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Review Article

Agroforestry's contribution to livelihoods and carbon sequestration in East Africa: A systematic review

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ABSTRACT

Agroforestry is a powerful practice for sustainable and regenerative intensification because it promotes multi-functional landscapes that deliver ecological functions that contribute to livelihoods, land productivity, biodiversity conservation, and other ecosystem services. Despite a large body of literature on agroforestry in East Africa, a systematic understanding of its livelihood benefits and contribution to carbon sequestration is still lacking. A systematic review was used to provide a quantitative and qualitative synthesis of available evidence and knowledge gap from 185 publications that met the selection criteria regarding the contribution of agroforestry to livelihoods ($n = 152$) and carbon sequestration ($n = 43$) in East Africa. The main livelihood benefits include fodder, food, firewood and income, reported in over 70, 63, 56 and 40 publications, respectively. These and other benefits diversify livelihoods of rural communities and act as safety nets in times of climate shocks. Agroforestry systems in East Africa stock an average of 24.2 ± 2.8 Mg C ha^{-1} in biomass and 98.8 ± 12.2 Mg C ha^{-1} in the soil. Much of the aboveground carbon is held in homegardens (34.3 ± 7.9 Mg C ha^{-1}), perennial tree-crop systems (29.9 ± 12.7 Mg C ha^{-1}) and trees on boundaries (26.7 ± 14.1 Mg C ha^{-1}). Empirical studies are needed for better understanding of belowground carbon in agroforestry and emission of greenhouse gases in different agroforestry practices. A smaller number of studies reported income from sale of carbon credits, suggesting a gap in the development of science regarding carbon rights, land tenure, tree tenure rights, and the potential impact of climate change on the growing niches of tree species in the region. The results show that agroforestry is a powerful climate adaptation and mitigation solution as it can increase household resilience and sequesters significant amounts of carbon dioxide from the atmosphere.

1. Introduction

Agroforestry is widely recognized as a land use strategy that delivers benefits for climate change adaptation and mitigation, while providing solutions for challenges facing smallholder farmers (van Noordwijk et al., 2023). At the adaptation level, agroforestry provides products (e.g. food, fodder, firewood, medicines) and income to local communities facing climate shocks. Agroforestry is also known to contribute to livelihoods by improving crop and livestock production through their influence on available soil water and light (Muthuri et al., 2004), and protection of people, places and property from the impacts of climate change such as floods. The trees prevent soil erosion by reducing the speed of water, acting as windbreaks and holding the soil by their roots (Muchane et al., 2020; Quandt et al., 2023). The benefits of agroforestry on crop and livestock production is attributed to the creation of favourable microclimate (Bayala et al., 2014), soil fertility improvement (Muchane et al., 2020), water regulation (Kuyah et al., 2019) and regulation of agricultural pests (Pumariño et al., 2015). Agroforestry can also increase the resilience of the soils to drought by building up soil organic carbon, fixing nitrogen and increasing the diversity and

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abundance of microbial community (Muchane et al., 2020). The negative effects of trees on crops through shading and competition for water are normally managed to maximize benefits of agroforestry.

As a potential part of mitigation strategies, agroforestry sequesters carbon in plant biomass and soils. Globally, agroforestry systems stores an average of about 21.4 Mg C ha^{-1} in biomass (Zomer et al., 2016). In the tropics, agroforestry systems store an average of 9, 21 and 50 Mg C ha^{-1} in semiarid, sub-humid, humid areas, respectively (Montagnini and Nair, 2004). A conservative estimate between 1.0 and 18 Mg C ha^{-1} in aboveground biomass has been suggested for agroforestry systems in Africa (Nair and Nair, 2014). These estimates are coarse and simply indicative of agroforestry's potential. Their scientific value has been questioned because some are derived from studies based on generalisations or erroneous assumptions (Nair and Nair, 2014). A quantitative synthesis of the evidence in primary studies is needed to increase our understanding about the distribution and amount of biomass carbon in agroforestry systems.

There are high expectations about the role of agroforestry as a strategy for carbon sequestration. First, agroforestry is mainly practiced by subsistence farmers who may benefit from climate finance, even when the absolute amounts are modest. Second, agroforestry has been identified by many countries as a strategy for achieving their restoration targets (Mansourian and Berrahmouni, 2021) and fulfilling the Nationally Determined Contributions (NDCs) to the Paris Agreement (Rosenstock et al., 2019; Duguma et al., 2023). Yet agroforestry is not accounted in national measurement, reporting, and verification (MRV) systems, partly because of the challenge of carbon quantification. While some progress has been made in estimation of biomass carbon in agricultural landscapes, existing literature give variable estimates, a limitation that is attributed to methodological problems (Nair and Nair, 2014). Overcoming this limitation is needed to realize the full potential of agroforestry as a pathway for climate change mitigation.

The benefits of trees on farms have been widely documented, and constitute a large body of literature on agroforestry in East Africa. However, a systematic understanding of agroforestry's contribution to livelihoods and carbon storage is still lacking. This is because many of the existing reviews focused on the impact of agroforestry on crop productivity, mainly plot level experimental or observational studies. There exist reviews on agroforestry in Africa that describe the benefits of specific trees, for example *Piliostigma thonningii* (Hailemariam et al., 2021), African locust bean (*Parkia biglobosa*) (Houndonougbo et al., 2020), *Allanblackia* (Jamnadass et al., 2010; Schmidt et al., 2019), baobab (*Adansonia digitata*) (Gebauer et al., 2016) and *Boswellia* and *Commiphora* species (Hassan et al., 2019). Primary studies on carbon sequestration on the other hand report context specific results, depending on the site (climate, soil type) and the system (tree species, densities, age and management). Uneven geographic distribution of research and a lack of understanding of agroforestry benefits during specific climate hazards are a major knowledge gap to understanding the role of agroforestry for climate change adaptation (Quandt et al., 2023).

The overarching goal of this review is to provide both a quantitative and qualitative synthesis of available evidence and knowledge gaps regarding the contribution of agroforestry to livelihoods and carbon sequestration in East Africa. The paper describes available evidence on agroforestry-based livelihood benefits in East Africa, which is needed to enable their quantification across different agroforestry practices. It will also contribute to the understanding of the amount of carbon stored in agroforestry systems. This can help promote the usage of trees in the region, for example, in programs that aim to create additional revenue through carbon finance, and may facilitate selection of priority tree species for domestication programs aimed at linking enhanced livelihood to adaptation and mitigation through agroforestry. The focus on East Africa is motivated by the fact that agroforestry features prominently in the region's climate agenda, for example Kenya, Rwanda and Uganda have proposed agroforestry in their nationally appropriate mitigation actions (Rosenstock et al., 2019).

2. Methodology

2.1. Literature search

A comprehensive search was applied on Web of Science and SCOPUS to obtain information on the contribution of agroforestry to livelihoods and carbon sequestration in East Africa (Table 1). The search strings included agroforestry as the land use type, the location of the study and the livelihood benefits of agroforestry or metrics of carbon sequestration (Table 1). Multiple searches were conducted to ensure that a rigorous methodology was applied in getting the literature and that the review did not miss out on relevant information. Individual country names as well as the region (East Africa) were included in the search terms to limit the number of search results returned yet capture data that does not explicitly refer to the country or region where the study was conducted. This review was limited to published (peer reviewed) literature; time constraint, difficulty in identification and the unreliable nature of grey literature did not allow evaluation of unpublished literature. References of peer reviewed publications retrieved were scanned for relevant literature that was not found through the search.

2.2. Selection, screening and data extraction

A three-step process was used to filter publications and to assess their relevance (Fig. 1a). Duplicate references were removed from articles retrieved; abstracts and titles of articles retained were examined to remove irrelevant literature and to identify potential publications; publications obtained as full text were then examined and data in those publications meeting the selection criteria extracted.

The following criteria were used to select publication for inclusion in the study: (1) Studies reported in peer reviewed journals, covering all years of the database until 2022; (2) Original household surveys (interviews or group discussions), observational or experimental studies conducted on farms in East Africa; excluding pot or greenhouse experiment or laboratory studies; and (3) Studies reporting quantitative or qualitative information on at least one outcome on livelihood benefits or carbon sequestration.

Data extracted from each publication included: (1) the location where the study was conducted (country, study site and geographical coordinates), (2) the evidence base (observational, household survey,

Table 1
List of search terms used to retrieve publications indexed in Web of Science and SCOPUS. Timespan = all years of the database until 2022; language = English and French. Search by all fields was used because it yielded more records from Web of Science Core Collection compared to search by topic. The search on SCOPUS was limited to article, review book chapter and conference paper, (excluding book, editorial, short survey, letter and data paper). Further refinement on SCOPUS included selection of countries in East Africa.

Livelihood benefits	ALL= ((income OR fruit OR nut OR timber OR wood OR fodder OR firewood OR woodfuel OR charcoal OR medicine OR gum OR resin OR "bee forage") AND (agroforest* OR "Trees on farm" OR "trees outside forest") AND (Burundi OR Ethiopia OR Eritrea OR Kenya OR Rwanda OR Somalia OR "South Sudan" OR Sudan OR Tanzania OR Uganda OR "East Africa"))
Carbon sequestration	ALL=(("Allometric equation" OR "allometric model" OR "allometric relationship" OR "allometry regression equation" OR "biomass equation" OR "biomass estimation" OR "biomass function" OR "biomass determination" OR "biometric equation" OR "aboveground biomass" OR "belowground biomass" OR "biomass density" OR "biomass carbon" OR "biomass stock" OR "carbon estimation" OR "carbon sequestration" OR "carbon stock") AND (agroforest* OR "trees on farm" OR "trees outside forest") AND (Burundi OR Ethiopia OR Eritrea OR Kenya OR Rwanda OR Somalia OR "South Sudan" OR Sudan OR Tanzania OR Uganda OR "East Africa")).

English and French were used because they are the most common languages for scientific communication in Africa.

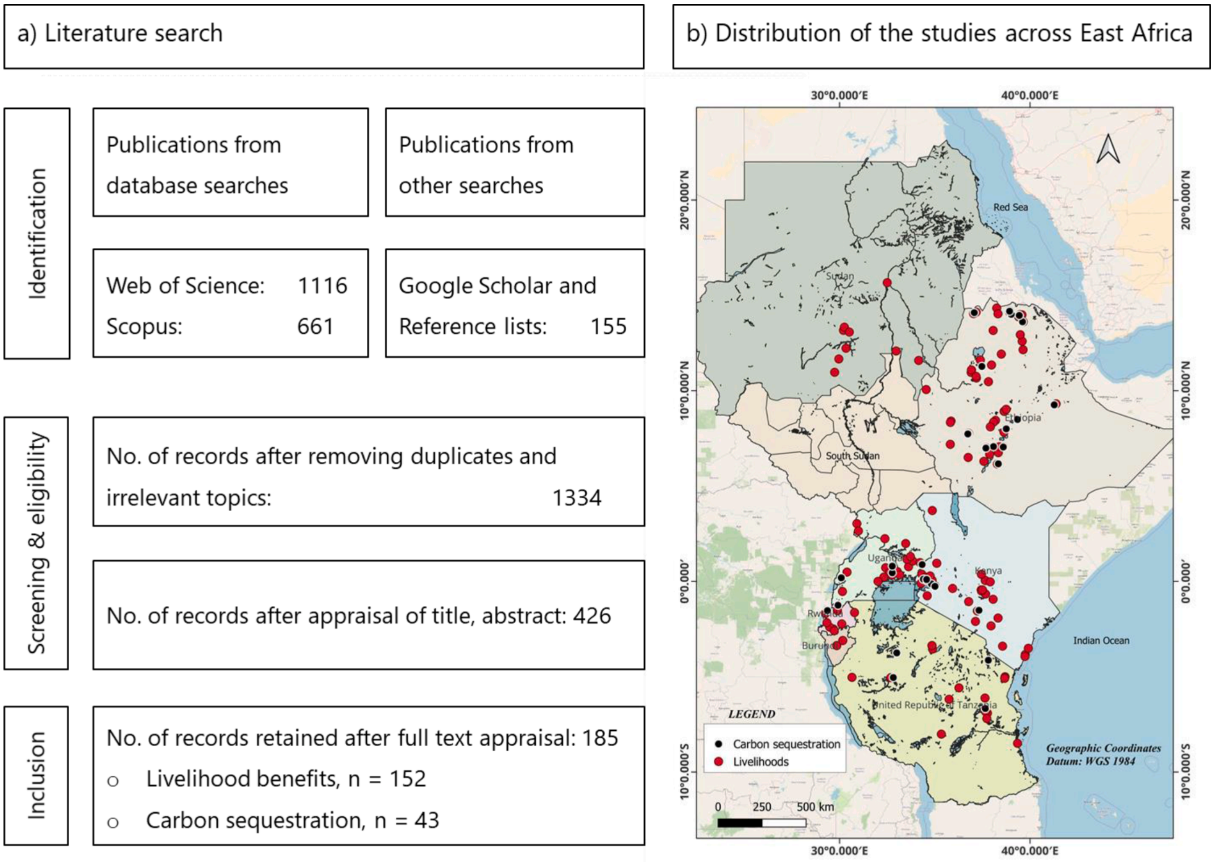

Fig. 1. A step-wise flow diagram illustrating literature search and screening of records retrieved (a), and the distribution of studies across East Africa (b). The dots represent the number of publications that reported on livelihood benefits (red) and carbon sequestration (black). A total of 185 publications were used for an in-depth review of livelihood benefits ($n = 152$) and carbon storage for agroforestry systems in East Africa ($n = 43$). Some publications reported both livelihood benefits and carbon stocks.

experimental, group discussion, modelling, remote sensing), (3) agroforestry practice (classified based on descriptions provided by the studies reviewed), and (4) the livelihood benefit, carbon stock or proxies of carbon sequestration. Other information extracted include bibliographic data (author, year), the species and companion plant where applicable, the age of the trees or agroforestry practice, and the depth to which soil samples were collected for studies reporting soil organic carbon (SOC). Quantitative information on means were recorded as reported in tables, within the text or extracted from figures.

Data reported as dry matter was converted to aboveground carbon using the default fraction (47%) of carbon documented by the Intergovernmental Panel on Climate Change (IPCC). The term dry matter was used interchangeably with biomass to refer to the mass of the plant material in a dehydrated state. The frequencies and percentages of studies for a particular livelihood benefit or carbon sequestration were calculated based on the number of studies reviewed in that category. A vote-count was used to assess the impact of trees on the livelihood benefits where anecdotal evidence (e.g. from household interviews and group discussion) was provided. Results from the review are organized into three thematic areas: major agroforestry practices in East Africa, livelihood benefits of agroforestry, and carbon sequestration in agroforestry. A discussion of potentials and limitations, and the way forward is provided together with some final conclusions.

3. Major agroforestry practices in East Africa

Table 2 shows the most commonly studied agroforestry practices in East Africa. The literature also reported other less frequent practices referred to as (1) farmer driven land restoration techniques: farmer managed natural regeneration (FMNR) (Brown et al., 2011) and framework tree species (Stangeland et al., 2011), (2) production of commercial poles - linear agroforestry (Peden et al., 1996; Tumwebaze et al., 2012), (3) traditional agroforestry practices such as Taungya system (Chamshama et al., 1992; Nigussie et al., 2020) and traditional tree fallow (Rahim et al., 2008; Mpanda et al., 2021), and (4) investigations of agroforestry trees under feeding experiments (Karachi and Zengo, 1998; Mpairwe et al., 1998; Roothaert, 1999; Ondiek et al., 2000; Rubanza et al., 2005; Ndemanisho et al., 2006). Forty-six publications did not mention the type of agroforestry studied while 10 publications reported data on multiple agroforestry practices.

3.1. Homegardens

Homegardens referred to a land use near the homestead where a mix of annual and perennial crops are grown with multipurpose trees, and sometimes in association with domestic animals. The plant component includes trees, shrubs, herbs, climbers and food crops that form three to four canopy layers. A total of 23 publications reported diverse livelihood benefits in homegardens; a further 13 publications reported carbon sequestration in homegardens. The majority of the publications reported studies conducted in Ethiopia (19 publications), and few from Kenya (3), Sudan (3), Uganda (2), Tanzania (1) and Rwanda (1). Of the 13 publications that reported carbon sequestration in homegardens, 11 referred to studies conducted in Ethiopia, two in Kenya and one in Rwanda. A prominent type of homegarden in Ethiopia is the ‘enset-coffee’ homegarden typified by a combination of enset (*Enset ventricosum*) and coffee (*Coffea arabica*) (Negash and Kanninen, 2015; Lulu et al., 2020). There are also distinct ‘enset-based’ and ‘coffee-based’ homegardens in

Table 2
The most commonly studied agroforestry practices in East Africa and their contribution to livelihood benefits. Count represent the number of publications that reported on the agroforestry practice. Benefits listed here are those documented in the studies reviewed, and not those generally provided by the agroforestry practice listed. Agroforestry practices were categorized based on descriptions provided by the studies reviewed.

Agroforestry system/ practice	Count [%]	Description and examples	Livelihood benefits	Reference
Homegardens	23 [13]	A land use near the homestead where annual and perennial crops are cultivated with trees, and sometimes in association with livestock. Homegardens are characterised by a high diversity of plants, multi-story structure, and primarily function to produce food for household consumption. Specific types of homegardens described are enset, enset-coffee and coffee homegardens.	Food, firewood, medicinal use, fodder, shade, income, construction material, household items and timber	Linger (2014); Jemal et al. (2018); Betemariyam et al. (2020); Furo et al. (2020); Manaye et al. (2021); Sahle et al. (2021)
Hedgerow intercropping, hedgerows	20 [12]	Hedgerow intercropping: a practice where crops are grown between lines of trees or shrubs (usually nitrogen fixing leguminous species) that are spaced at regular intervals and pruned regularly to reduce shading. The trees are spaced 4 to 8 m between rows and 0.25 to 2.00 m within rows; with closer rows in humid areas and wider rows in dry areas.	Fodder, firewood, wood, timber	Jama and Getahun (1991); Jama et al. (1995); Heineman et al. (1997); Chamshama et al. (1998); Hafner et al. (2021)
		Hedgerows: lines of shrubs (and sometimes interspersed with trees) that are closely spaced to form a barrier, or demarcate a land use. Hedgerows can be managed to increase foliage production or wood production.		Akyeampong (1996); Akyeampong and Dzowela (1996)
Perennial tree-crop systems	18 [10]	A system containing plantation (cash) crops such as coffee, tea, cacao, coconut, cashew, khat, cardamom and multipurpose trees or shade tolerant herbaceous crops as the main components. Plantation crops can generate value added goods for the international market.	Food, fodder, firewood, timber, income, poles, medicinal use, construction material	Teketay and Tegineh (1991); Aiyelaagbe (1994); Bullock et al. (2014); Pinard et al. (2014); Gwali et al. (2015); Biazin et al. (2018); Admasu and Jenberu (2022); Sebuliba et al. (2022)
Woodlots	17 [10]	An area on the farm set aside entirely for trees. Single or mixed species stands of trees can be planted on cropland or degraded land for wood production, or to rehabilitate the land. Woodlots can be intercropped, e.g. with vegetables in the first two years early; the trees then grow alone and are harvest around the fifth year; food crops are replanted in the case of rotational woodlots.	Wood, firewood, fodder, income, timber, construction material	Karachi et al. (1994); Ramadhani et al. (2002); Nyadzi et al. (2003); Kimaro et al. (2011); Gebreegziabher and van Kooten (2013); Ndayambaje et al. (2014); Mukangango et al. (2020); Reppin et al. (2020)
Scattered trees on farm	16 [9]	A practice where scattered trees grow on cropland, often from naturally dispersed seeds that germinate and are protected during farm operations, or from seedlings planted by the farmer. The spatial arrangement of trees may be random or linear.	Income, firewood, fodder, charcoal, gum arabic, resin, wood	Muchiri et al. (2002); Tabuti and Mugula (2007); Fadl and El Sheikh (2010); Kalame et al. (2011); Ndayambaje et al. (2014); Reppin et al. (2020); Mekonnen et al. (2021)
Silvopastoral systems	14 [8]	Integration of trees with livestock. The animals freely roam and graze under natural stands of trees or scattered trees in croplands, or may be stall-fed with forage from fodder trees and shrubs grown on the farm. The trees provide high-quality forage that supplement available feeds, especially during the dry season.	Fodder, shade, firewood, timber, food	Mengistu et al. (2002); Nyaata et al. (2002); Roothaert et al. (2003); Hess et al. (2006); Kiptot (2007); Balehegn et al. (2015); Fungo et al. (2020); Yaebiyo et al. (2021)
Parkland agroforestry systems	11 [6]	A traditional land use system where scattered multipurpose trees are retained on cultivated land or land that was recently fallowed. Parklands constitute extensive tree-crop intercropping, where crops are grown beneath the crowns of trees such as *Faidherbia albida, P. biglobosa*, or *Vitellaria paradoxa*.	Food, fodder, firewood, income, shade, timber, charcoal, construction material, farm implements / tools	Okullo et al. (2004); Chiemela et al. (2018); Fahmi et al. (2018); Birhane et al. (2019); Tadesse et al. (2019); Tadele et al. (2020)
Boundary planting	8 [5]	The practice of growing trees on farm boundary. Trees can be planted in rows, initially at a close spacing (e.g. 1 m) and later thinned to 2 or 4 m spacing; trees may also be retained as scattered trees along boundaries. The trees mark farm boundaries or enterprises, and can be pruned or pollarded for various products.	Fodder, food, firewood, income, shade, timber, charcoal, wood, poles, bee forage	Kassa and Nigussie; Roothaert et al. (2003); Kidanu et al. (2005); Duguma (2013); Nigatu et al. (2020); Reppin et al. (2020); Manaye et al. (2021); Fuchs et al. (2022)
Improved fallow	7 [4]	A practice where land is rested from cultivation, during which fast-growing leguminous species are planted to restore soil fertility and provide products. Many of the leguminous species used in these systems (e.g. *Calliandra calothyrsus, Sesbania sesban, Prosopis chilensis*) fix nitrogen and add organic matter to the soil.	Wood, fodder, firewood, poles	Akyeampong and Muzinga (1994); Swinkels et al. (1997); Gathumbi et al. (2002); Rao et al. (2002); Stahl et al. (2002); David and Raussen (2003); Ndufa et al. (2009)
Fruit tree-based agroforestry		The intentional simultaneous cultivation of annual or perennial crops with fruit producing trees on the	Income, food	Admasu and Jenberu (2022)

(*continued on next page*)

Table 2 (*continued*)

Agroforestry system/ practice	Count [%]	Description and examples	Livelihood benefits	Reference
		same area of land. Fruit tree-based agroforestry may occur as orchards or low intensity homegardens based on apple (*Malus domestica*), mango (*Mangifera indica*), avocado (*Persea americana*); or fruit trees intercropped with staples.		
Trees on soil conservation structures		Trees planted on soil-conservation structures to control runoff, reduce soil loss, stabilize the structure and maximise utilization of the land use. Examples include tree strips or grass strips with trees; trees planted on bench terraces, progressive terraces or soil bunds.	Food, fodder, firewood, green manure, staking material	Niang et al. (1998); Angima et al. (2000); Angima et al. (2002); O'Neill et al. (2002); Droppelmann and Berliner (2003); Abdelkdair and Schultz (2005); Bucagu et al. (2013); Nigatu et al. (2020); (Cyamweshi et al., 2021)

Ethiopia.

Homegardens are characterised by high species diversity with multipurpose trees or fruit tree species as the dominant woody components. In Ethiopia, homegardens are dominated by coffee, enset, khat (*Catha edulis*), avocado, banana (*Musa* spp.) and vegetables (Sahle et al., 2018; Betemariyam et al., 2020; Birhane et al., 2020; Sahle et al., 2021). These can be surrounded by a live fence comprising of multipurpose tree species or may be unfenced (Linger, 2014). Livelihood benefits in homegardens vary because of the different plant species and stages of establishment. At their initial stages, homegardens provide more vegetables, spices and traditional medicines (Mekonen et al., 2015; Tadesse et al., 2019; Sahle et al., 2021). At an older stage of establishment, homegardens provide fruits, other tree products and income. Shade tolerant spices such as wild cardamom (*Aframomum angustifolium*), small cardamom (*Elettaria cardamomum*) and wild pepper (*Piper capense*) were frequently reported in homegardens in Ethiopia (Reyes et al., 2006; Furo et al., 2020). Trees such as *Millettia ferruginea* and *Albidia gumminifera* provide shade while *Grevillea robusta* and *Erythria brucei* provide support to the spices and vines (Furo et al., 2020).

3.2. Hedgerow intercropping, hedgerows and hedges

Hedgerow intercropping (or alley cropping) referred to planting annual crops between widely spaced rows of woody plants or trees, often at a spacing of 4 m or 8 m. The trees or shrubs are pruned to reduce shading and competition. The pruned material is used as fodder or applied to the soil as mulch or as green manure to improve fertility (Jama and Getahun, 1991; Jama et al., 1995). The wood from pruning is used as firewood or staking material. Hedgerow intercropping works well where soil moisture is not limiting during the crop growing season but tend to depress crop yield in areas where soil moisture is limiting due to competition (Cooper et al., 1996).

Hedgerows or hedges referred to lines of closed spaced shrubs that are used to form a barrier or demarcate an area on the farm (Table 2). Hedgerows were also reported as part of living fences around homesteads, where they play protective and ornamental roles (Mekonen et al., 2015; Nyberg et al., 2020b). Hedgerows can be tree-grass systems designed to produce fodder or integrated into a maize cropping system. In terms of fodder, Akyeampong (1996) and Akyeampong and Dzowela (1996) found that hedgerows that combine *C. calothyrsus* and Napier grass (*Pennisetum purpureum*) produced more fodder than those with *C. calothyrsus* or Napier alone. This makes hedgerows and hedgerow intercropping appealing to mixed crop-livestock farmers as the leguminous shrubs produce high-quality fodder that can be used to supplement commercial feeds (Franzel et al., 2014). However, hedgerows optimized for fodder production do not produce sufficient firewood to meet daily household needs (Akyeampong, 1996; Akyeampong and Dzowela, 1996). Similarly, managing hedges for firewood production can compromise the quality and quantity of fodder.

3.3. Silvopasture

Silvopasture is a practice where trees are included in pastures, rangelands or other grazing systems that may involve free roaming animals that graze under natural stands of trees or scattered trees in croplands (Nair et al. 2021). Silvopasture may also involve stall-fed animals that are provided with forage from fodder trees and shrubs (e.g. fodder banks) planted on cropland or pasture area to serve as a supplemental high-quality fodder. Fodder banks with leguminous species such as *Sesbania micrantha, Sesbania rostrata, Sesbania quadrata* and *S. sesban* were reported in Ethiopia (Mengistu et al., 2002); *C. calothyrsus, Crotalaria goodiiformis* and *Aspilia mossambicensis* were reported in Kenya (Nyaata et al., 2002; Roothaert et al., 2003; Hess et al., 2006) while *Vernonia amygdalina* and *C. calothyrsus* were reported in Uganda (Fungo et al., 2020). Most of these species produce large amount of leaf biomass that is used to supplement animal feeds during the dry season. Leaf biomass is harvested by lopping the top or pruning branches of fodder trees. There are cases where livestock are allowed to grass on fodder banks (Chakeredza et al., 2007) although this approach was not reported in the literature reviewed. Farmers also produced fodder in boundary planting (Kassa and Nigussie; Roothaert et al., 2003), scattered trees on farms (Tabuti and Mugula, 2007; Mekonnen et al., 2021) or trees planted on soil conservation structures (Angima et al., 2000, 2002; O'Neill et al., 2002).

Free grazing animal production systems are common in semi-arid areas, for example in rangelands or parklands. Trees in these systems provide fodder, shade and shelter for the animals (Balehegn et al., 2015; Birhane et al., 2019; Yaebiyo et al., 2021). Trees such as *Ficus thonningii, Acacia polyacantha* and *F. albida* are highly preferred in silvopasture as they allow grass to grow beneath their canopies because of the positive effect on soil moisture and soil fertility (Balehegn et al., 2015; Birhane et al., 2019). The variety of browse species available in East Africa is wide (Appendix 1; Le Houerou (1980)). In Karamoja, Uganda, goats browse on *Balanites aegyptiaca, F. albida, Grewia similis* and *Grewia mollis* (Muwanika et al., 2019). In Ahferom, Ethiopia, *F. thonningii* is the most preferred fodder species (Balehegn et al., 2015; Yaebiyo et al., 2021). Other trees dominant in rangelands include *Acacia* spp., *Vachellia* spp., *Ziziphus spina-christi* and *F. albida* (Yaebiyo et al., 2021). The leaves, pods and fruits of these trees are sources of high protein fodder for animals during the dry season. Trees in silvopasture are also be managed to provide other products (Table 2).

3.4. Trees on soil conservation structures

Trees feature commonly on soil conservation measures in East Africa, including contour hedgerows in the highlands of Kenya (Angima et al., 2000, 2002; O'Neill et al., 2002; Mutegi et al., 2008) and Rwanda (Niang et al., 1998; Bucagu et al., 2013), river banks in Ethiopia (Nigatu et al., 2020), bunds in Rwanda (Cyamweshi et al., 2021), and water harvesting structures in Kenya (Droppelmann and Berliner, 2003) and Ethiopia (Abdelkdair and Schultz, 2005). Tree can be used alone in strips (e.g. on gentle slopes) or planted on grass strips (e.g. on steep slopes) to control runoff and soil loss. The trees provide a vegetative barrier that controls soil loss and runoff, stabilize the soil, and add organic matter to the soil. Farmers utilize the space between the trees for crop or fodder production. Soil and litter that build-up on the upslope can lead to natural formation of a terrace.

Trees are also planted on the edges of terraces to stabilize the soil and to maximize land use. Two different forms of agroforestry, improved fallows (David and Raussen, 2003) and rotational woodlots (Raussen et al., 1999), reported trees on bench terraces; no study explicitly referred to progressive terraces, although livelihood benefits were documented on trees on bunds (Cyamweshi et al., 2021). In Uganda, trees were used to improve water storage and reduce soil evaporation on bench terraces (Siriri et al., 2010, 2013). The same authors compared the performance of improved fallows with *S. sesban, C. calothyrsus, Alnus acuminata, Tephrosia vogelii*, and *Acanthus pubescens* planted on scoured terrace benches (David and Raussen, 2003). The trees had positive economic returns, and produced fodder, staking material and firewood (Raussen et al., 1999; David and Raussen, 2003).

3.5. Fruit tree-based agroforestry

A total of 146 fruit tree and shrub species were documented in the literature reviewed (Appendix 1). Fruit trees are multipurpose and support other farm enterprises such as livestock, bee keeping and fish farming (The National Academy of Sciences, 2008). Three things stand out on the list: (1) some of the fruit trees are considered to have great potential in addressing critical socio-economic and environmental challenges in Africa. For example, *B. aegyptiaca*, baobab, carissa (*Carissa edulis*), marula (*Sclerocarya birrea*) and tamarind (*Tamarindus indica*) are ranked amongst top ten promising crops with great potential for nutrition, food security, rural development and sustainable land management (The National Academy of Sciences, 2008; Stadlmayr et al., 2013). (2) Include priority species identified as targets for promotion and domestication in East Africa (Akinnifesi et al., 2008). The species were favoured by farmers because of their livelihood benefits, mainly nutritional, medicinal and income-generating values. (3) Include those listed in the fruit tree portfolio developed in Kenya (McMullin et al., 2019). The fruit tree 'portfolio' consists of species that flower at different times of the year, so that at least one species in the list is ripe every month, and therefore can provide year-round food security.

The majority of the fruit tree species are indigenous to tropical Africa, corresponding to earlier reports that sub-Saharan Africa is home to hundreds of edible fruit and nut species (Bosch et al., 2002). On the contrary, the frequency of exotic species was high compared to indigenous species, which also agree with reports that fruit production in Africa in currently dominated by few exotic species. Some of the studies reviewed found exotic species (e.g. avocado, mango, guava (*Psidium guajava*), citrus spp.) in all farms with trees (Teketay and Tegineh, 1991; Bullock et al., 2014; Biazin et al., 2018; Whitney et al., 2018a; McMullin et al., 2019). Indigenous species are increasingly being found in farms; some have been domesticated (e.g. *B. aegyptiaca, Z. spina-christi*) while others such as baobab occur spontaneously in the landscape (Fentahun and Hager, 2010). Studies reviewed provide overwhelming evidence regarding the preference of fruit trees by farmers in East Africa, and mention income, food, firewood, construction material, shade and medicines as the criteria of selecting the trees for on-farm cultivation.

Fruit trees were commonly found in homegardens, as trees grown individually around homes, or in coffee or enset-based agroforestry systems (Gwali et al., 2015; Biazin et al., 2018; Birhane et al., 2020). Fruit trees were also integrated in orchards (Nigussie et al., 2019; Admasu and Jenberu, 2022) or perennial tree-crop systems (Teketay and Tegineh, 1991; Negash and Starr, 2015). A recent study in Ethiopia found that avocado fruit yields was high when they were grown with coffee and enset (Biazin et al., 2018). The study attributed the high yields to better management for trees grown together with coffee, e.g. appropriate spacing, pruning, manure application, mulching and irrigation during the dry season (Biazin et al., 2018). On the contrary, individual trees around homes may not benefit from such agronomic and tree management practices. Apple-based agroforestry involved intercropping apples with beans, potatoes, barley, or spices (Nigussie et al., 2019; Admasu and Jenberu, 2022). Farmers testified that apple-based agroforests increased their finances, improved nutritional or food security and provided more employment opportunities (Nigussie et al., 2019; Admasu and Jenberu, 2022). Cashew-coconut system is another form of fruit-tree based agroforestry common in the coast of Kenya (Aiyelaagbe, 1994). Farmers in the region plant cashew (*Anacardium occidentale*), coconut (*Cocos nucifera*), mango, sweet orange (*Citrus sinensis*), custard apple (*Annona squamosa*) and other fruit species for sale and home consumption (Aiyelaagbe, 1994).

Domestication of indigenous species can support development of fruit tree-based agroforestry in East Africa. For a long time, utilization of indigenous fruit species relied on collection from their wild habitat or picking fruits from volunteer stands. However, cultivation of wild fruit trees has become more important as access to natural habitats (forests) is becoming more regulated, and many rural households are moving from subsistence to a cash-orientated economy. Domestication of wild fruit species has been emphasized following the realization that their natural habitats are being lost to deforestation, and that overexploitation could drive some species close to extinction (Akinnifesi et al., 2008). Indigenous fruit species are well adapted in their regions and therefore can grow easily with minimum requirements, and can be easily adapted into existing farming systems (Akinnifesi et al., 2008). Domestication of fruit trees is seen as a strategic pathway to improving rural livelihoods through enhanced nutrition and generation of income.

4. Livelihood benefits of agroforestry

The studies reviewed reported 34 livelihood benefits from different agroforestry practices, 17 of which were reported in five or more publications (Fig. 2). Fodder, food, firewood and income were the most common benefits, reported in over 70, 63, 56 and 40 publications, respectively. Benefits of agroforestry identified from the publications are discussed under four broad livelihood groups: food and nutritional security covering food (fruits, leaves, and edible oil) and food additives (stimulants, spices and condiments); wood-based energy (firewood, charcoal and biofuel); livestock integration (fodder production, animal husbandry); and income. Benefits such as medicinal, gum and resins, ornamental use and production of farm implements and household items are discussed under income. Four of the top 10 species with the most uses (*C. calothyrsus, M. indica*, L. *leucocephala, P. americana*) and seven of the top 10 species mentioned in the most publications (*C. calothyrsus, M. indica,* L. *leucocephala, P. americana, G. robusta, P. guajava, A. heterophyllus*) (Appendix 1) are also in the top-100 tree species prioritised for planting in the tropics and sub-tropics (Kindt et al., 2021). The three species with most uses (*P. thonningii, C. africana, A. coriaria*) do not appear in the top-100 identified by data mining in Kindt et al. (2021).

4.1. Food and nutritional security

Agroforestry contributes to food and nutritional security by providing edible products, supporting livestock and crop production, and providing wood-based energy and oil for cooking. A total of 146 tree species were reported as used for food, with mango, avocado, guava, tamarind and oranges as the most reported fruit tree species (Appendix 1). Fruits diversify diets of urban and rural communities and are used as safety nets during food shortages. Fruits were reported as important sources of vitamins and products rich in minerals for communities who use them to supplement their diets. Anecdotal testimonies showed that people pick and eat fruits when going about farm work or herding, or include fruits in their regular meals. Fruits are also available at different times of the year, including times when most rural households face food

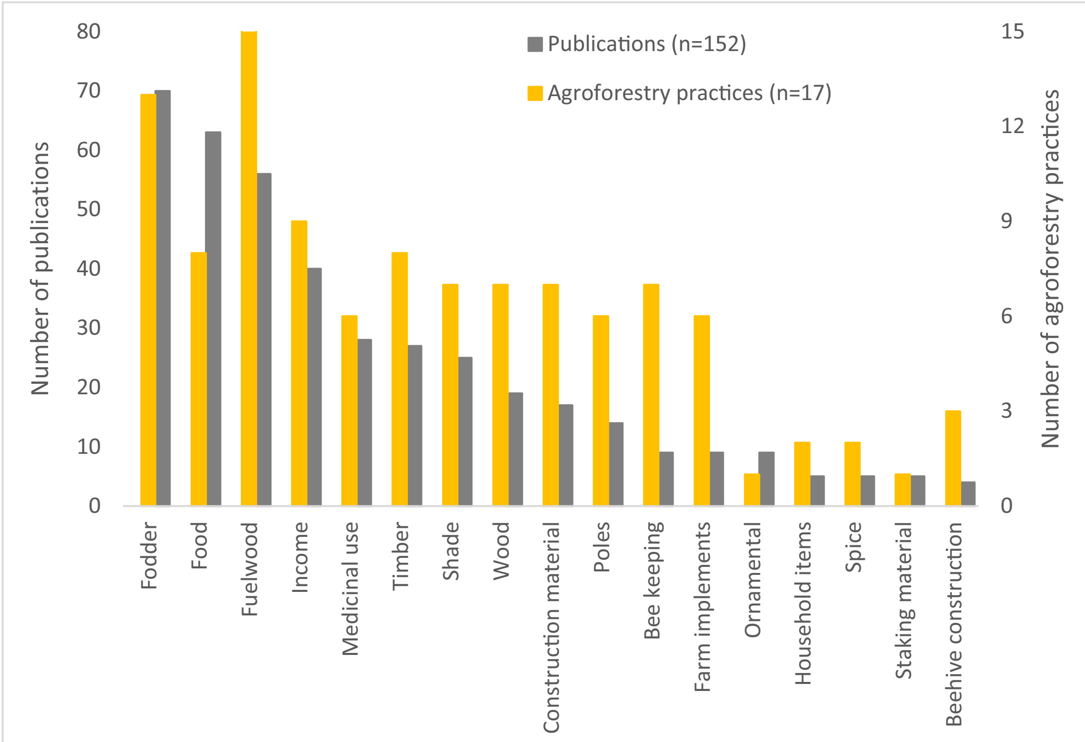

Fig. 2. The number of publications reporting different benefits and the number of agroforestry practices producing those benefits. The list covers only benefits reported in more than five publications. Benefits such as perfume, stimulants, condiments, edible oil, handicraft and carvings, additives, dye, honey and use of trees as a shield during conflict were reported fewer than five publications.

shortage i.e. during the dry season, when crops are washed away by floods, or when there is crop failure (Agea et al., 2007; Jamnadass et al., 2013; Masters, 2021). Communities also utilize leaves of trees as food. Trees such as *B. aegyptiaca, Ficus dicranostyla, G. mollis*, tamarind, *Harrisonia abyssinica* provide edible leaves. The leaves are boiled and eaten alone or combined with other vegetables (Masters, 2021).

Most studies on trees that provided food were mainly conducted in homegardens (11 publications) and perennial tree-crop systems (8 publications); few studies evaluated tree foods in FMNR (3 publications) and parklands (3 publications). Homegardens are dominated by fruit trees (e.g. avocado, mango, *Z. spina-christi* and *B. aegyptiaca*) and other food producing woody species and vines (Linger, 2014; Biazin et al., 2018). Stimulants such as coffee, tea (*Camellia sinensis*) and khat (Jemal et al., 2021; Sahle et al., 2021), spices such as pepper (*Capsicum frutescens*), small cardamom and wild cardamom (Bullock et al., 2014; Furo et al., 2020), and plants that produce edible oils e.g. shea tree and *Allanblackia stuhlmannii* (Okullo and Waithum, 2007; Schmidt et al., 2019) are also major components of homegardens in East Africa. The resultant heterogeneity in homegardens ensure yield stability, diversity of food products, and year-round provision with low input. Food provision in perennial tree-crop systems was mainly associated with apple-based agroforestry (Nigussie et al., 2019; Admasu and Jenberu, 2022), coffee based agroforestry (Teketay and Tegineh, 1991; Gwali et al., 2015; Biazin et al., 2018; Aragaw et al., 2021), cardamom agroforestry (Reyes et al., 2006; Bullock et al., 2014) and cashew-coconut system (Aiyelaagbe, 1994).

Agroforestry also contributes to food and nutritional security by influencing availability of cooked food, through provision wood-based energy (section 4.2) and cooking oil. The seeds of Allanblackia trees produce edible oil that is used as cooking oil and to make soap (Schmidt et al., 2019). The seedcake that remains after extracting the oil can be used as a protein-rich animal feed, which can milk and meat production. Allanblackia is one of the priority trees for domestication (Akinnifesi et al., 2008). Other species that produce oil but were reported for other benefits include palm oil (*Elaeis guineensis*), *B. aegyptiaca, Moringa oleifera*, marula and shea tree.

4.2. Wood-based energy

Production and use of firewood and charcoal constitutes a major livelihood strategy in East Africa. Rural households in the region almost entirely depend on firewood and other traditional biomass energy sources such as charcoal, animal dung and crop residues for their cooking and heating energy needs (Bewket, 2003; Felix and Gheewala, 2011; Njenga et al., 2021). Firewood is also used in cottage industries for tea processing, brewing, curing tobacco (*Nicotiana tabacum*), brick making and drying meat and fish (Ramadhani et al., 2002; Iiyama et al., 2014; Kegode et al., 2017). With increasing population, lack of cheaper alternatives, and preference, the demand of wood-based energy is likely to continue into the future (Iiyama et al., 2014). Already, the region is experiencing shortages of woodfuel. For instance Kenya experience a 27% and 55% deficit for firewood and charcoal, respectively (MoEWNR, 2013). The scarcity of cooking energy results in increased burden on women and children who travel long distances to forests and carry heavy loads of firewood (Njenga et al., 2021). Agroforestry increases availability of firewood on farm, which reduces and reallocate the time spent collecting firewood to other productive activities (Hughes et al., 2020; Njenga et al., 2021) and reduces the dangers associated with collecting firewood. Producing firewood on farm can also reverse land degradation and deforestation associated with charcoal production (Iiyama et al., 2014; Sharma et al., 2016; Wassie and Adaramola, 2019), and free the dung used as cooking fuel in some communities for soil fertility improvement.

Firewood was produced in almost all agroforestry practices reported (Table 2), although the main practice specifically designed for firewood production is the small-scale woodlots and rotational woodlots. In Morogoro, Tanzania, 5-year rotational woodlots produced sufficient wood (23.2–51.0 Mg ha^{-1}) to meet household firewood demands for

7–16 years (Kimaro et al., 2011). Improved fallows and alley cropping are also a major source of firewood, even though their primary function is to restore and improve soil fertility. Firewood was also reported as a secondary product from agroforestry practices that aims to control erosion (e.g. contour hedgerows), support livestock production (e.g. silvopasture), as well as multi-purpose agroforestry practices (e.g. homegardens). Farmers obtain firewood from these systems by selectively thinning, pruning or collecting deadwood.

A total of 82 publications provided evidence for the role of agroforestry in provision of wood-based energy in East Africa, including 53, 10 and 19 publications on firewood, charcoal production and wood production, respectively. Eight of the publications provided quantitative values; the rest reported the use of particular tree species or agroforestry in general for provision of firewood, or firewood as a reason for maintaining trees on-farm. The high number of studies in this livelihood benefit corroborates with preposition that agroforestry produces much of the firewood used in East Africa (Ndayambaje and Mohren, 2011). It also resonates with increasing calls to produce firewood on farms, as forests and woodland where the firewood was previously obtained are quickly declining or access is restricted. Agroforestry was showed to hold the greatest potential for providing charcoal and firewood in Tanzania (Bar et al., 2017), owing to the large spatial extent of agricultural landscapes with trees and the high density of trees on farms (*ibid*). A similar potential has been demonstrated in Kenya, where 40% of the households at the coast (Kwale county) and in the highland (Embu county) depend on agroforestry exclusively for their firewood supply (Gitau et al., 2019; Njenga et al., 2021).

4.3. Livestock integration

Agroforestry supports livestock integration through provisioning of fodder, shade and shelter for the livestock and herdsmen (Fig. 2). Most farmers in east Africa feed their animals on Napier grass, a perennial forage with low crude protein but high fibre content. Farmers deplete their stock of Napier grass during the dry season, then resort to low-quality materials such as crop residues, further depressing animal performance. Farmers with fodder trees have the advantage of year-round availability of high-quality forage. Over 200,000 smallholder farmers in East Africa are estimated to have fodder trees on their farms (Franzel et al., 2014), although the quality of fodder in these farms varies depending on the site (Hess et al., 2006).

Fodder production was reported in almost all agroforestry systems (Table 2), although fodder banks, alley cropping and hedgerows were the leading agroforestry practices that integrate fodder trees. Experimental studies show that shrubs such as *C. calothyrsus* can be successfully planted in hedges along boundaries, as contour hedgerows (Akyeampong, 1996; Akyeampong and Dzowela, 1996), and even intercropped with grass strips (Niang et al., 1998; Angima et al., 2000; O'Neill et al., 2002). *Panicum maximum* (panicum) grass was also successfully intercropped with multipurpose trees in water harvesting structures in Kenya (Droppelmann and Berliner, 2003; Abdelkdair and Schultz, 2005). Field experiments in Burundi showed that combination of *Tripsacum laxum* with *Leucaena diversifolia* or *C. calothyrsus* produced amount of dry matter comparable to a pure grass-based system (Akyeampong and Dzowela, 1996). In western and Central Kenya, *C. calothyrsus* did not compete with maize in hedgerow intercropping (Heineman et al., 1997; O'Neill et al., 2002). Experiments in Mtwapa, Kenya, found that intercropping of Napier grass with leguminous fodder trees increased the quantity and quality of herbage production especially during the dry season (Mureithi et al., 1995). Production of fodder can be increased by management practices such as hedging or pollarding to induce vegetative growth.

Feeding experiments show that fodder trees increased dry matter intake, improved animal growth and milk production, and improved quality of manure. Animals maintained or improved body weight and/or increased milk production when panicum was supplemented with pigeon pea (*Cajanus cajan*), L. *leucocephala* or *S. sesban* (Karachi and Zengo, 1998); *Setaria splendida* was supplemented with *Mimosa scabrella* (Niang et al., 1996); Napier grass was supplemented by *Gliricidia sepium* (Mpairwe et al., 1998); Rhodes grass (*Chloris gayana*) hay was supplemented with L. *leucocephala* and *G. sepium* (Ondiek et al., 2000; Rubanza et al., 2005). Farmers can use *Albizia lebbeck, M. oliefera*, L. *leucocephala* and *G. sepium* leaf meals as a protein supplement (in place of cotton seed) to weaner goats with a small reduction in animal performance (Ndemanisho et al., 2006). Using leguminous shrub forage as supplement is less expensive and has higher margins compared to using commercial concentrate (Ondiek et al., 2000; Franzel et al., 2014). In addition to increasing performance of animals, fodder shrubs provide income from sale of forage or fodder seeds or seedlings.

4.4. Income

4.4.1. Income from tree and tree products

Forty publications reported income as a benefit of agroforestry, which is also one of the main reasons for maintaining trees on farms (Fig. 2). Much of the income comes from sale of trees and tree products such as fruits, timber, firewood, fodder, poles, staking material, traditional medicines, gums and resins, spices, stimulants and essential oils. Farmers also obtain income from sell of products from farm enterprises supported by agroforestry, such as livestock or livestock products (Hughes et al., 2020), honey and waxes from bee keeping (Tadesse et al., 2014; Sahle et al., 2021), or surplus staple from vegetables and cereals (Miller et al., 2017; Whitney et al., 2018b). Some products (e.g. fruits) are collected periodically, while others (e.g. fuelwood and charcoal) provide a steady source of income for some households (De Giusti et al., 2019). Firewood produced on-farm generates substantial income for farmers across East Africa, gum arabic from *Senegalia senegal* is a key source of income for farmers in Sudan (Ballal et al., 2005; Rahim et al., 2007; Fadl and El Sheikh, 2010), while fruit production is a major income from fruit tree-based agroforestry (section 3.5). Charcoal enterprise supports the livelihood of both rural and urban households (Iiyama et al., 2014), as an alternative income generating activity that requires low capital. Almost all agroforestry practices were noted to provide income although only seventeen tree species were associated income generation (Appendix 1).

The review shows that agroforestry contributes to and in certain situation increases household income, although only few studies quantified income from agroforestry. A recent national level survey found that 66% of rural smallholders in 22 countries in Africa grow trees on their farms, and that farmers in Ethiopia, Tanzania and Uganda get up to 14, 13 and 19% of the total annual gross income from trees (Miller et al., 2017). At local level, fruit and firewood production accounted for 12% of agricultural income in Tandai village, Tanzanian (Fasse et al., 2014). The proportion of income was high (14%) when farmers who grow cash crops and have skilled off-farm employment were considered (Fasse et al., 2014). A comparable proportion was found in Láilay Adiyabo district in Ethiopia, where farmers got 14% of the total household income from sell of *A. polyacantha* seeds and the remainder of firewood, farm tools and construction material that was not used by the household (Birhane et al., 2019). Compared to non-adopters, agroforestry increased income of adopters in Nyamagabe District, Rwanda (Kiyani et al., 2017), Isiolo County, Kenya (Quandt et al., 2019), western Kenya (Hughes et al., 2020; Nyberg et al., 2020a), and cardamom farmers in Tanzania (Reyes et al., 2006). Another ways of increasing income is through substitution of products that farmers would otherwise buy, which enables farmers to reduce costs (Nyberg et al., 2020a). Anecdotal testimonies reveal that farmers benefited from reduced expenditure on food, fodder, firewood, construction material and farm input (Okorio et al., 2004).

4.4.2. Income from carbon sequestration

A smaller number of studies reported the contribution of agroforestry to income from sale of carbon credits (Brown et al., 2011; Benjamin and Sauer, 2018; Buxton et al., 2021). Farmers in East Africa participate in various schemes that reward adopters of sustainable land management practices, including growing trees (Foster and Neufeldt, 2014). An example is The International Small Group Tree Planting Program (TIST), which has been operating in Kenya, Tanzania, and Uganda since 2005 (Benjamin and Sauer, 2018). TIST quantifies carbon stored on farms of participating members, sells the carbon through VCS (Verra) Standard, and then pay farmers for raising trees. Since 2005, TIST has been incentivising farmers to plant trees for various goods and services and to sequester carbon (Buxton et al., 2021). Other programs providing evidence of income from carbon sequestration are the Humbo Community-based Natural Regeneration Project, which is recognised for creating a new stream of income through the generation of carbon offset credits under the Clean Development Mechanism (CDM) (Brown et al., 2011); and the Kenya Agricultural Carbon Project (KACP) which issued carbon credits under the VCS standard for sequestering carbon in soil (Nyberg et al., 2020a).

A key challenge with income from carbon sequestration includes the high transaction costs for small projects that must be aggregated, a mismatch between community needs and some of the project objectives, and a slow and costly approval process (Jindal et al., 2008). The advantage is that the trees offer multiple benefits with carbon being a co-benefit. As such, the land does not have to be taken out of original use in favour of carbon and therefore farmers' livelihoods are not disrupted. Another limitation regards the low potential for carbon sequestration in agroforestry compared to forested areas. This means that the international carbon finance schemes may not provide substantial incentives in areas with low potential (Mbow et al., 2014). In addition, the opportunity cost of sequestering carbon is high and outcompetes carbon benefits in areas with high potential areas. This suggests that agroforestry must to be profitable, otherwise farmers may not forego a more profitable cash crop in favour of carbon sequestration. This is compounded by the long contract periods that are required for the carbon credit schemes before one can harvest the trees, foregoing other emerging opportunities; issues of land ownership / tenure and tree tenure notwithstanding.

4.5. Other agroforestry income impacts on livelihoods

Agroforestry improves overall human, financial, natural, and social capitals of communities. In western Kenya, participants of a school agroforestry project program experienced improved school attendance and performance. Spill over effects of the program were improvement in child health, community agroforestry knowledge, household income savings and strong relations at family and community level (Borish et al., 2017). A review of extension programs in Western Kenya found increased assets amongst households represented by female program participants (Hughes et al., 2020). In Ethiopia, apple production led to expansion and improvement of communication, education and health infrastructure and services (Admasu and Jenberu, 2022). This developments are attributed to production and sale of apple fruits and seedlings (Admasu and Jenberu, 2022). Farmers across East Africa also raise trees as assets, which they sell to meet various household needs.

Economic benefits of agroforestry are context specific. The net present value (NPV) for agroforestry parklands with sorghum, pearl millet and sesame were higher than monocultures of these crops in Sudan (Fadl and El Sheikh, 2010; Fahmi et al., 2018). Woodlots also gave high financial returns and required less investment costs compared to scattered trees on farms or homegardens (Ramadhani et al., 2002; Duguma, 2013). In Tanzania, the NPV of rotational woodlots was 6.3 times higher than that of maize-fallow (Ramadhani et al., 2002) while intercropping fodder grass with *Acacia decurrens* provided 11 times more income than sole fodder production in Ethiopia (Mekonnen et al., 2021). On the contrary, the NPV for implementing sustainable land management practices in maize farms were negative for agroforestry but positive for intercropping and manure application across three counties (Siaya, Kakamega, Bungoma) in Kenya (Dallimer et al., 2018). Dallimer et al. (2018) analysed benefits by individual farmers and underscores the need for subsidies or other support measures that can facilitative uptake of agroforestry. This is especially the case where opportunity cost of agroforestry is high, and tree products do not play a leading role in income generation (De Giusti et al., 2019). While income from agroforestry may be low in some cases, farmers still recognise the great role of trees as a source of income because of their various non-monetary benefits. For example, agroforestry support forest conservation by providing products that would otherwise be sourced from forests; and provide societal level benefits such as climate regulation. A positive impact of agroforestry can be seen if a holistic approach is used to quantify benefits of agroforestry.

5. Carbon sequestration in agroforestry systems in East Africa

This review shows that agroforestry systems in East Africa stock an average of 24.2 ± 2.8 Mg C ha^{-1} in biomass and 98.8 ± 12.2 Mg C ha^{-1} in the soil (Fig. 3). The combined estimate of carbon in biomass and the soil is larger than what was estimated to be the potential carbon storage (29–53 Mg C ha^{-1}) of agrosilvicultural systems in the humid tropics of Africa (Albrecht and Kandji, 2003), but lower than systems with high stem density, large mean tree size, and longer maximum ages i.e. over 60 years reported in Southeast Asia (Roshetko et al., 2007). The difference with earlier estimates is mostly in the soil part where several methodological issues need to be considered (Hairiah et al., 2020), such as variation in the soil depth included and changes in soil bulk density that influence which soil is included in a fixed-depth sample (Schrumpf et al., 2011). The amount varies depending on agroforestry practice, ranging from 26.7 ± 7.0 Mg C ha^{-1} in improved fallows to 153 ± 23 Mg C ha^{-1} in homegardens. Carbon sequestered in agroforestry in East Africa is less than forested areas but greater than what would be found in low biomass systems such as natural grasslands, pastures and or annual crops without trees.

Much of the aboveground carbon is held in homegardens (34.3 ± 7.9 Mg C ha^{-1}), perennial tree-crop systems (29.9 ± 12.7 Mg C ha^{-1}) and trees on boundaries (26.7 ± 14.1 Mg C ha^{-1}) (Table 3). Aboveground biomass estimated by CO_2FIX model for enset-tree (73.2 Mg/ha), enset-coffee (105.7 Mg/ha) and tree-coffee system (116.2 Mg/ha), translating to biomass carbon of 96.6, 139.5, 153.4 Mg/ha, respectively (Negash and Kanninen, 2015) was higher than estimates reported in the region and therefore left out in the calculation of mean carbon storage. Estimates in comparable systems give half the amount: enset (34.9 Mg/ha), enset-coffee (59.2 Mg/ha) and fruit-coffee (58.3 Mg/ha) (Negash and Starr, 2015). Homegardens and perennial tree-crop systems are a type of complex agroforestry systems where perennial food crops are mixed with multipurpose trees (Nair et al. 2021). Trees in these systems are allowed to grow for longer periods because of their benefits e.g. shade, timber, medicinal products etc. (Table 2). Livelihood benefits reported in homegardens show that the practice is an integral part of food systems in East Africa, and that it contributes to the economic welfare of households. Perennial tree-crops on the other hand contribute to household income and food security, generate foreign exchange, and can be used in restoration of degraded lands. These systems therefore provide effective carbon sequestration as carbon is stored in trees and processed wood products for longer periods.

Aboveground carbon storage in woodlots is fairly comparable across studies in Kenya and Tanzania, except for one study in Siaya County in Kenya where the combined biomass carbon of trees, hedges and permanent crops within woodlots was 122.6 ± 59.2 Mg C ha^{-1} (Henry et al., 2009). A value of 122 Mg C ha^{-1} is obviously higher than carbon storage of 5.1- 33.75 Mg C ha^{-1} in different farmer groups participating in asset-based community development project in the same environment (Fuchs et al., 2022) and storage mean of 39.4 Mg C -ha^{-1} in the same area (Reppin et al., 2020), even if the two latter studies did not account

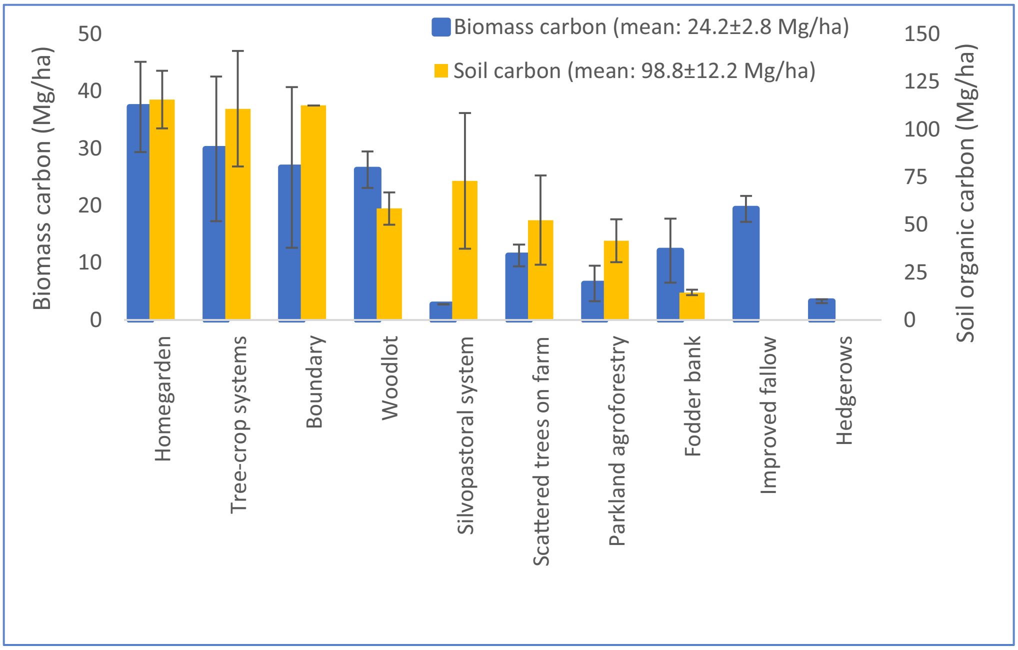

Fig. 3. Biomass and soil carbon in different agroforestry practices in East Africa. The values are means from 43 publications that reported carbon sequestration in agroforestry.

Table 3
Estimates of above- and below ground biomass carbon (Mg C ha^{-1}) and soil organic carbon (0–60 cm depth, Mg C ha^{-1}) in major agroforestry practices in East Africa. The values are mean ± standard error.

Agroforestry practice	Aboveground carbon	Belowground carbon	Soil organic carbon	Country	Reference
Boundary planting	26.7 ± 14.1		112.7	Ethiopia, Kenya	Manaye et al. (2021), Nigatu et al. (2020); Reppin et al. (2020); Fuchs et al. (2022)
Fodder bank	9.2 ± 4.2		14.5 ± 1.4	Uganda, Ethiopia	Mengistu et al. (2002); Furo et al. (2020)
Hedgerows	2.5 ± 0.2			Ethiopia, Kenya	Heering (1995); Fuchs et al. (2022)
Homegarden agroforestry	28.2 ± 6.0	9.6 ± 2.8	115.7 ± 15.1	Ethiopia, Kenya	Henry et al. (2009); Negash and Starr (2015); Vanderhaegen et al. (2015); Sahle et al. (2018); Betemariyam et al. (2020); Birhane et al. (2020); Lulu et al. (2020); Reppin et al. (2020); Manaye et al. (2021); Negash et al. (2022)
Improved fallow	14.1 ± 1.7	7.4 ± 0.8		Kenya, Uganda	Stahl et al. (2002); David and Raussen (2003); Ndufa et al. (2009)
Parkland systems	4.9 ± 2.5	*1.9 ± 0.8*	41.6 ± 11.3	Ethiopia	Gelaw et al. (2014); Gurmessa et al. (2016); Chiemela et al. (2018); Dilla et al. (2019); Manaye et al. (2021)
Perennial tree-crop systems	23.7 ± 10.0	8.2 ± 4.8	110.9 ± 30.3	Ethiopia, Uganda	Tumwebaze and Byakagaba (2016); Justine et al. (2019); Toru and Kibret (2019); Betemariyam et al. (2020)
Scattered trees on farm	8.2 ± 1.4	2.9 ± 1.0	52.5 ± 23.4	Ethiopia, Kenya, Tanzania	Kuyah et al. (2012b, 2012a); Kuyah et al. (2013); Gebrewahid et al. (2018); Reppin et al. (2020); Gebremeskel et al. (2021); Hagos et al. (2021)
Silvopasture	2.1 ± 0.01		73.0 ± 35.6	Ethiopia, Kenya, Tanzania	Gelaw et al. (2014); Gurmessa et al. (2016); Osei et al. (2018); Reppin et al. (2020)
Woodlot	25.0 ± 5.6	4.559	58.6 ± 8.5	Ethiopia, Kenya, Tanzania	Osei et al. (2018); Lulu et al. (2020); Manaye et al. (2021)

for carbon in crops within the plot and hedges around woodlots. This over-estimation is attributed to the use of global allometric equations designed for tropical forests in the study by Henry et al. (2009) as opposed to site specific or regional allometric equations that were used in other studies. Rotational woodlots in Tanzania stock an average of 29.2 ± 5.5 Mg C ha^{-1} (Nyadzi et al., 2003; Kimaro et al., 2011). Eucalyptus-based small-scale woodlots in Ethiopia would have higher aboveground carbon but this was not quantified (Duguma, 2013; Gebreegziabher and van Kooten, 2013; Lulu et al., 2020). While rotational woodlots are harvested regularly, the average carbon stocks therein is higher than carbon stocks in degraded land, cropland and pastures. Their contribution to soil carbon, especially restoration of degraded landscapes is also significant (Nyadzi et al., 2003; Kimaro et al., 2011).

Aboveground carbon in hedgerows, improved fallows and fodder banks was lower compared to complex agroforestry systems. Trees in these systems are mainly used for fodder and firewood and are normally harvested ahead of those in complex agroforestry systems. De Giusti et al. (2019) described agroforestry systems that provide fodder and firewood as providing low mitigation benefits. The amount of aboveground carbon stored in hedgerows in Kenya: 5.87 Mg C ha^{-1} (Fuchs et al., 2022) and Ethiopia: 4.81 Mg C ha^{-1} (Heering, 1995) is therefore ephemeral, given that hedgerows are regularly pruned for fodder and firewood. Aboveground carbon in improved fallows varies depending on climatic conditions, soil conditions and the duration of fallows. An average of 12±1.9 Mg C ha^{-1} can be stored in short-rotation fallows with *A. pubescens, C. cajan, C. calothyrsus, Crotalaria grahamiana, S. sesban* and *T. vogelii*; while long-duration fallows with *Eucalyptus saligna, G. robusta, A. acuminata* can stock an average of 13.3 ± 2.2 Mg C ha^{-1} in aboveground biomass. Fodder banks also exhibit high variation due to climatic conditions and tree species. Aboveground carbon in fodder banks with *C. calothyrsus* and *V. amygdalina* in Uganda was 22.7 Mg C ha^{-1} (Fungo et al., 2020); while *S. micrantha, S. rostrata, S. quadrata* and *S. sesban* stored 5.4 Mg C ha^{-1} in the same carbon pool in Ethiopia (Mengistu et al., 2002). Even though carbon sequestered in hedgerows, fodder banks and improved fallows is returned back to the atmosphere when wood from these systems is used as fuel, the act of producing firewood from farms contributes indirectly to climate change mitigation by protecting existing forests and woodlands from degradation and reducing consumption of fossil fuel by providing an alternative source of energy (Crossland, 2015).

Multiple benefits of carbon sequestration were illustrated in a life cycle assessment on use of char recovered as a by-product of cooking with firewood in gasifier cook stoves for soil amendment in rural Kenya. Using the char as biochar for soil amendment is a better option from climate perspective as it sequesters the stable biochar carbon in soil compared to using it as fuel (Sundberg et al., 2020). Biochar improve soil water and nutrient retention and fertility in and yields significantly increase and the benefits are persistent for over a decade (Kätterer et al., 2019). However, in circumstances where biomass for cooking energy is scarce or unsustainably harvested it is better to use the recovered char as fuel as it also brings other environmental and socio-economic benefits (Sundberg et al., 2020). Further use of more efficient firewood and charcoal stoves reduce demand for woodfuel preserving carbon stocks in standing biomass and reduce emissions during cooking mitigating against health problems associated with smoke in the kitchen.

Similar to aboveground carbon, SOC was highest in homegardens followed by perennial tree-crop systems and boundary (Figure 4). Homegardens and perennial tree-crops are mostly found in humid and sub-humid areas and the tree components in them can stay in farms for more than 20 years (Nair et al. 2021). Soil organic carbon is expected to remain stable in complex agroforestry systems despite continuous harvests of annual crops and tree products. Complex agroforestry systems are characterized by production of large amount of litter and prunings that improve soil organic matter. Organic matter from root decay also contribute to accumulation of SOC in these systems. For example, the rate of annual loss of SOC was 3 times higher in areas converted (from forest) to khat monoculture than to agroforestry systems with both khat and coffee (Negash et al., 2022). SOC in a 32–54-year-old agroforestry plots was 117.3 Mg C ha^{-1}, compare to 94.1 Mg C ha^{-1} in a 15–27-year-old khat monoculture and 171.8 Mg C ha^{-1} in the forest (Negash et al., 2022). The amount of carbon in litter and roots was higher in agroforestry than in khat monocropping (Negash et al., 2022). The contribution of boundary systems to SOC was high, although the benefit is not significant at field level as boundary trees only cover a small area of the farm. The same applies to hedgerows, except where biomass is applied as green manure or much. Soil carbon were not quantified in hedgerows and improved fallows, although extrapolation from studies in western Kenya shows that estimate potential to store between 0.7 and 12.4 Mg C ha^{-1} in the soil (Albrecht and Kandji, 2003).

There is still need for better understanding of belowground carbon in agroforestry and emission of GHG (N_2O and CH_4) in different agroforestry systems. The theoretical basis of carbon sequestration and GHG emission in agroforestry has been well established. However, there is limited empirical data to validate the concepts. For example, 11 out of 32 publication that reported on biomass carbon did not report belowground biomass. Consequently, belowground carbon was estimated as a fraction of aboveground carbon through root-to-shoot ratio. The number of publications reporting SOC in agroforestry system was also very low relative to the number of studies providing livelihood benefits. Lack of uniform methodology is still a major hindrance, especially for making comparisons. Such lack of data limits accounting for all carbon pools that influence dynamics of carbon in agroforestry. Very few studies compared SOC in agroforestry and non-agroforestry systems, making it difficult to estimate carbon changes due to inclusion of trees on farm. The age of trees was also not reported in almost all studies, which limits calculation of carbon sequestration rates. Regarding non-CO_2 GHG, information from elsewhere suggest that N_2O emission may increase in systems that integrate nitrogen-fixing trees (Kou-Giesbrecht and Menge, 2021), and that integration of livestock could also contribute to methane emission. Efforts should be made to ensure that agroforestry remains a net sink by sequestering more carbon than the amount of CH_4 and N_2O emitted from the system.

Agroforestry presents synergy between climate change mitigation and provision of livelihood benefits. This is critical as carbon sequestration alone is not a driver of tree growing amongst smallholder farmers in Africa as a whole. For agroforestry to be attractive to farmers as a tool for climate change mitigation, the trees must provide immediate short-term benefits with carbon sequestration as a co-benefit (Mbow et al., 2014), in addition to being intercropped with appropriate understorey crop when young. Farmers meet pressing livelihood deficits through economic activities outside the farm and remittances from relatives. This suggest that agroforestry must be subsidized or optimized to provide short-term benefits that improve livelihoods in order to achieve long term benefits such as mitigation (De Giusti et al. 2019). Optimizing agroforestry to be profitable or subsidizing implementation costs can make agroforestry's benefits match those of forfeited land use alternatives (Mbow et al., 2014). In addition, extension services / systems targeting tree growing by smallholder farmers need to be strengthened or established where none exist. The majority of agroforestry practices reviewed hold great opportunity for carbon sequestration as they provide livelihood benefits and only have climate change mitigation as a co-benefit. Homegardens and perennial tree crop systems are example, providing economic and social benefits to the household while achieving long term carbon sequestration. However, limited data on agroforestry's carbon sequestration potential suggest that farmers and other land users may not fully benefit from all the potential benefits of integrating trees with farm enterprises.

6. Conclusion

This study examined the multiple impacts of agroforestry interventions in East Africa to provide an evidence-base that can support policy development and investment decisions for advancing sustainable development in the region. The reviewed literature showed that agroforestry systems are multifunctional and supports livelihoods by increasing farmer's capacity to acquire food, firewood, fodder and income, and provides other products are used by communities facing climate-related threats. The trees and tree products are mainly used for subsistence and income, and to a small extend for insurance and to build assets for rural households. Agroforestry systems also store substantial amounts of carbon in plant biomass and in the soil. Homegardens are the most multifunctional agroforestry practice with the highest number of livelihood benefits and largest amount of carbon stocks in aboveground biomass and in the soil. The large carbon stocks in agroforestry, the widespread use of agroforestry in East Africa and the global consensus of the approach as a strategy for climate change mitigation and adaptation positions agroforestry as a low-hanging fruit that can enable countries in the region to achieve their NDC pledges while making landscapes and livelihoods resilient to climate change.

Agroforestry can contribute revenue from carbon sequestration as a co-benefit. However, the number of studies focusing on carbon benefits of agroforestry are very few suggesting that challenges that can affect harnessing benefits related to carbon sequestration such as carbon rights, land tenure, tree tenure rights, and the potential impact of climate change on the growing niches of tree species need to be addressed. There is also need to develop the legislation and institutional frameworks to govern the region's engagement in the carbon market.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix

Table A1

Table A1. Association of trees and shrub species with different livelihood benefits in East Africa. The values represent the number of publications that mentioned the benefit. Food and additives includes edible products of trees such as fruits, leaves, seeds and edible oil as well as food additives such as gum arabic, spices, stimulants, condiments; fuelwood includes firewood and charcoal, nontimber wood products (NTWP) refers to poles, staking material and wood in general, bee keeping refers to evidence related to bee forage, bee hive construction and honey. The asterisk (*) indicate top-20 species with the most ($n = 5$) uses.

Tree /shrub species	Food and food additives	Fodder	Fuelwood	Timber and NTWP	Shade	Medicinal use	Construction material	Income	Bee keeping	Farm implements, household items	No. of benefits	No. of publications
*Calliandra calothyrsus**		21	5	4	1	1			1		6	33
*Mangifera indica**	18	1	1	1	4			2			6	27
Sesbania sesban		11	3	10							3	24
*Leucaena leucocephala**		13	4	4	1	1					5	23
*Persea americana**	14		1	2	3			1			5	21
*Cordia africana**	5	3	2	1	3	1	1			2	8	18
Grevillea robusta			5	10	2			1			4	18
Psidium guajava	14	1			1			1			4	17
*Piliostigma thonningii**	3	2	1	1	1	2	1		2	2	9	15
*Artocarpus heterophyllus**	8	1			3	1		1			5	14
Tamarindus indica	11					1		1		1	4	14
Eucalyptus camaldulensis		1	7	3			3				4	14
Balanites aegyptiaca	9	4	1								3	14
Carica papaya	9					2		1			3	12
*Albizia coriaria**		1	2	1	2	2	2			1	7	11
*Croton macrostachyus**	1	1	3	1	4	1					6	11
*Faidherbia albida**	1	3	3	1	3						5	11
Ficus sycomorus	6				4	1					3	11
Citrus sinensis	10							1			2	11
*Vachellia etbaica**		2	3	2	1	1	1				6	10
*Syzygium guineense**	6		1		1		1		1		5	10
*Albizia gummifera**			3	2	3		1		1		5	10
Adansonia digitata	8							1			2	9
*Grewia mollis**	3	1	1			1				2	5	8
*Acacia decurrens**		1	3	1			1	2			5	8
*Senna siamea**		1	1	4		1	1				5	8
Azadirachta indica	3	1	1		2	2					4	8
Ficus sur	3	1			2					2	4	8
Ficus thonningii	3	3			1				1		4	8
Ziziphus spina-christi	5	2					1				3	8
Gliricidia sepium		4	2	2							3	8
*Acacia polyacantha**		1	1	2			1	1		1	6	7
*Ficus natalensis**	1		1		3	1	1				5	7
Maesopsis eminii			1	3	2	1					4	7
Markhamia lutea			1	4	1	1					4	7
Carissa spinarum	6					1					2	7
*Cajanus cajan**	1	1	1	2				1			5	6
*Melia azedarach**	1		1	2	1	1					5	6
Senegalia senegal	4					1		1			3	6
Eucalyptus globulus			3	2			1				3	6
Morus alba	3	3									2	6
Rhus natalensis	3	3									2	6
Senna spectabilis		1	1	2		1					4	5
Vachellia seyal		2	1	1		1					4	5

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(*continued*)

Tree /shrub species	Food and food additives	Fodder	Fuelwood	Timber and NTWP	Shade	Medicinal use	Construction material	Income	Bee keeping	Farm implements, household items	No. of benefits	No. of publications
Vachellia sieberiana		1			2	1	1				4	5
Moringa oleifera	1	2				2					3	5
Malus domestica	4							1			2	5
Lantana camara	1	4									2	5
Millettia ferruginea					4					1	2	5
Citrus limon	5										1	5
Ximenia americana	5										1	5
Indigofera lupatana		5									1	5
Vernonia amygdalina	1	1	1							1	4	4
Bersama abyssinica			1		1		1			1	4	4
Erythrina abyssinica			1	1		1			1		4	4
Acacia crassicarpa			1	2				1			3	4
Alnus acuminata			2	1						1	3	4
Olea europaea		1	2	1							3	4
Annona squamosa	3					1					2	4
Carissa edulis	3	1									2	4
Diospyros mespiliformis	3					1					2	4
Ficus vasta	2				2						2	4
Grewia bicolour	2	2									2	4
Grewia tembensis	2	2									2	4
Sarcocephalus latifolius	1					3					2	4
Leucaena diversifolia		2		2							2	4
Sesbania micrantha		2		2							2	4
Annona muricata	4										1	4
Borassus aethiopum	4										1	4
Citrus aurantiifolia	4										1	4
Grewia villosa	4										1	4
Sclerocarya birrea	4										1	4
Vitex doniana	4										1	4
Crotalaria goodiiformis		4									1	4
Vachellia tortilis		4									1	4
Albizia chinensis	1			1	1						3	3
Bridelia micrantha	1	1	1								3	3
Grewia similis	1	1					1				3	3
Acacia angustissima		1	1	1							3	3
Acacia julifera			1	1				1			3	3
Acacia leptocarpa			1	1				1			3	3
Acacia saligna		1		1	1						3	3
Combretum molle		1	1	1							3	3
Entada abyssinica			1		1	1					3	3
Fagaropsis angolensis		1		1		1					3	3
Polyscias fulva				1	1				1		3	3
Tephrosia vogelii		1	1	1							3	3
Canarium schweinfurthii	2					1					2	3
Salvadora persica	2	1									2	3
Ficus ovata	1				2						2	3
Securidaca longipedunculata	1					2					2	3
Eucalyptus saligna			1	2							2	3
Leucaena pallida		1		2							2	3
Mimosa scabrella		2		1							2	3
Vachellia abyssinica			2		1						2	3
Anacardium occidentale	3										1	3
Annona reticulata	3										1	3
Casimiroa edulis	3										1	3
Citrus reticulata	3										1	3
Pappea capensis	3										1	3
Syzygium cumini	3										1	3
Vangueria madagascariensis	3										1	3
Vitex payos	3										1	3
Acalypha fruticosa		3									1	3
Cedrela odorata				3							1	3
Commiphora eminii		3									1	3
Warburgia salutaris						3					1	3
Carissa macrocarpa	1	1									2	2
Flacourtia indica	1		1								2	2
Grewia ferruginea	1	1									2	2
Mimusops kummel	1						1				2	2

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Tree /shrub species	Food and food additives	Fodder	Fuelwood	Timber and NTWP	Shade	Medicinal use	Construction material	Income	Bee keeping	Farm implements, household items	No. of benefits	No. of publications
Terminalia brownii	1				1						2	2
Acacia mearnsii			1		1						2	2
Albizia schimperiana			1		1						2	2
Antiaris toxicaria					1		1				2	2
Dichrostachys cinerea			1				1				2	2
Dodonaea angustifolia			1	1							2	2
Dombeya torrida			1		1						2	2
Justicia schimperiana						1			1		2	2
Khaya grandifoliola		1		1							2	2
Sapium ellipticum		1							1		2	2
Schefflera abyssinica									1	1	2	2
Sesbania quadrata		1		1							2	2
Sesbania rostrata		1		1							2	2
Terminalia glaucescens					1	1					2	2
Vernonia auriculifera			1		1						2	2
Annona senegalensis	2										1	2
Azanza garckeana	2										1	2
Dovyalis abyssinica	2										1	2
Eriobotrya japonica	2										1	2
Grewia tenax	2										1	2
Hyphaene thebaica	2										1	2
Lannea schweinfurthii	2										1	2
Opuntia ficus-indica	2										1	2
Phoenix dactylifera	2										1	2
Phoenix reclinata	2										1	2
Prunus persica	2										1	2
Rhus vulgaris	2										1	2
Vangueria apiculata	2										1	2
Vitellaria paradoxa	2										1	2
Ziziphus mucronata	2										1	2
Acacia ataxacantha		2									1	2
Acacia mellifera		2									1	2
Aspilia mossambicensis		2									1	2
Cedrela serrata				2							1	2
Crotalaria grahamiana				2							1	2
Eucalyptus grandis				2							1	2
Phyllanthus sepialis		2									1	2
Psorospermum febrifugum						2					1	2
Schinus molle					2						1	2
Tithonia diversifolia		2									1	2
Allanblackia stuhlmannii	1										1	1
Annona cherimola	1										1	1
Averrhoa bilimbi	1										1	1
Bauhinia thonningii	1										1	1
Berchemia discolour	1										1	1
Bridelia scleroneura	1										1	1
Bridelia taitensis	1										1	1
Capparis decidua	1										1	1
Chrysophyllum albidum	1										1	1
Citrus aurantium	1										1	1
Citrus medica	1										1	1
Citrus pardisi	1										1	1
Citrus × *aurantiifolia*	1										1	1
Cocos nucifera	1										1	1
Commiphora africana	1										1	1
Commiphora pedunculata	1										1	1
Cordia monoica	1										1	1
Detarium microcarpum	1										1	1
Diplostigma canascens	1										1	1
Elaeis guineensis	1										1	1
Ficus dicranostyla	1										1	1
Ficus mucuso	1										1	1
Flueggea virosa	1										1	1
Garcinia buchananii	1										1	1
Garcinia mangostana	1										1	1
Gardenia ternifolia	1										1	1

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Tree /shrub species	Food and food additives	Fodder	Fuelwood	Timber and NTWP	Shade	Medicinal use	Construction material	Income	Bee keeping	Farm implements, household items	No. of benefits	No. of publications
Grewia arborea	1										1	1
Kigelia africana	1										1	1
Lannea acida	1										1	1
Lannea alata	1										1	1
Lannea microcarpa	1										1	1
Lannea triphylla	1										1	1
Maerua edulis	1										1	1
Malus sylvestris	1										1	1
Mammea americana	1										1	1
Myrianthus arboreus	1										1	1
Nauclea latifolia	1										1	1
Opilia campestris	1										1	1
Oxytenanthera abyssinica	1										1	1
Pachystigma schumannianum	1										1	1
Parkinsonia aculeata	1										1	1
Pithecellobium dulce	1										1	1
Premna resinosa	1										1	1
Prunus cerasifera	1										1	1
Prunus domestica	1										1	1
Pseudospondias microcarpa	1										1	1
Punica granatum	1										1	1
Rhamnus prinoides	1										1	1
Rosa abyssinica	1										1	1
Saba comorensis	1										1	1
Saribus rotundifolius	1										1	1
Strychnos innocua	1										1	1
Syzygium cordatum	1										1	1
Tennantia sennii	1										1	1
Terminalia catappa	1										1	1
Uvaria scheffleri	1										1	1
Vangueria infausta	1										1	1
Vangueria venosa	1										1	1
Vitex madiensis	1										1	1
Ziziphus abyssinica	1										1	1
Acacia abyssinica			1								1	1
Acacia auriculiformis				1							1	1
Acacia brevispica		1									1	1
Acacia bussei					1						1	1
Acacia mangium				1							1	1
Acacia melanoxy				1							1	1
Acanthus pubescens			1								1	1
Acrocarpus fraxinifolius				1							1	1
Afzelia africana				1							1	1
Alangium chinense										1	1	1
Albizia grandibracteata							1				1	1
Albizia lebbeck		1									1	1
Allophyllus abyssinicus							1				1	1
Alsophila manniana							1				1	1
Alstonia boonei							1				1	1
Apodytes dimidiata									1		1	1
Balanites pedicellaris		1									1	1
Baphia abyssinica							1				1	1
Becium grandiflorum		1									1	1
Blighia unijugata			1								1	1
Boscia angustifolia		1									1	1
Callistemon citrinus						1					1	1
Calpurnia aurea						1					1	1
Canthium oligocarpum							1				1	1
Capparis tomentosa						1					1	1
Cassipourea malosana				1							1	1
Casuarina cunninghamiana				1							1	1
Casuarina equisetifolia			XX	1	1						2	2
Casuarina glauca				1							1	1
Ceiba pentandra						1					1	1
Celtis africana							1				1	1

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Tree /shrub species	Food and food additives	Fodder	Fuelwood	Timber and NTWP	Shade	Medicinal use	Construction material	Income	Bee keeping	Farm implements, household items	No. of benefits	No. of publications
Celtis gomphophylla							1				1	1
Celtis phillipensis							1				1	1
Celtis zinkeri							1				1	1
Chamaecytisus palmensis		1									1	1
Chionanthus mildebraedii			1								1	1
Combretum aculeatum			1								1	1
Combretum collinum			1								1	1
Cordia ovalis		1									1	1
Cordia sinensis		1									1	1
Croton sylvaticus			1								1	1
Deinbollia kilimandscharica							1				1	1
Diospyros abyssinica							1				1	1
Ehretia abyssinica										1	1	1
Ekebergia capensis									1		1	1
Elaeodendron buchananii				1							1	1
Erythrina brucei					1						1	1
Erythrina burana		1									1	1
Erythrina poeppigiana				1							1	1
Eucalyptus urophyla				1							1	1
Euphorbia abyssinica									1		1	1
Ficus elastica					1						1	1
Ficus exasperata					1						1	1
Ficus lutea					1						1	1
Ficus vallis-choudae					1						1	1
Grewia trichocarpa			1								1	1
Hagenia abyssinica						1					1	1
Ilex mitis									1		1	1
Inga oerstediana					1						1	1
Jatropha curcas			1								1	1
Juniperus procera							1				1	1
Khaya anthotheca				1							1	1
Lannea welwitschii					1						1	1
Lecaniodiscus fraxinifolius			1								1	1
Lepisanthes senegalensis									1		1	1
Lonchocarpus eriocalyx		1									1	1
Macaranga capensis			1								1	1
Maerua angolensis		1									1	1
Manilkara butugi									1		1	1
Maytenus putterlickioides		1									1	1
Maytenus senegalensis		1									1	1
Milletia dura		1									1	1
Morus mesozygia							1				1	1
Neolamarckia cadamba					1						1	1
Nuxia congesta							1				1	1
Ocotea kenyensis							1				1	1
Olea welwitschii							1				1	1
Osyris quandripartita							1				1	1
Pavetta ternifolia					1						1	1
Periserianthus falcataria				1							1	1
Pinus patula							1				1	1
Pittosporum virdifolium							1				1	1
Pouteria adolfi-friedericci							1				1	1
Pouteria alnifolia							1				1	1
Pouteria altissima							1				1	1
Prunus africana						1					1	1
Psydrax parviflora			1								1	1
Rhus glutinosa			1								1	1
Rothmania urcelliformis										1	1	1
Senna septemtrionalis			1								1	1
Sericomopsis hildebrandtii		1									1	1

(*continued on next page*)

(*continued*)

Tree /shrub species	Food and food additives	Fodder	Fuelwood	Timber and NTWP	Shade	Medicinal use	Construction material	Income	Bee keeping	Farm implements, household items	No. of benefits	No. of publications
Spathodea campanulata					1						1	1
Syzyygium jambos						1					1	1
Tectona grandis				1							1	1
Terminalia schimperiana						1					1	1
Trema orientalis		1									1	1
Trichillia dregeana							1				1	1
Trilepisium madagascariense							1				1	1
Triumfetta rhomboidea		1									1	1
Triumfetta tomentosa		1									1	1
Vachellia amythethophylla						1					1	1
Vachellia nilotica		1									1	1
Vernonia lasiopus		1									1	1
Ziziphus pubescens						1					1	1
Catha edulis	2			1							2	2
Coffea arabica	2			1							2	2
Camellia sinensis	1			1							1	1
Cinnamomum verum	1										1	1
Syzygium aromaticum	1										1	1
Count of species	146	84	65	66	53	46	44	17	16	15		

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