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Agroforestry—a key tool in the climate-smart agriculture context: a review on coconut cultivation in Sri Lanka

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Long-term monoculture of coconuts has resulted in several land-use-related concerns, such as decreasing land productivity, degraded soil, and ineffective resource utilization on a local and global level. Modifying traditional coconut farming with agroforestry concepts is a well-suited predominant nature-based solution for Sri Lanka as well as for other coconut-growing countries to achieve environmental, social, and economic benefits. By intentionally and intensively integrating annual and perennial plants with farm animals in a dynamic and interactive manner, this land-use system creates a sustainable harmonious mini-ecosystem with landscape restoration. Agroforestry mixed with coconut cultivation decreases the risk of crop failure, generates additional income sources, and balances the ecosystem functions by increasing species richness, enhancing soil physical, biological, and chemical properties, opening new carbon sequestration pathways, purifying air and water sources, and being an excellent feedstock source for bioenergy generation. This environmentally friendly farming will promote the Kyoto Protocol and lessen global warming by limiting the atmospheric buildup of greenhouse gases. A proper and accurate plan is required to implement a successful and profitable long-lived coconut-based agroforestry system. The objective of this paper is to recognize the various agroforestry concepts applicable to coconut-based farming, highlight the wide range of benefits and ecosystem services that can be gained through *in-situ* and ex-situ agroforestry practices, and explore the challenges that may arise during the integration of agroforestry techniques into a coconut-based farming system.

KEYWORDS

carbon sequestration, coconut monoculture, landscape restoration, land-use system, sustainable mini-ecosystem

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GRAPHICAL ABSTRACT

Highlights

- The most relevant papers on agroforestry and coconut-based farming systems published between 2000 and 2022 were searched and reviewed.
- The papers were analyzed, focusing on simultaneous and sequential farming principally practiced in resource-limiting scenarios.
- Coconut-based climate-smart agricultural components, challenges, potential solutions, and supporting technologies were presented and reviewed.
- The benefits of coconut-based climate-smart agriculture for biodiversity conservation and sustainability management were discussed.
- A proper and accurate plan is required to implement a successful long-lived coconut-based agroforestry system in Sri Lanka.

1 Introduction

Coconut (*Cocos nucifera*) is a leading plantation crop that earns considerable export earnings in Sri Lanka (Pavalakumar et al., 2023). It is a tropical palm classified under the family Arecaceae. More than 400,000 ha of lands or in other hand nearly 20% of arable lands in the country is used to cultivate coconuts covering all agro-ecological regions: intermediate (50%), wet (30%), and dry (20%) zones (Godage et al., 2021; Raveendra et al., 2021). In 2019, Sri Lanka produced approximately 3,086 million coconut nuts, placing it as the fourth largest coconut producer, well behind Indonesia, the Philippines, and India, but significantly ahead of most other coconut-growing countries (Panda et al., 2020; Dissanayaka et al., 2022).

The Coconut Research Institute of Sri Lanka recommends growing 158 palms per 10000 m^2 as the ideal planting density, with an 8 m × 8 m spacing, based on the canopy and root architecture of coconut palms (Advisory Circular, 2018). Nevertheless, the average land utilization of one coconut palm is about 15.4%, leaving 84.6% of the land unoccupied (Senarathne and Udumann, 2019). As a result, biophysical resources such as space, sunlight, water, and labor are not completely exploited in monocropping systems for coconuts and yield lower returns per unit of land area than in other agricultural sectors (Nuwarapaksha et al., 2022). Apart from that, the main obstacles facing this industry include soil erosion, consistent revenue generation, and other associated risks.

Coconut farming with agroforestry is a well-suited predominant nature-based solution for Sri Lanka that might overcome most of these problems while boosting its economic needs. Agroforestry is a complex, but flexible, system of land use patterns and cultivation technologies that blends various tree components, seasonal crops, and/or animal components, targeting the environmental, social, and economic benefits (Maponya et al., 2021). A long-lived coconut palm represents the tree component in this situation. Other components are maintained under the free space among the coconut canopies/squares. Agroforestry is a particular configuration of trees, crops, and animals in space and time (Ayyam et al., 2019). The unique arrangement of the system is determined by the woody components (Ruslanjari et al., 2020). Based on the lifestyle and needs of the population, the quality of the land, and the local climate, the system, and its agronomic structures vary from region to region and country to country (Paudel and Shrestha, 2022).

Although the term “agroforestry” is relatively new to the world, its principles/concepts have been practiced for a long time ago in every part of the world (Patra, 2022). In the Southeast Asian region, agroforestry has integrated 77.8% of all agricultural land. In contrast, it accounts for 50.5% of land in East Asia, 27.0% in South Asia, and 23.6% in Northern and Central Asia (Park et al., 2022). This practice started in home gardens about 25 centuries ago in Sri Lanka to protect forests, wildlife, and plants and beautify nature (Nianthi, 2010). Other than that, some agroforestry concepts practiced in ancient times in Sri Lankan history were coconut-based agroforestry systems with capsicum, gliricidia, cocoa, and coffee cultivations in coastal regions, coconut planting as an alley cropping system, cattle grazing in coconut plantations, coconut planting in home gardens, and chena cultivation (Paudel and Shrestha, 2022).

As evidence of its beneficial impacts, it has received increased attention globally in recent years. Meantime, research publications on agroforestry have increased (Figure 1). New trends in agroforestry as a climate-smart agricultural system have been identified by the Intergovernmental Panel on Climate Change (IPCC) and the United Nations Framework Convention on Climate Change (UNFCCC) to mitigate future climate changes as a pathway for balancing ecosystem services realized by the United Nations Forest Forum (UNFF), as an effective biodiversity convention method recognized by the Convention on Biological Diversity (CBD), and as a pathway for Nationally Appropriate Mitigation Action (NAMA) and National Adaptation Program of Action (NAPA), which have been developed with the requirements of current world (Park et al., 2022). The objectives of this review are to assess and understand (1) the concepts of agroforestry, (2) the benefits and services of the agroforestry system, and (3) the limitations of practicing coconut-based agroforestry farming.

2 Components of coconut agroforestry systems

Trees, crops, and livestock are major components of this complex farming practice. These elements are combined in a complementary or neutral manner, considering both above-ground and below-ground resource utilization.

2.1 Botanical species

This component includes annual and perennial grasses, shrubs, and trees (Mosquera-Losada and Prabhu, 2019). Before incorporating crops into the coconut monoculture system, it is preferable to assess the availability of resources, such as water content, shade level, land topography, soil and crop characteristics, labor and market demand, farmer preference, and socio-economic factors, aside from the age of the palm (Nuwarapaksha et al., 2022). In the Pacific region, traditional coconut mixed agroforestry systems are characterized by fruit crops and other valuable trees such as breadfruit (*Artocarpus altilis*), traditional banana and plantain clones (*Musa* spp.), citrus (*Citrus* spp.), Malay apple (*Syzygium malaccense*) and Polynesian vi-apple (*Spondias dulcis*) (Thaman et al., 2006). In Asian tropical regions, diverse groups of crops, including beverages, fodders, and pasture species, fruit and nut-yielding crops, green manure and cover crops, medicinal and aromatic crops, millets, pulses, oil seeds, spices, tuber crops, vegetables, and floricultural crops are integrated with coconut either as intercrops, support trees, on-farm boundaries, or scattered trees in coconut based agroforestry

FIGURE 1
Academic publications trend of agroforestry and related services in the Asian regions between 2010 and 2018, based on data of Park et al. (2022).

systems (Kumar and Kunhamu, 2022). Most of these crops are suitable for local coconut farming (Nuwarapaksha et al., 2022; Paudel and Shrestha, 2022). Since most medicinal plant species are adaptive to diverse environmental conditions, they are ideally suited for the ground layer of perennial tree cultivation besides grasses. Aloe vera (*Aloe indica*), asparagus (*Asparagus racemosus*), and misridana (*Kaempferia angustifolia*) are such species that can be easily intercropped with coconut (Bari and Rahim, 2012).

2.2 Animal species

Mainly indigenous breeds are reared in this system. The average herd size is around 20-100 heads, depending on the animal type, resource availability (land and feeding material), and cropping pattern. It is mostly family members that take care of these animals (Oyelami and Osikabor, 2022). As the livestock component, cattle, buffalo, goat, swine, poultry, duck, rabbit, apiculture, and aquaculture farming is practiced under coconut palms (Prastyaningsih et al., 2019; Kumar and Kunhamu, 2022).

3 Classification of agroforestry systems in the tropical zone

Even though there are no clear margins, several agroforestry systems have been identified based on the degree of major component integration (Table 1 and Figure 2).

Based on their level of productivity, agroforestry systems can also be divided into three primary groups: commercial, intermediate, and subsistence systems (Ayyam et al., 2019). Commercial agroforestry systems are operated targeting a single commodity at a large scale, employing a sizable labor force. Subsistence agroforestry systems are maintained to meet the fundamental needs of the landowner and his family, in which the surplus harvest can be sold. Intermediate systems exhibit these systems' mixed characteristics (Ayyam et al., 2019). Rethman et al. (2007) classified these systems into new subclasses considering the time scale of farming as simultaneous and sequential farming. In simultaneous farming, trees and crops are grown in the same field simultaneously, while in sequential farming, they are raised separately during cropping and fallowing seasons.

4 Services from coconut-based agroforestry implementation

4.1 Decreasing the risk of crop failure and generating additional income sources

This may open different entrepreneur opportunities to gain additional income for farmers and generate job opportunities for the surrounding area (Table 2). In addition to food and beverages, agroforestry systems facilitate nature-based products such as timber (carpentry and wood carving), handmade items, sawmilling products, essential oils, fiber, honey, and bio-briquette (Atreya et al., 2021; Kumar and Kunhamu, 2022; Nuwarapaksha et al., 2022). Herbal wealth, especially for pharmaceutical products and local medicines (Ayurveda), also can be easily obtained from agroforestry systems. Multipurpose trees, bushes, and animals in the agroforestry system will make an ecotourism site more appealing in addition to the advantages already described.

Combining diverse crop species with various crop characteristics reveals different stress tolerance levels for biotic and abiotic stresses (Rivest et al., 2013). Furthermore, due to their potential for producing allelochemicals and bio-pesticides, elements of the agroforestry system occasionally serve as biological barriers for controlling harmful weeds, diseases, insect pests, and nematodes

TABLE 1 Major agroforestry systems in the tropical region, adapted from Ayyam et al. (2019); Dhyani et al. (2021), and Sharma et al. (2016).

Agroforestry	Major components	Examples
Agri-silvicultural systems	Integrating annual and perennial plants and crops that have different growth forms	Shifting cultivation, Chena* Plantation-based cropping system* Scattered trees on farms, parklands* Shelterbelts and windbreaks Boundary planting and live hedges Woodlots for soil conservation Industrial plantations with crops Home gardens*
Silvi-pastoral system	Integrating trees, pasture with/without livestock	Silvi-pastures Horti-pastoral Tree on rangelands* Plantation crops with pastures Seasonal forestry grazing
Agri-silvi-pastoral systems	Integrating crops, pasture, and trees with livestock	Home gardens* Multipurpose woody hedgerows
Apiculture with trees*	Integrating trees with bees	
Aqua forestry	Integrating trees with fish	

*Present in Sri Lanka.

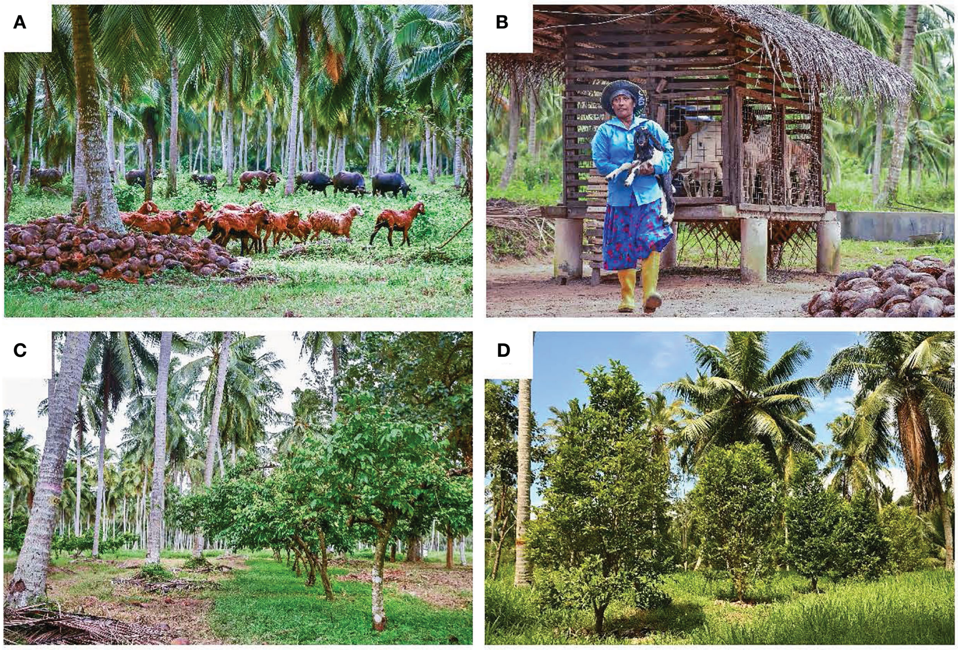

FIGURE 2
Different coconut-based agroforestry systems **(A)** Silvi-pastoral system with coconut, goat farming, and buffalo farming; **(B)** Goat housing system under the coconut-based silvi-pastoral system; **(C)** Agri-silvicultural systems with coconut and cocoa farming; **(D)** Agri-silvicultural systems with coconut and resin crop (*Gyrinops walla*) farming.

(Reddy, 2017; Ayyam et al., 2019). Therefore, crop losses from biotic stresses are much lower in this land use system than monoculture field.

Less availability of good quality feeding materials is a major constraint in local livestock farming, especially in the dairy industry (Zoysa, 2017). Most livestock farmers select cut and carry feeding system harvesting fodder materials from roadsides, common areas, and surrounding fields. Silvopastoral systems supply high-quality forage and enhance forage availability for livestock farming with minimum cost and effort (Smith et al., 2022). Since resource requirements including nutrients, moisture, and light of coconut and forage/fodder species are completely different, the interspecific competition in this system is near zero. That will encourage fodders to grow freely without biotic and abiotic stresses. *Brachiaria milliformis*, *Brachiaria brizantha*, and *Brachiaria ruziziensis* are some fodder and pasture species that can be cultivated in Sri Lankan coconut plantations (Dissanayaka et al., 2022).

4.2 Maintaining a healthy and active ecosystem

Successful coconut-based agroforestry systems increase the utilization and management of resources (land, labor, water, light,

TABLE 2 Economics data (average from 2005 to 2007) of coconut agroforestry with medicinal plants based on data of Bari and Rahim (2012).

Treatments			Benefit-cost ratio
Upper layer	Middle layer	Ground layer	
Coconut	Guava	Aloe vera	3.54
Coconut	Lemon	Aloe vera	2.82
–	–	Aloe vera (as open cultivation)	1.65
Coconut	Guava	Asparagus	3.21
Coconut	Lemon	Asparagus	3.08
–	–	Asparagus (as open cultivation)	1.87
Coconut	Guava	Misridana	5.06
Coconut	Lemon	Misridana	3.83
–	–	Misridana (as open cultivation)	2.33

'-' means no crops are cultivated in upper and middle layers.

nutrients, time, space, and finance). As a collection of a wide range of flora and fauna, agroforestry establishment supports many ecosystem services that provide human and animal well-being (Mosquera-Losada and Prabhu, 2019). According to Atreya et al. (2021), these benefits and ecosystem services can be classified into four main subcategories: impacts on biodiversity, soil characteristic, carbon sequestration, and water and air quality.

4.3 Increasing biodiversity

Even though the South Asian region has high biodiversity, rising population, high deforestation, switching agricultural fields to other uses, frequently occurring natural disasters such as forest fires, climate change, high reliance on forest products, and an increase in the presence of invasive species have created a high threat on the biodiversity (Baliton et al., 2017). As a collection of a wide range of living beings, agroforestry establishment also increases the species richness in the cultivated lands and surroundings. Playing a significant role in conserving different genetic makeup without additional costs, agroforestry would provide a home for a wide range of microorganisms, flora, and fauna (Kumar and Kunhamu, 2022). Altogether, it creates a stable and balanced mini-ecosystem connecting biotic and abiotic components on coconut-growing land. Diverse vegetation cover reduces habitat fragmentation and increases habitat and landscape quality without sacrificing the farmer's objectives. It also restores the habitats of various endangered species, conserving biodiversity and reducing the rate of habitat loss, unlike traditional and conventional farming operations (Prastyaningsih et al., 2019; Ruslanjari et al., 2020). Other than that, abundant flowering species and medicinal plants in the system would attract predators and other useful organisms, including birds, pollinators, lacewings, ladybirds, hoverflies, and parasitic wasps to the field and increase the pollination activities and suppress pest and pathogenic activities (Reddy, 2017). Agroforestry practice will encourage ecological corridors between fragmented flora and fauna habitats (Jose, 2009). In the future, preserved agroforestry germplasm collections would serve as a source for genetic engineering and better variety development (Ayyam et al., 2019).

4.4 Soil health improvement

By incorporating different agroforestry systems into the degraded coconut fields, soil health can improve by enhancing its physical, chemical, and biological properties (Atapattu et al., 2017b). As a collection of diverse rooting behaviors and structures, the agroforestry system will help to control soil erosion, especially in sloppy areas. Sub-sectors of agroforestry, such as wind-breakers, alley cropping, and riparian buffers, would control wind-transported fine material erosion, which is a major challenge in arid and semi-arid environments (Toma et al., 2021). On-ground vegetation cover minimizes water loss from transpiration and evaporation, thus conserving soil moisture. In addition, different canopy structures can slow down the kinetic energy of rainfall, which can damage the soil structure and can cause water erosion (Atreya et al., 2021).

Furthermore, agroforestry reduces soil nutrient leaching by controlling surface runoff and improving water infiltration to the deeper soil layers (Sharma et al., 2016). Each component of this system helps to restore soil nutrient content: deep root systems transport nutrients from the deeper soil layers to the surface layers, and plant biomass and livestock waste materials are excellent sources of manure (Sharma et al., 2016). Previous research has shown that N-fixing plants like *Acacia* spp. and *Gliricidia* performs better in terms of soil organic matter content, total nitrogen content, soil exchangeable potassium content, and available phosphorus content compared to the monocropping system, ultimately reducing the requirement for synthetic fertilizers (Raveendra et al., 2021) (Figure 3).

According to Abbas et al. (2017) and Hombegowda et al. (2016), the process of converting forest land into an agricultural ecosystem through deforestation can result in a substantial loss of soil organic carbon, ranging from 50-61%. It is positively proportionate to the initial soil organic carbon stock, and losses depend on clay mineralogy, soil type, climatic factors, land preparation techniques, soil conservation techniques, and the potential of soil erosion, runoff, and leaching. Agroforestry can replace the soil organic carbon pool by combining carbon inputs with diverse nutritional compositions and decomposition rates, such as leaves, roots, forests, fungi, and animals, and by confining soil losses (Hombegowda et al., 2016).

According to a previous study, the organic matter content of the soil has been significantly positively affected by the coconut and cashew agroforestry system, although in varied ways between the top soil layer and the subsoil layers (Figure 3) (Senarathne and Udumann, 2019). The rate of plant litter decomposition, root decaying, and exudation from the rhizosphere is higher in the coconut agroforestry system compared to monoculture farming. That will encourage higher soil organic matter content and water-holding capacity (Toma et al., 2021). However, the rate of application varies with crop and livestock combinations, the intensity of farming practices, and soil qualities (Tables 3, 4).

Ultimately, it increases the soil organic matter content and becomes home to a diverse range of microbial communities. The soil microbial community activates the soil enzymatic activities that will help recycle soil nutrients such as carbon, nitrogen, and phosphorus (Figure 4).

Almost all of the chemical properties in agroforestry lands are suitable for promoting plant growth. For example, the low values of base saturation in agroforestry indicate that the system is rich in macronutrients and has a lower acidification effect compared to other cropping patterns (Schwab et al., 2015). Indirectly it gives an idea about higher organic matter content and low leaching potential on the side. Additionally, agroforestry has higher clay mineral percentages and humified organic matter content, as reflected in the cation exchange capacity (Schwab et al., 2015). Finally, it can be concluded that agroforestry systems are viable solutions for rehabilitating degraded coconut lands (Raveendra et al., 2021) and increasing nut yield and land productivity (Kumar and Kunhamu, 2022) (Table 5).

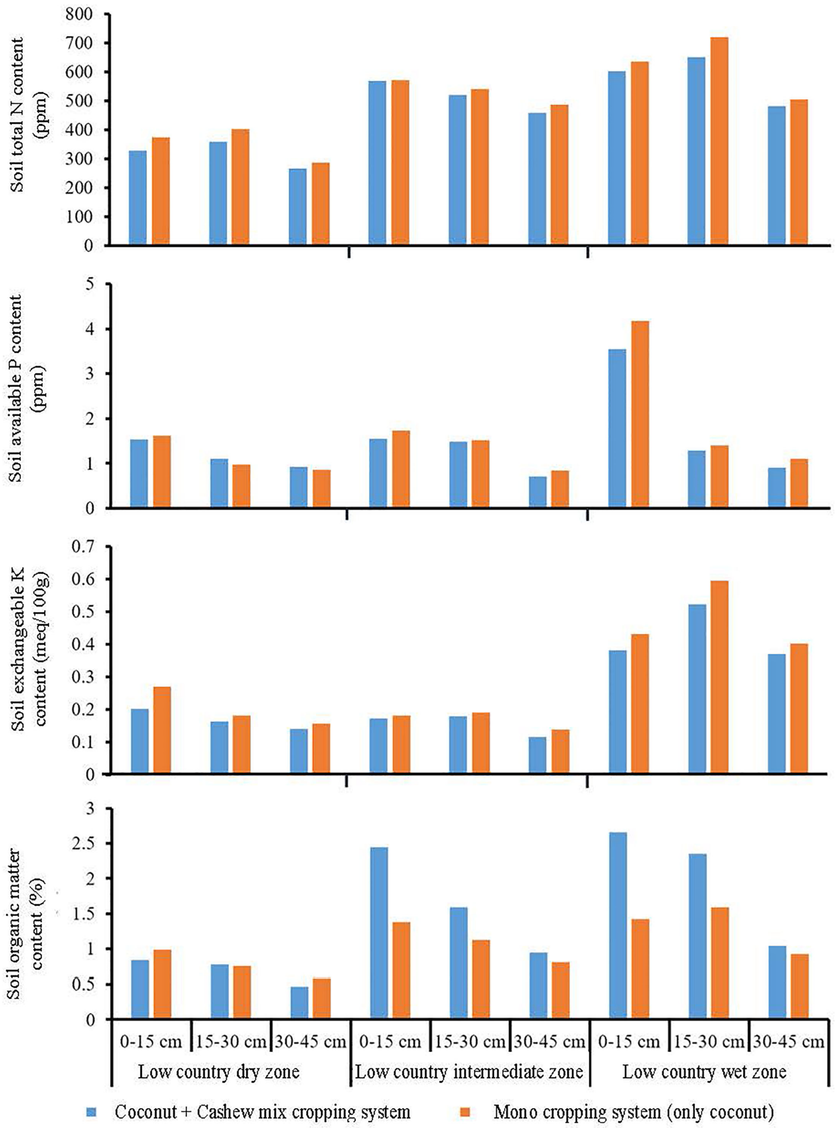

FIGURE 3
Differences between coconut monocropping system and coconut-based cashew (*Anacardium occidentale*) agroforestry system on soil chemical properties (total N, available P, exchangeable K and soil organic matter content) in wet, intermediate, and dry zones of lowland Sri Lanka, based on data of Senarathne and Udumann (2019).

TABLE 3 Percentage of relative change in soil organic carbon stock at different soil profiles after the conversion from agriculture to agroforestry systems, based on data of Hombegowda et al. (2016).

Conversion	Relative change in soil organic carbon as a % of overall change among the soil profile depths			
	0-10 cm	10-30 cm	30-60 cm	60-100 cm
Home garden to agroforestry	20	22	26	33
Coffee field to agroforestry	32	42	26	NS
Coconut field to agroforestry	17	25	24	35
Mango field to agroforestry	23	27	24	26

NS, Not significant.

TABLE 4 Soil carbon stock under different agroforestry systems in the tropics, based on data of Nair et al. (2009).

Agro-ecological zone	Agroforestry system	Soil carbon stock (Mg ha^{-1})
Humid lowlands	Shaded perennial systems	21-235
	Alley cropping	10-25
	Home-gardens	108-119
	Tree intercropping	27-76
Tropical highlands	Shaded perennial systems	21-97
	Silvopastoral systems	132-173
Arid and semi-arid lowlands	Silvopastoral systems Fodder banks Live fencing	33 24

4.5 Source of carbon sequestration

Agroforestry as an afforestation activity transfers carbon in the atmosphere to reservoirs in both above-ground (stems, leaves, and other herbaceous parts of plants) and below-ground (vegetative parts, soil organisms, and different soil horizons) biomass in the system (Ramachandran Nair et al., 2010) *via* a phenomenon called carbon sequestration. The potential of this action can be enhanced by promoting high biodiversity, minimizing the tillage activities, and applying crop residues on site (Hombegowda et al., 2016). This will help to control atmospheric carbon dioxide concentration in the surrounding environment and the harmful effects of global warming. As documented by Intergovernmental Panel on Climate Change (IPCC), agroforestry will have the highest potential of carbon sequestration by 2040 (600 Mt C year^{-1}), while grazing management (375 Mt C year^{-1}), forest management (250 Mt C year^{-1}), and crop-land management (150 Mt C year^{-1}) are lower (Watson et al., 2000). Furthermore, better maintenance of existing agroforestry lands could result in an additional 17,000 Mg C year^{-1} by 2040. With an expansion of 630 million ha, this value could increase to 586,000 Mg C year^{-1} in the future.

4.6 Acting as a natural air and water purifying system

The increased vegetation cover in the field allows more carbon dioxide to be captured and oxygen to be released into the atmosphere (Nianthi, 2010). It balances the carbon dioxide and oxygen ratio in the air while supporting the Kyoto protocol. In addition, it decreases the chance of concentrated livestock farms releasing ammonia gas and bad odor. It will slow down wind speed and wind chills, protecting crops, livestock, and buildings from extreme weather events (Jose, 2009). As a robust vegetative buffer, agroforestry systems help maintain good air quality.

A well-established agroforestry system is a cost-effective pathway to maintain active watershed hydrology (Nianthi, 2010). This practice helps clean both surface and sub-surface water bodies by removing considerable sediments, nutrients, and pesticide accumulation (Nair, 2011) and facilitating a comfortable aquatic habitat. Furthermore, it prevents the potential of eutrophication in water bodies in the ecosystem by minimizing soil erosion and maximizing plant nutrient use efficiency (Jose, 2009) (Figure 5). As an overall effect of all of these effects, it regulates flooding during rainy seasons and recharges the groundwater table (Mosquera-

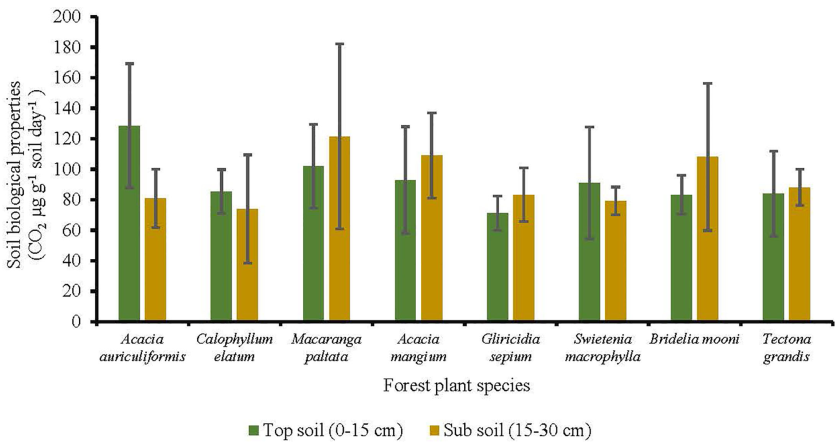

FIGURE 4
Soil biological properties of different botanical species cropped with coconut in agroforestry systems, based on data of Atapattu et al. (2017b).

TABLE 5 Effect of different agrosystems on soil chemical properties, based on data of Schwab et al. (2015).

Land use system	pH ($CaCl_2$)	Electrical conductivity (mS/cm)	Base saturation (%)	Cation exchange capacity ($cmol_c$/kg)
Conventional cropping	4.36	1.38	67.05	3.10
Transition period to agroforestry	4.50	1.90	77.68	3.13
Agroforestry	4.92	2.63	95.66	4.04

Losada and Prabhu, 2019). While being a live barrier for water loss, agroforestry systems can retain about 96.83-99.52% of rainfall annually, even in 33% sloppy land. The agri-horti-silvi-pastoral system with contour bunds, benches, and half-moon terraces can retain 98.27-99.00% of annual rainfall (Sarvade et al., 2019).

4.7 Agroforestry for energy generation

Some tree species and products in this complex system are excellent feedstock sources for bioenergy generation. For example, *Gliricidia* stems like woody materials can be utilized as firewood sources for cooking, heating, and for advanced machinery, and the generation of biochar, a charcoal-like secondary energy source (Atapattu et al., 2017a). Oilseeds can be used for the production of liquid biofuels like biodiesel, while lignocellulosic biomass can be used for ethanol production. According to previous literature, the agroforestry system has the potential to supply 70% and 20% of fuelwood requirements in Asia and African regions, respectively (Sharma et al., 2016).

4.8 As a sustainable system

Previous studies have shown that agroforestry has a substantially lower global and regional impact than a monoculture system (Utomo et al., 2016) (Figure 5). The negative impact on ecology is greatly reduced in this cropping system since fewer toxic agrochemicals and agronomic methods (such as pest and disease management, and weeding) are needed.

Agroforestry will mitigate greenhouse gas accumulation in the atmosphere by acting as a carbon dioxide and methane sink. Increasing on-farm fertilizer utilization through cultivating nitrogen-fixing legume crops, green manuring, cover cropping, and applying livestock manure and/or compost as a substitute for synthetic chemical fertilizers also reduce nitrous oxide gas emission (Sudha et al., 2021; Dissanayaka et al., 2022). Agroforestry will minimize climate changes and reduce the frequency of extreme weather events (such as flooding, drought, and high wind) occurrences, soil degradation rates, and water scarcity (Baig et al., 2021).

Species composition in agroforestry has different fire-adapted, fire-tolerant, or fire-dependent levels. These variations give different flammable load and flammability qualities, which can reduce the fire risk and number of fires per annum in an area compared to monocropping fields (Atreya et al., 2021; Damianidis et al., 2021).

Vegetation cover in the system creates the best levels of ambient temperature, relative humidity, atmospheric pressure, light intensity, and wind speed for better growth of humans, crop, and animals (Atreya et al., 2021). The beneficial micro-climatic conditions in the land reduce the heat stress on the livestock and help to rear animals healthily by maintaining favorable shade and temperature levels for better pregnancy rates, animal fertility, and productivity, including meat, eggs, milk, honey, and wool, which can be increased while reducing weight loss (Ramil Brick et al., 2022).

Considering the benefits of this multi-functional cropping system above, agroforestry can be identified as one of the key pathways for achieving the Sustainable Development Goals (SDGs) launched in 2015 (Waldron et al., 2017; Octavia et al., 2022). In

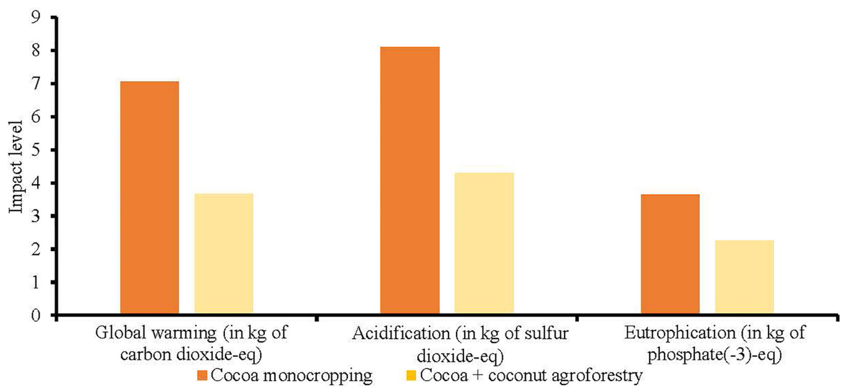

FIGURE 5
Impact on climate change level of 1 ton of cocoa pod production as monoculture or as agroforestry, based on data of Utomo et al. (2016).

summary, it covers mainly SDGs on zero hunger (Goal 2), clean water and sanitation Goal 6), affordable and clean energy (Goal 7), decent work and economic growth (Goal 8), sustainable cities and communities (Goal 11), responsible consumption and production (Goal 12), climate action (Goal 13), and life on land (Goal 15), although it can be linked to other goals as well.

5 Being successful in agroforestry

Proper application of agronomic practices including land preparation, selection of quality planting materials with best planting techniques and spacing, weed control, soil and moisture conservation methods, fertilization, pest and disease control, and irrigation is important for successful coconut-based agroforestry systems (Ayyam et al., 2019). If animal components are included in the system, following appropriate livestock farming practices such as feeding, housing, disease control, and vaccination is also important. Other than that, fencing, shade tree planting, and labor management are also important for a well-established agroforestry system (Mosquera-Losada and Prabhu, 2019).

6 Challenges in the agroforestry system

Several constraints keep farmers away from agroforestry implementation around the world.

6.1 Lack of policy and institutional support

Policies related to trade, land rights, labor, and taxes on agricultural products can have a negative impact on agroforestry practices (Dhyani et al., 2021; Maponya et al., 2021). Even though farmers are expected to have incentives like free access to inputs and farming security, corresponding institutions' responses are not sufficient (Baig et al., 2021). Limited technical assistance, skilled officers, demonstration sites and activities, and limited research on agroforestry practices may cause challenges in implementing agroforestry on coconut lands.

6.2 Limited knowledge of the agroforestry implementation process, its benefits, cost factors, and the market for agroforestry-based products

Poor communication between relevant parties including researchers, extension officers, farmers, market, and the government is creating a gap between research and implementation of different systems. Lack of marketing opportunities, price fluctuations, transportation difficulties, and limited processing and storage capacities limit the farmers' income (Ibrahim et al., 2019). Most of these constraints are particularly prevalent in developing countries.

6.3 Costly initiation process

A proper and accurate plan is required considering land size, existing crops in the field, market demand, and farmer status. The initial cost of planting supplies, machinery, and infrastructures could be higher (Atreya et al., 2021). They might need technical assistance for the initial phase of the establishment. High costs for skilled and unskilled labor, unavailability of skilled labor, quality of unskilled labor, and administrative costs associated with labor matters also influence low productivity in agroforestry systems (Maponya et al., 2021).

6.4 Management complexity

Presence of various biotic and abiotic stresses including heat, cold, drought, flood, salinity, weeds, pest and disease conditions, land characteristics including topography, land extend, and soil characteristics, climate and weather conditions in the region, availability of inputs such as light, water, machinery, and also farmers' socio-economic background play crucial roles in determining their the adaptation ability to this system (Nuwarapaksha et al., 2022). In addition to these, competition between crops for resources like light, space, water, and nutrients and the allelopathic action of some crops/plants may reduce the crop yield, making management more complex. Harvesting operations in taller canopy level trees, such as coconut, can also cause damage to the lower canopy layers. Sometimes birds and mammals attracted to the system may destroy the final yield, especially in fruit crops. Larger trees require an extended period of maturation which delays net return.

7 Conclusion

Coconut cultivation is one of the leading foreign exchange-earning industries, and it has spread to nearly all agro-ecological zones of Sri Lanka. The introduction of agroforestry principles into the coconut farming industry is a suitable natural solution that Sri Lanka can use to raise land productivity, mitigate some of the challenges associated with the industry, and, to a certain extent, meet the nation's economic needs. The goal of agroforestry is to achieve environmental, social, and economic benefits through the complex system of land use that combines various tree components, seasonal crops, and occasionally farm animals. Depending on mixing components, it can be categorized into agri-silvicultural systems, silvi-pastoral systems, agri-silvi-pastoral systems, apiculture, and aqua forestry. In a coconut-based agroforestry system, a wide variety of crops, such as beverages, fodder, and pasture species, fruit and nut-yielding crops, green manure and cover crops, medicinal and aromatic crops, millets, pulses, and oil seeds, spices, tuber crops, vegetables, and floricultural crops, are integrated as vegetative components with coconut, either as intercrops, support trees, on-farm boundaries, or scattered trees. Mainly indigenous animal breeds are reared as livestock or poultry components. Mixed coconut agroforestry farming reduces the likelihood of crop failure. This may generate additional income sources and also diversify diets. Furthermore, being a pathway to achieve regional and global sustainability, it balances the ecosystem functions by increasing species richness, enhancing soil's physical, biological, and chemical properties, opening new carbon sequestration pathways, purifying air and water sources, and mitigating greenhouse gas accumulation in the atmosphere. It is a simple pathway for the achievement of SDGs. Limitations on policy implementation, institutional supports, knowledge of the agroforestry implementation process, its benefits, cost factors, the market for agroforestry-based products, and costly and complex management keep farmers away from agroforestry implementation around the world. A proper and accurate plan is required to implement successful long-lived cultivation while overcoming these constraints.

Ethics statement

Written informed consent was obtained from the individual for the publication of any potentially identifiable images or data included in this article.

Author contributions

Conceptualization, DMNSD and AJA; Methodology, SSU; Validation, DKRPLD and TDN; Writing—Original Draft Preparation, DMNSD and SSU; Writing—Review and Editing, AJA, TDN, and DKRPLD; Supervision, AJA; Visualization, DMNSD and SSU; Project Administration, AJA. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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