and climate action (#13) as reported in 92 %, 88 %, 39 %, and 22 % of the selected literature, respectively (Fig. 5). Only few articles mentioned that agroforestry can contribute to gender equality, clean water supply, clean energy, and institutional development.

3.4. Factors affecting agroforestry programs

Agroforestry practices are dependent on multiple socio-economic and environmental factors. In our review of Nepal's agroforestry, we found a number of social, ecological, and institutional drivers that affect agroforestry development activities. Under the socio-economic domain, the provisioning of economic incentives, farmers willingness to adapt agroforestry, and the size of the farm holding were found to be the major drivers, as reported in >10 % of the literature for each of the driver. Similarly, institutional factors such as government policies, and use of technology

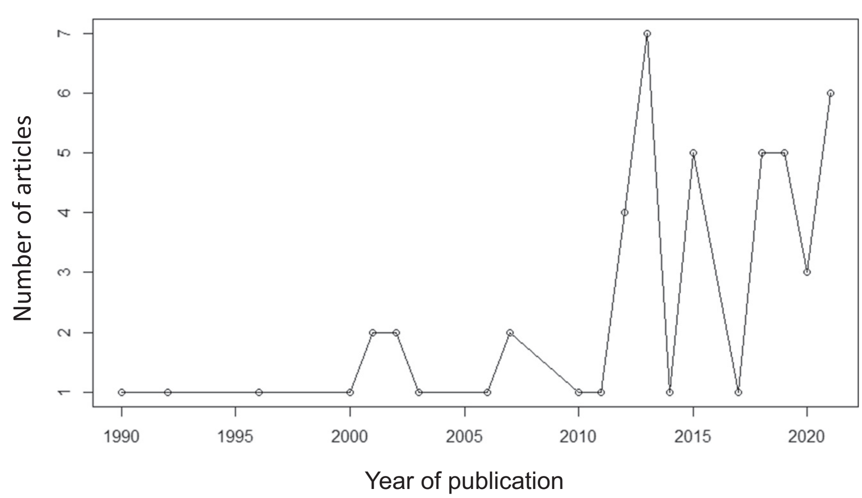

Fig. 2. Trends of article publication (n = 51) about agroforestry practices in Nepal (1990–2021).

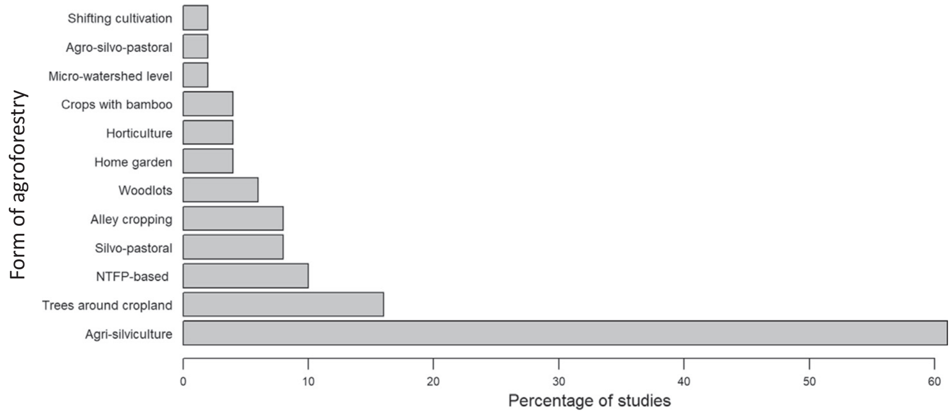

Fig. 3. Percentage of articles representing forms of agroforestry.

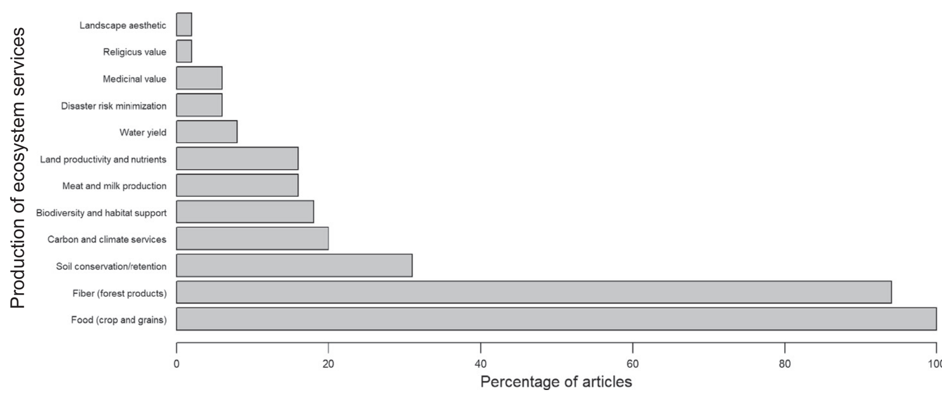

Fig. 4. Percentage of articles (n = 51) about ecosystem services supply from agroforestry in Nepal.

and management intensifications were also reported as the major drivers of agroforestry pathways (>10 % articles). From the ecological perspective, selection of appropriate tree species, land suitability for agroforestry and soil properties were found to be the main determinant of agroforestry. Various other factors were also reported to affect agroforestry (Fig. 6).

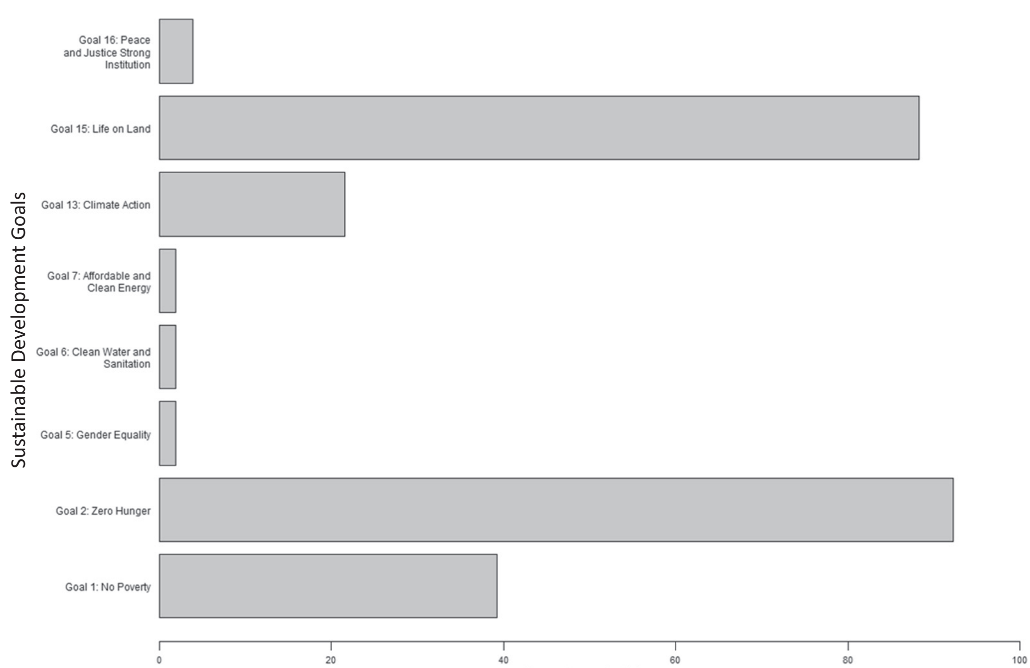

Fig. 5. Percentage of articles (n = 51) showing contribution of agroforestry to UN Sustainable Development Goals (SDGs).

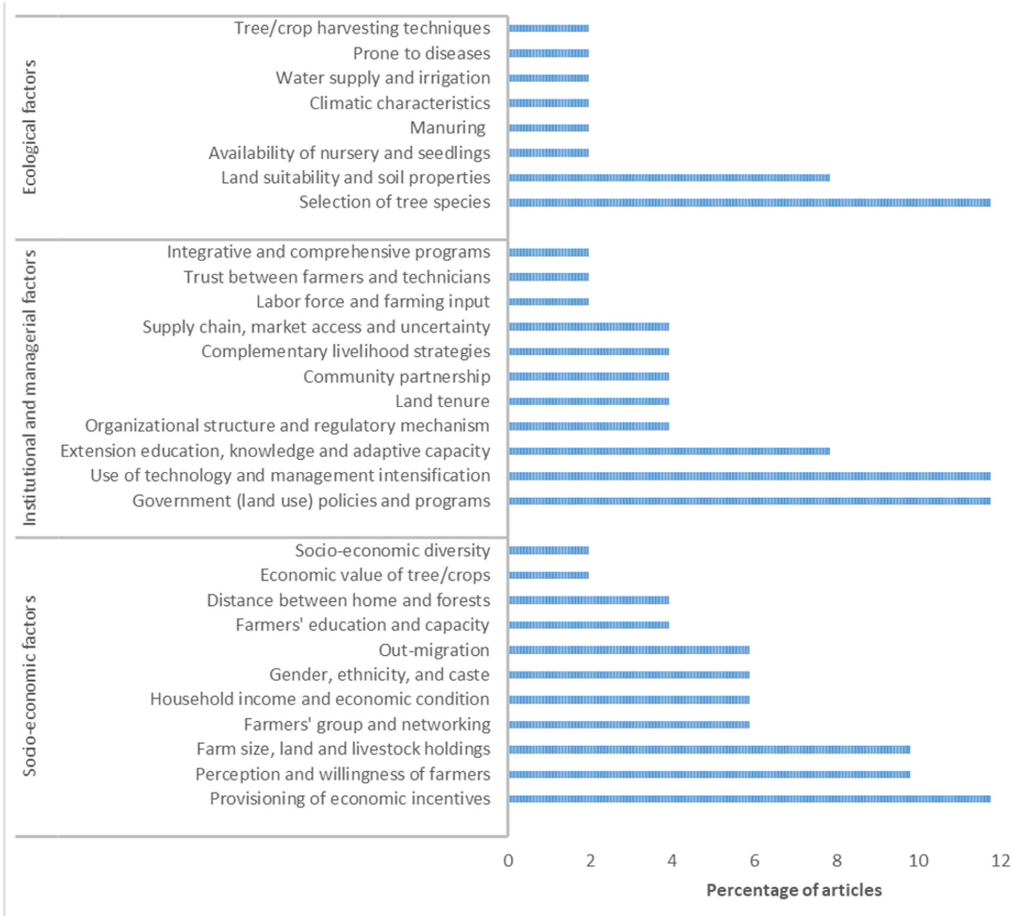

Fig. 6. Percentage of the articles notifying various factors affecting agroforestry development.

3.5. Integrated approach to agroforestry: a case of Super Zone Development Program

As noted, Super Zone Development Program (SZDP) aimed to increase production and productivity of the agricultural land through an integrated approach, considering catchment level management. Program activities under the SZDP can be categorized as primary programs and secondary programs. Primary programs include the establishment of custom hiring centres, post-harvesting centres, cold stores and agricultural marts, establishment of high-tech nursery for fruits and vegetable seedlings, improvement of irrigation system including solar irrigation, demonstration plot, and capacity building activities. Secondary programs under SZDP includes land productivity conservation, water source protection, seedling production and distribution, river-bank protection, land use planning, and management plan development. Specialized unit of the SZDP (i.e., Project Implementation Unit) has been implementing the primary programs while secondary programs are being implemented by various organizations including Department of Forest and Soil Conservation.

Under SZDP, improved irrigation programs have been implemented in 4000 farmlands places, including 63 solar irrigation stations. >2000 fishponds, 17 high-tech nurseries for fruit tree, farmyard manuring in >5000 places, greenhouse vegetable facilities in about 100 places have been established and implemented in SZDP areas. Financial incentives and grants for water source protection and irrigation, grants to farmers while adopting livestock hybrid for increased production, demonstration plot establishment, and capacity building as well as gender and social inclusion have been under the program component of SZDP. With the combined efforts under SZDP, a substantial increase in the production of target products in the super zones can be observed (Table 2).

Package-based integrated agroforestry program in SZDP has shown a promising positive impact in the production of target products. An average increase in the production of maize (by 161.6 % in Dang district), paddy (by 60.8 % in Kanchanpur district), potato (by 50.7 % in Dadeldhura district), fish (by 48.7 % in Bara district), and apple fruit (by 45.7 % in Jumla district) while supplying other ES such as forest products, soil retention, water supply and biodiversity, is a remarkable achievement in the agroforestry sector through the implementation of SZDP in Nepal.

4. Discussion

4.1. Reflecting on current agroforestry practices

In the past, agroforestry practices were grossly forest-based, implying that they were based on the conversion of forestland into agricultural or other land use purposes. As we observed until the mid of 20th Century, common practices of agroforestry were shifting cultivation and Taungya, which were formed from the conversion of forestland and were designed to halt further deforestation and forest degradation (Amatya et al., 2018; Angelsen, 1995). However, in the recent decades, various forms of farm-based agroforestry are being practiced and shifting cultivation is decreasing globally (Heinimann et al., 2017). An increasing trend of publications about agroforestry in the last decade (i.e., >75 % articles published after 2010), having >80 % farm-based agroforestry in Nepal, indicates that it is mainstreamed in land use discourses. A recent study by Ulak et al. (2021) also found that agri-silviculture and horticulture are the most frequently practiced agroforestry in Nepal. The shift towards farm-based agroforestry, including that of the Nepal's SZDP interventions on farmlands, highlights the roles of agroforestry in multiple dimensions of conservation and

Table 2
Production details of target product from 16 Super Zone Development Programs in Nepal.

Sn	District	Target product	Starting year	Area (ha)	Production (Mt/ha)	Increase in production[a]
1	Jhapa	Paddy	2016/17	6745	5.6	31.5 %
2	Dhanusa	Fish	2017/18	1219	6.0	7.0 %
3	Bara	Fish	2016/17	657	8.0	48.7 %
4	Kabhre	Potato	2016/17	6000	23.8	8.4 %
5	Sindhuli	Fruit (Junar)	2016/17	1015	12.5	2.0 %
6	Kaski	Vegetables	2016/17	1106	16.1	15.1 %
7	Syangja	Fruit (Orange)	2018/19	1346	12.3	26.0 %
8	Rupandehi	Fish	2018/19	856	5.4	9.9 %
9	Kapilbastu	Paddy	2018/19	4100	4.2	17.8 %
10	Gulmi	Coffee	2018/19	990	14.3	7.7 %
11	Dang	Maize	2016/17	2310	6.3	161.6 %
12	Bardiya	Paddy	2018/19	1720	5.3	22.0 %
13	Jumla	Fruit (Apple)	2016/17	2305	10.2	45.7 %
14	Kailali	Wheat	2016/17	1225	4.4	41.0 %
15	Kanchanpur	Paddy	2018/19	6462	6.2	60.8 %
16	Dadeldhura	Potato	2017/18	880	23.9	50.7 %

[a] It denotes the increase in the production of target product in the Super Zone areas as compared to that of the district average production of the corresponding district.
Source: Adopted from MoALD, 2021.

development paradigms. Nevertheless, highly technical forms of agroforestry (i.e., hedgerow intercropping or alley cropping) is still not fully operationalized at the farmers' level. In this regard, previous studies have also emphasized on the needs of local people (Aryal et al., 2020; Carter, 1992), farmers' choice (Neupane and Thapa, 2001), willingness to engage (Magar et al., 2020), and farmers' education (Hammerton et al., 2018) as the crucial parts of operationalizing agroforestry practices. This indicates that agroforestry should be built on farmers' traditional knowledge, confidence, and their community of practice in farming system, rather than technically fine but complex agroforestry systems.

More than two-thirds of the agroforestry practices are representative of mid-hills that are initiated and implemented at the individual farmers' level, with small landholdings. This indicates that agroforestry practices are still confined to the household level, and out-scaling and up-scaling of agroforestry practices at the wider community level for broader social and ecological benefits is still lacking. Similar to our findings, other research also suggested for upscaling of agroforestry for economic benefits and livelihoods in India (Singh et al., 2016), land use integration in Ethiopia (Guteta and Abegaz, 2016), restoring overall socioecological interactions in Brazil (Tubenchlak et al., 2021), balancing water, energy, land and crop dynamics in the Sahel region of Africa (Elagib and Al-Saidi, 2020), and tropical landscape management and ecosystem restoration (Miccolis et al., 2019; Plieninger et al., 2020). Plantation of multipurpose (including fruit and fodder) tree species in farmland or retainment of naturally grown tree has been the most popular and frequently observed management interventions in Nepal's agroforestry practices. Not only in Nepal, the multipurpose tree plantation is popular in other countries as well, including India (Semwal et al., 2013), Central America (Plath et al., 2011), and Indonesia (Rahmawaty et al., 2020). Although some practices such as commercial crops under tree shade, coffee and fruit tree plantation are being recently practiced, the implementation of those practices at mass scale is lacking.

An important feature of agroforestry is to support crops and grain production along with forest products simultaneously, as observed in almost all the selected literature. Although very few literature explicitly mentioned the ES supplied through the agroforestry practices (Kuyah et al., 2019; Shin et al., 2020; Torralba et al., 2016), we depicted that agroforestry is supplying all categories of ES such as provisioning (i.e., crop and grains, and forest products), regulating (i.e., carbon and climate services, and disaster risk minimization), supporting (i.e., biodiversity conservation, and soil retention), and cultural (i.e., religious value and landscape aesthetic) ES. Besides, our review showed that agroforestry has very high potentials to supply food, fibre, and terrestrial ES, simultaneously. Moreover, efforts to end poverty and climate action are found to be substantially supported by agroforestry practices. A study by Waldron et al. (2017) also found that agroforestry can increase food production while serving other environmental objectives, simultaneously. Likewise, van Noordwijk (2020) also reported that agroforestry offers synergies among SDGs and can minimize trade-offs in environmental and economic goals. Agroforestry practices are being considered as promising models for rural development in Lao PDR (van der Meer Simo et al., 2020), and socio-economic upliftment in Malaysia (Musa et al., 2019). However, comprehensiveness in designing agroforestry interventions and assurance of effective implementation mechanisms are important in delivering multiple ES and development goals.

Further, the success of agroforestry depends on which form of agroforestry is being practiced and how integrative are the program activities in terms of addressing ecological, social, and economic dimension of people and landscape. We found SZDP as one of the integrated agroforestry practices being implemented in Nepal, which has taken forest, agriculture, and livestock as the core component of agroforestry, and is supplemented by other activities such as land productivity management, natural hazard prevention, infrastructure protection, water source protection, social inclusion, and livelihood improvement (Aryal et al., 2019). This integrated approach is integrative of core ecological factors, supported with other social, economic, and supporting functions for multi-functionality of land use practice. This approach to agroforestry can be a framework for agroforestry transition for the early adopters such as Lao PDR, Myanmar, and other countries with similar socio-economic conditions.

4.2. Drivers of agroforestry transformation

Comprehensive planning and effective implementation of agroforestry is dependent on multiple social, economic, and institutional drivers. Various studies have conducted to understand the factors affecting agroforestry, such as in Pakistan by Irshad et al. (2011), in Cameroon by Nkamleu and Manyong (2005), in Ethiopia by Gebru et al. (2019), in South Africa by Mwase et al. (2015), and in India by Chouhan et al. (2017). The common factors affecting agroforestry is found to be farmers' perception and socioeconomic characteristics (Irshad et al., 2011), initial cost of agroforestry (Mwase et al., 2015), household characteristics and security of land tenure (Nkamleu and Manyong, 2005), and management and adaptation strategies (Gebru et al., 2019). Our findings are in-line with the previous literature. For example, He et al. (2015) and Gregorio et al. (2015) emphasized selecting appropriate tree species is crucial in agroforestry, Chavan et al. (2015) and Guillerme et al. (2011) stressed on government policies to have strong influence on farmers' preference and overall agroforestry development, and others (i.e., Chowdhary et al., 2019; Coe et al., 2014) believe on technology advancement to manage agroforestry to meet the emerging multiple needs of people. As observed by Mwase et al. (2015) that agroforestry practices demands high establishment costs, we also found that availability of economic incentives substantially affect agroforestry practices.

Besides, other drivers of agroforestry are also revealed in previous literature, such as, (1) lack of market for agroforestry products (García de Jalón et al., 2018; Gyau et al., 2014), (2) distance from home to market and scale of products for selling (Pello et al., 2021), (3) long waiting period for the return on investment in agriculture (Atangana et al., 2014; Dhakal and Rai, 2020), (4) overlapping government jurisdictions and fragmentation of sectoral policies such as, Department of Forest and Soil Conservation, Department of Agriculture, Department of Land Management, Department of Roads (Aryal et al., 2021a), and (5) lack of coordination among the government, non-government and community stakeholders in case of agroforestry (Laudari et al., 2019; Singh and Dhyani, 2014). As we found numerous factors are affecting agroforestry, efforts on agroforestry development however have largely been confined to the plantation/retention of tree species in and around the farmlands (Aryal et al., 2019). To transform agroforestry practices for ES and SDGs, interventions in agroforestry must also address those factors which affect it including, socio-economic drivers, land tenure, economic incentives and market access, capacity building and technological development, climate change adaptation and coordination among the stakeholders.

4.3. Agroforestry, ecosystem services and sustainable development goals

Growing demands of provisioning ES (i.e., at the local level) and non-provisioning ES (especially at the regional and global scale) has put a great challenge in land use planning and landscape management. For example, growing demand of foods (i.e., an increase of 59–98 % by 2050 (Elferink and Schierhorn, 2016)) on one hand, and satisfying the climate goals of keeping temperature < 2° above preindustrial levels on the other, complicate land use planning. To this front, agroforestry as a land sharing approach to conservation and development, which is being practiced in almost half of the farmlands worldwide (Oli et al., 2015; Zomer et al., 2009), can be improvised and upscaled to achieve diversified needs of society and nature. Various studies have already pointed to agroforestry as one of the best policy alternatives to minimize land use conflicts and to support SDGs through the supply of various provisioning and non-provisioning ES (Jose, 2009; Kuyah et al., 2019; Leimona and van Noordwijk, 2017; Martin et al., 2020; van Noordwijk, 2020; Waldron et al., 2017). Few studies further claimed that agroforestry is the best suitable program to low and middle income countries in the tropics to achieve SDGs (Castle et al., 2021; Martin et al., 2020). Nevertheless, those references are inadequate to clarify the modalities and pathways of agroforestry for ES and SDGs from the contested landscapes in the tropics.

We found that the integrated approach to agroforestry has a very high potential to address trade-offs in ES by providing multiple yet conflicting ES simultaneously. Fig. 7 shows the form and framework of agroforestry, which simultaneously produces various competing ES from the contested landscape. Integrated approach to agroforestry, comprising various complementary and supplementary programs to the core components, is instrumental to supply various ES simultaneously, which ultimately leads to the achievement of SDGs. Integration of trees and crops is the inherent feature of agroforestry, which also comes with the livestock component (Nair et al., 2021b). Focused activities such as tree plantation in croplands, improved agriculture, farmyard manuring, high-tech nurseries establishment, improved breeding, and silvicultural management are indeed the fundamentals of agroforestry.

Management of core components is not sufficient to supply multiple ES, and hence, must be complemented by various landscape management activities, including soil conservation and watershed management, infrastructure protection and natural hazard prevention, social inclusion and empowerment, and economic development activities (Aryal et al., 2019; Buck et al., 2020). As observed in SZDP in Nepal, integrated approach to agroforestry should consider comprehensive land management, including land, water, vegetation, and climate perspectives (Aryal et al., 2019; Jarrett et al., 2017). Nevertheless, because of the heterogeneity in tropical farming system (Adhikari, 2018), site-specific land use management must be developed and implemented to ensure integrated and adaptive agroforestry programs. As noted by Khadka et al. (2021) that agroforestry is a powerful tool for profit maximization from a small piece of land, economic considerations such as initial costs of agroforestry establishment, production cost, and market

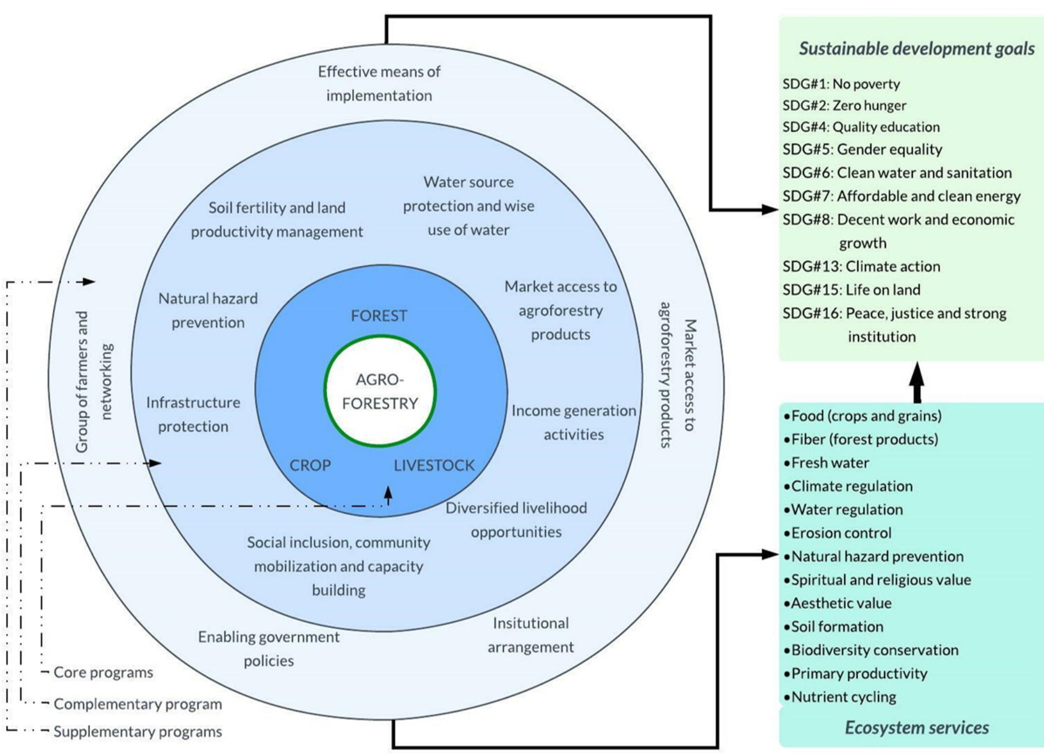

Fig. 7. Linkages of agroforestry, ecosystem services and sustainable development goals.

orientations must also be considered while implementing agroforestry. In addition, economic incentives and opportunities for employment and other income generating activities should be explored and implemented accordingly.

The core and complementary programs must be operated within the framework of enabling policies, institutional arrangement, and effective means of implementation. Formation of farmers' group of networks would ease individuals/communities from designing of the agroforestry to the supply of ES towards local and non-local beneficiaries. Similarly, in case of developing countries with poor socioeconomic condition and subsistence farming economy, agroforestry transition for ES and SDGs is not possible without assuring viable markets for agroforestry products. The need for integrated approach to agroforestry has also been highlighted by other authors, for instance, Khanal et al. (2020) and de Foresta (2013) noted that holistic approach to legal and institutional provisions are necessary for agroforestry development. Likewise, van Noordwijk (2020) stressed on effecting means of implementation of agroforestry to achieve the desired outcomes from its implementation. Institutional arrangement for the implementation of holistic landscape management is crucial in advancing agroforestry alternatives as suggested by various authors (i.e., Cechin et al., 2021; Ndlovu and Borrass, 2021; Stewart, 1988). Besides, sustainable market for ES is crucial to attract and sustain subsistence farming system towards integrated agroforestry practices (Aryal et al., 2021b; Mercer et al., 2014; Ranjan, 2021). Systematic operation of agroforestry interventions, being in line with enabling government policies and strategies, and within the effective institutional and implementation arrangement would result in integrated approach of agroforestry to supply ES and support SDGs.

The linkage between agroforestry, ES, and SDGs is not obvious, but dependent on the scale and scope of agroforestry practices. To illustrate, forest-based traditional agroforestry practices are not likely to have positive impacts on climate smart farming, (agro-) biodiversity and others, instead they contribute to the loss of forest and biodiversity (Martin et al., 2020). In this regard, Paul et al. (2017) also mentioned that agroforestry might not be a suitable option for climate with extreme weather and society with farmers who need immediate income from the land use practices. To an extreme, Ollinaho and Kröger (2021) claimed that agroforestry can just be an approach to entail deforestation and expansion of agribusiness. Similarly, Murthy et al. (2017) mentioned that agroforestry can create trade-offs by reducing farm yields, increasing competition for water and nutrients, and demanding labour intensive management. Considering the possible outcomes of agroforestry, we, therefore, argue for the integrated approach which consider multiple domains of socio-ecological systems and address the plausible concerns in a sustainable manner.

Integrated approach to agroforestry, as shown in Fig. 7, can establish the strong linkages with the supply of ES and SDGs. Further, in the contested landscape, agroforestry is considered as the best policy alternative to minimize trade-offs and maximize synergies among ES because of the following reasons: (1) supports food security, rural livelihoods, employment and diversified source of income (Dhakal et al., 2012; Rana et al., 2018; Tiwari et al., 2012); (2) addresses climate issues, including agricultural adaptation (Adhikari, 2018; Ahmad et al., 2021; Biggs et al., 2013); (3) improves land productivity and soil functioning (Regmi and Garforth, 2010); (4) increases economic return from either of agriculture and forestry alone (Khadka et al., 2021; Neupane and Thapa, 2015); (5) minimizes pressure on forestland and reduces deforestation (Giri and Katzensteiner, 2013); (6) utilises abandoned and marginal lands (Cedamon et al., 2018; Dhakal and Rai, 2020); (7) establishes sustainable soil management practices (Schwab et al., 2015); (8) allows synergistic interaction among woody and non-woody services (Oli et al., 2015); (9) suits traditional and indigenous practices in many tropical regions (Carter, 1992; Dhakal et al., 2015); and (10) supports financially challenged and disadvantaged group of people (Acharya, 2006; Pandit et al., 2019). To supply all those services simultaneously across time and space, agroforestry practices need to be managed through holistic and integrated approach as shown in Fig. 7.

We acknowledge that more action-research is needed to make the explicit linkages of agroforestry to ES and SDGs. Our study could further be enriched by measuring and quantifying various ES from SZDPs in Nepal, to elaborate the strength of linkages among agroforestry and ES, which we recommend for future course of research. Nevertheless, based on our analysis, we depicted the importance of agroforestry in supplying various ES (i.e., minimizing trade-offs and maximizing synergies). As a promising policy alternative to ensure balanced supply of ES, an integrated approach to agroforestry is recommended with the following approach: (1) agroforestry practices should be prioritized in farmlands rather than in forestland because forest based agroforestry might be counterproductive to forest, carbon and biodiversity, (2) agroforestry practices must consider forest, farm and livestock as the core component, however, priorities might differ according to the site-specific conditions, socioeconomic background and environmental objectives, (3) soil and watershed management activities (i.e., integrated watershed management at micro-catchment level) must be designed and carried out to complement the core programs to minimize the trade-offs in ES, (4) current practice of household levels of agroforestry should be upscaled by forming farmers' group or other forms of networking for effective and efficient agroforestry management, and (5) enabling policies, institutional arrangement, economic incentives to the farmers, and markets for agroforestry products must be assured to catalyse the transformation of agroforestry practices.

5. Conclusion

We reviewed and analysed agroforestry practices in Nepal from the perspective of its form of origin, management modalities, and programs to supply ecosystem services (ES) and sustainable development goals (SDGs). Over the past half century, the practice of agroforestry has been shifted from forest-based (i.e., shifting cultivation, Taungya) to farm-based (i.e., agri-silviculture). We revealed 12 different forms of agroforestry practices reported in Nepal, in which agri-silviculture is the most studied form of agroforestry. Agroforestry is reported to supply wide range of ES ranging from provisioning to non-provisioning. Previous studies claimed that 8 SDGs are supported by agroforestry programs. Package-based integrated agroforestry program, implemented under the Super Zone Development Program of Nepal, was found to be effective in supplying various ES simultaneously, along with the substantial increase in target products (i.e., crops, fruits, and vegetables).

Our findings show that agroforestry program should be implemented in a holistic and integrated framework. As we found, agroforestry program is affected by various socio-economic, institutional, and ecological factors, thus interventions in agroforestry must accordingly be based on all those factors comprehensively. Nevertheless, agroforestry practices are site-specific and should be built on farmers' knowledge and community of practice, and the good practices must be up-scaled and out-scaled for wider application. We have discussed the linkages of agroforestry with ES and SDGs and found that integrated agroforestry implies a positive relationship with various ES (i.e., 13 ES as categorized in Millennium Ecosystem Assessment Report) and 10 SDGs (including no poverty, zero hunger, climate action, and life on land). In this regard, agroforestry practices which is believed to be practicing in half of the world's farmland, possess a promising policy alternative in the contested landscape to minimize trade-offs in ES by addressing ecosystem restoration objectives and SDGs. In order to translate the policy alternative into practice, we suggest an integrated approach to agroforestry that contains: (1) core programs: integrated management of forest, farm and livestock, (2) complementary programs: holistic management of the landscape, including soil and watershed management activities, social inclusion, livelihood and employment generation, infrastructure protection, and natural hazard prevention, and (3) supplementary programs: enabling policies and institutional arrangement, including organizational development, market assurance, and effective means of implementation of the core and complementary programs.

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CRediT authorship contribution statement

Mr. Kishor Aryal: Conceptualization, Visualization, Data curation, Formal Analysis; Methodology; Validation; Writing-Original draft preparation, Writing-Review & Editing.

Prof. Tek Maraseni: Writing-Review & Editing, Supervision.

Prof. Armando Apan: Writing-Review & Editing, Supervision.

Data availability

Data will be made available on request.

Declaration of competing interest

Authors declare no conflict of interest.

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