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Traditional homegardens change to perennial monocropping of khat (Catha edulis) reduced woody species and enset conservation and climate change mitigation potentials of the Wondo Genet landscape of southern Ethiopia

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ABSTRACT

Smallholder farmers in the Wondo Genet were forced to switch from long-standing, diverse traditional home gardens to monoculture khat production due to increasing population pressure-induced farmland constraints. The composition of woody species and the biomass carbon stock are thought to drop as homegardens transition from polyculture to monoculture; however there is little quantitative evidence to support this claim. This study was started to assess the effects on woody species, enset, and biomass carbon of converting traditional homegardens to a fast spreading perennial monocropping of khat (Catha edulis Forskal). In 10 m × 10 m (100m2) plots from 43 farms with neighboring land use patterns for each homegarden and khat, woody species and enset were inventoried, the total number of tree, shrub, and enset species counted, as well as the height and diameter of each species measured. To determine the biomass carbon stock of each land use type, both general and species-specific allometric equations are used. Simpson's diversity index, Shannon-Wiener, and Shannon equitability were used to evaluate the diversity of enset and woody species. There were 27 different types of woody species identified, with trees making up 67 % of the total and shrubs accounting for 33 %. Shannon, Simpson, and the richness of woody species all decreased by 46 %, 51 %, and 38 %, respectively, in comparison to residential gardens. For homegardens and khat, respectively, the mean Evenness values were 0.876 and 0.539. In homegardens, Coffea arabica was the most valuable woody species, followed by Cordia africana Lam, Persea americana, Eucalyptus camaldulensis, and Grevillea Robusta. In contrast, Catha edulis was the most valuable woody species in the Khat land use type, followed by Coffea arabica, Croton macrostachyus Del, and Cordia africana. In comparison to homegardens, the above-ground, below-ground, and total biomass carbon reported in khat land use types were reduced by 18 %, 63 %, and 42 %, respectively. Grevillea and Eucalyptus species made up 51 % of the total biomass carbon stock in the homegardens, which suggests that khat and quickly expanding fast-growing plants have displaced native woody species.Understanding the long-term effects of agro-biodiversity loss requires greater research on the implications of the decline in woody species diversity and biomass carbon stock on soil fertility and sustainable farming. This is due to the numerous functions that woody species and enset play.

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1. Introduction

Homegarden agroforestry systems based on enset-coffee are the predominant land use types in southern Ethiopia's densely populated areas, occupying roughly 576,000 ha, or 31 % of the region's arable land [1]. *Enset ventricosum (Welw.) Cheesman*, a perennial staple food crop, and coffee (Coffea arabica L.), a commercial crop, are cultivated alongside annual crops and multipurpose trees in this pattern of land use [1]. For more than 15 million people in the area, enset serves as a staple food and it is a herbaceous, versatile crop. In addition to being a food source, enset leaves are utilized as mulch to prevent soil erosion and runoff and as feed for cattle [2,3]. Homegardens with up to 90 woody species per farm and a variety of canopy structures are known to make greater use of available light, water, and nutrients [4].

Woody plants are crucial elements of homegarden systems because they provide income, fuel wood, building wood, animal food, and soil fertility maintenance [4,5]. Homegardens are believed to boost the agro-biodiversity and carbon sequestration potential of the environment by growing food and multipurpose trees on small plots of land [4]. In southern Ethiopia, the ability to harvest numerous crops and the ease of access to forest products from one's own farm are two significant factors contributing to the popularity of homegarden agroforestry systems [1]. As a result of their contribution in improving soil fertility by enriching soil organic carbon through continual input as the litter falls from various plant species, traditional enset-coffee homegardens are also acknowledged as being environmentally beneficial systems [6].Traditional homegardens can therefore help increase the systems' resilience to the effects of climate change [7,8].

However, there has been a recent rapid transition away from traditional homegardens to Khat-based systems, which are more focused on cash crops in locations near markets [9]. Khat (Catha edulis Forsk) increased from 6 % to 35 % of the farm area in market-convenient parts of the Wondo Genet district in the Sidama region between 1991 and 2013. As a result, the proportion of farmland dedicated to enset and coffee fell from 45 % to 25 % [9]. It was suggested that the system switch from the conventional enset-coffee to khat-based system would limit the diversity of plant species, which is a source of soil organic carbon [6]. When farmers switch from growing enset and coffee to khat, they frequently trim off the trees on their fields because the new crop is cultivated in monoculture [1].

The factors most frequently cited for replacing homegardens with khat are the increasing population pressure-induced constraints on farmland, price fluctuations of coffee, the frequency of khat harvesting and its higher income per unit area, institutional and cultural changes of the rural community, and technological advancements [10]. The potential of the landscape to sequester carbon and mitigate climate change are all directly harmed by the loss of plant species variety and subsequent deterioration in soil fertility. An

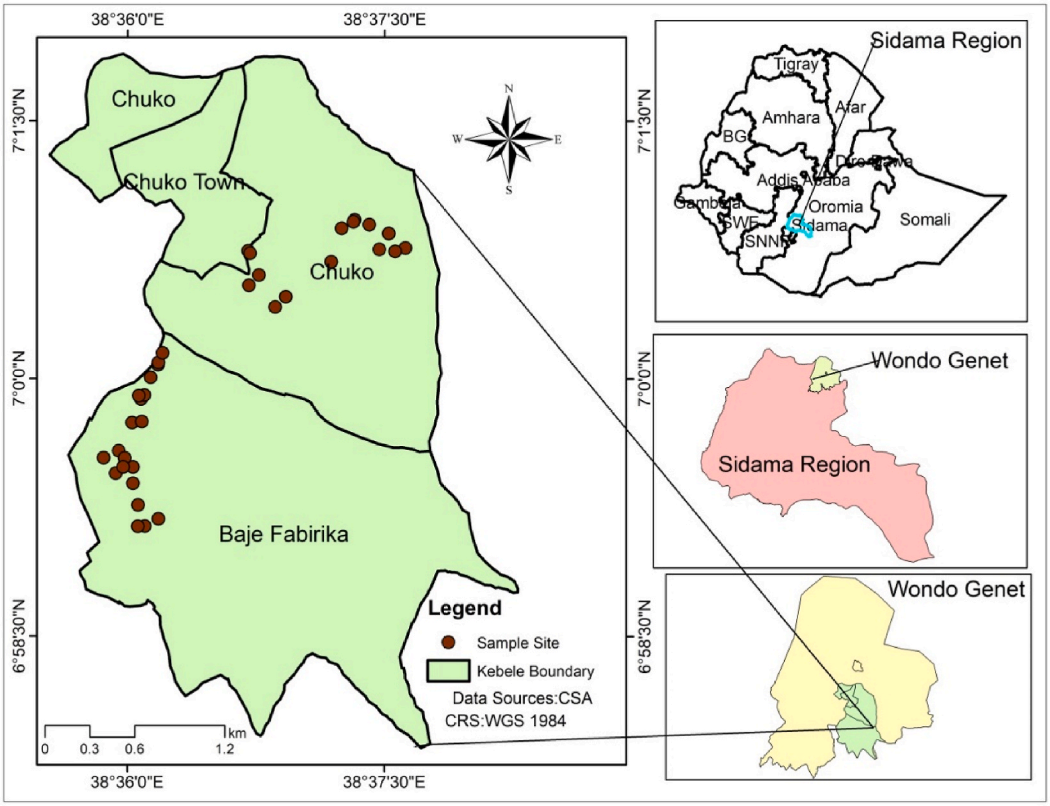

Fig. 1. Study area map of the two kebeles and sample farms within Wondo Genet woreda of Sidama region.

increase in monoculture khat at the expense of homegardens based on enset-coffee was linked to a drop in soil nitrogen and carbon, according to earlier studies [6,11].

But, since there is little quantitative data on the diversity of woody species and the carbon stock of both conventional and recently evolved systems, it is still unclear whether the recent changes have harmed the Wondo Genet landscape's ability to sequester carbon. We investigated the possibility that the traditional Enset-coffee-based systems' quick shift to khat monoculture results in the loss of the diversity of woody species, enset, and climate change mitigation potential of the Wondo Genet landscape. This study's major goal was to determine how the growth of khat monoculture in southern Ethiopia might affect the diversity of woody species, enset, and biomass carbon stock.

1.1. Materials and methods

The study was conducted in the Wondo Genet district of the Sidama Region, southern Ethiopia, in transition to khat hotspot areas (Fig. 1). Wondo Genet is located between 7° 06′ N and 38° 37′ E, with an average elevation of 1850 m a.s.l. The research area experiences a sub-humid tropical environment with 1247 mm of yearly rainfall on average. The rainfall pattern is bi-modal, with the long rainy season between July and October accounting for more than 50 % of the total rainfall and the short wet season between March and May contributing about 28 % [12]. The highest and lowest temperatures are 26.3 °C and 12.4 °C, respectively, with a 19.5 °C annual mean temperature [12]. Wondo Genet's geography is characterized by rolling upland between 1700 and 2600 m above sea level, with a third of the territory above 2200 m. Most of the region has a steep slope (>30 %) (15).

The soil in the research area is Andosol [13]. The principal qualifies of Andosols are Aluandic/Silandic Vitric Leptic Hydragric/Anthraquic, Gleyic, Hydric, Histic, Chernic/Mollic/Umbric Petroduric/Duric, Gypsic, Calcic, Tephric, Aeolic, Skeletic, Dystric/Eutric with a supplementary qualifiers of Arenic/Clayic/Loamic/Siltic, Protoandic, Aric, Dolomitic/Calcaric, Drainic, Eutrosilic/Acroxic, Fluvic, Folic, Fragic, Gelic, Humic/Ochric, Mulmic, Nechic, Novic, Oxyaquic, Panpaic, Placic, Posic, Pyric, Reductic, Sideralic, Sodic, Solimovic, Protospodic, Technic/Kalaic, Thixotropic, Toxic, Transportic and Turbic in nature [14].

In 2007–2008, the district had 126,144 residents overall. 64,681 men and 61,463 women made up the entire population. In Wondo Genet, various ethnic groups are present. The majority of the populace spoke Sidama. Muslims and Protestants make up the majority of the population [15]. The district has a 5.7 % forest area, 1.7 % grassland, 21.5 % cultivated land, 41.2 % shrub land, and 29.9 % built-up area [16].

1.3. Study site selection

One district (Wondo Genet) was chosen within the Sidama Region, and two kebeles (Baja Fabrika and Chuko) with a high concentration of khat cultivation were chosen on purpose (Fig. 1 and Table 1). First, a list of household heads from the Kebele (Ethiopia's smallest administrative division) was used to identify farmers who had enset and coffee gardens—hereafter referred to as "homegardens"—as both crops were grown in intercrop and sufficient khat area per farm to lay two plots with 100 m2 each.

This standard was chosen because farmers only utilize tiny plots of land for homegardens as hedge rows and dedicate the rest to khat. Second, a total of 43 farm households, including 16 farm households from Chuko and 27 from the Baja Fabrica Kebele, were chosen on purpose. Homegardens and khat were the two land use groups chosen for the woody species survey because they made up about 92.6 % of the farmland in both kebeles (Table 2).

Homegardens are plots designated for growing enset and coffee, two important agroforestry plants in southern Ethiopia [17]. Homegardens and Khat both get a yearly hoeing. Inorganic fertilizer is applied to khat, while manure is used as an input to residential gardens (Table 1). Khat has been cultivated in the region for less than three decades, although homegardens have been practiced for centuries [9]. A total of 86 plots were taken into consideration for the assessment of all woody species and enset (Table 1). This involved 43 plots per farm for each land use type. In the middle of the farm's field, the plots were randomly placed.

Table 1
Sampling plots within the farm households for the two land use types.

Kebeles	Households	Plots per land use types	
		Homegardens	Khat
Chucko	16	16	16
Baja fabrica	27	27	27
Total	43	43	43
Management types		hoeing once in a year (September–December)	hoeing once in a year (September–December)
Position of the land use		close to house in one side and adjacent to khat field on the other side	adjacent to homegardens (use to be part of homegardens)
Altitude (m.a.s.l)		1746–2182	1746–2182
Soil type		Andosols	Andosols
Slop		15–30 %	15–30 %
Age (years)		>45	<30

Table 2
Area share (Mean ± SD) of the different land use types and herd size for the two study kebeles.

kebeles	Area share (%)				Herd size (TLU)
	Home gardens	Khat	Annual crops	Grazing land	
Baja fab	20.6 ± 16.1	70.9 ± 21.7	1.8 ± 4.9	6.7 ± 18.1	1.5 ± 1.7
Chuko	40.8 ± 24.3	52.9 ± 24.2	2.8 + 6.3	3.5 ± 9.9	1.4 ± 1.9
Total	30.7 ± 20.5	61.9 ± 17.5	2.3 ± 5.6	5.1 ± 14.6	1.5 ± 1.4

1.4. Data collection

Between October 2021 and December 2021, a woody species and enset inventory was carried out, and information was gathered on the number, variety, and abundance of species from sampled households. For each sampled farm household, a plot measuring 10 m by 10 m (100 m^2) with adjacent homegardens (enset/coffee) and khat was surveyed for woody species and enset. The total number of woody species and enset were tallied inside the plot, and the vegetation structures were described using density, height, frequency, diameter at breast height (DBH), stamp height (DSH), species importance value index (IVI), and basal area.

The diameter of trees was measured at breast height (1.3 m above the ground), the diameter of shrubs was measured at stamp height (DSH) of 30 cm, the diameter of enset and khat was measured at stamp height of 10 cm, and the diameter of coffee was measured at 40 cm [18–20] above the ground. Tree and shrub diameters lower than 5 cm were taken into consideration. A caliper, a diameter tape, and a Suunto hypsometer, respectively, were used to measure DBH, DSH, and height [21]. Woody plants with numerous stems that are taller than 1.3 m were regarded as a single plant, but woody plants with multiple stems or forks that are shorter than 1.3 m had their individual stems measured and classified as two trees [22]. When measuring the stems of multi-stemmed shrubs, the diameter equivalent of the plant was determined by taking the square root of the total diameter of all the stems within the plant [22]. Using Eq. (1), the diameter equivalent was calculated:

$$de=\sqrt{\sum_{i}^{n} di^2} \tag{1}$$

Where de = equivalent diameter, n = number of stems, i = 1, 2 … n and d_i = single stem diameter of the same plant at a selected height.

The scientific names of woody species were allocated based on the Flora of Ethiopia [23] and the Flora of Ethiopia and Eritrea [24], which were used for field identification of the species.

1.5. Data analysis

1.5.1. Woody species diversity and density

For the number of woody species, enset, and basal area ha^{-1}, the data gathered from the two land use types were computed [25]˙. Shannon-Wiener, Shannon equitability (Evenness), and Simpson's diversity index were used to evaluate the diversity of woody species and enset [26–29]. In addition, the important value index (IVI) was calculated to examine each species' ecological significance within the investigated land use types [25]. Relative density, dominance, and frequency are added to determine the important value index. By computing woody species and comparing similarities between the two types of land use, Sorensen's similarity index [30] was used to supplement similarity analysis.

1.5.2. Biomass carbon stock estimation

Utilizing allometric biomass functions and plot-level inventory data, the biomass of trees, shrubs and enset plants were computed. An allometric equation created by Ref. [31] was used to calculate the above-ground biomass of the trees and shrubs (which includes the stem plus bark, branches, and foliage) using Eq. (2). The equations are utilized to calculate biomass using the prediction error with the lowest value [31]. Additionally, this equation was created for agroforestry trees with DBH greater than 2.5 cm, and it is applied to places with similar environmental characteristics (climate and soils) to the research area.

$$AGB = 0.091 \times DBH^{2.472,}\ R^2 = 0{:}98; \tag{2}$$

Where AGB is the estimation of the aboveground biomass (kg dry matter/plant) and DBH is the diameter (cm) at breast height (1.3 m).

Species-specific allometric equations were also used for estimating above-ground biomasses for enset and coffee [20,32] and Khat [18] using Eqs. (3)–(5), respectively.

$$\ln AGB_{enset} = -\ 6.57 + 2.316\ln(DSH) + 0.124\ln(H);\ R2 = 0.91 \tag{3}$$

$$AGB_{cofee} = 0.147\ x\ DSH^2;\ R2 = 0.80, \tag{4}$$

$$AGB_{khat} = 0.4796\ x\ DSH^{1.5818}\ x\ H^{0.1089};\ R2 = 0.96 \tag{5}$$

Where AGB is the estimation of the aboveground biomass (kg dry matter/plant) and DSH is the diameter (cm) at stump height and H is dominant plant height.

Then the woody species biomass was converted into carbon by using the allometric model developed by Ref. [33] using Eq. (6).

$$AGC \text{ or } BGC = AGB \text{ or } BGB * 0.5 \quad ,(6)$$

The belowground biomass (stump plus coarse roots (>2 cm)) for trees and shrubs, including coffee and khat were estimated using an allometric equation developed for agroforestry systems by Ref. [34] in western Kenya using Eq. (7).

$$BGB = 0.048 \times DBH/DSH^{2.303};\ R2 = 0.96, \quad (7)$$

Where BGB (kg dry matter/plant) = belowground biomass, DBH/DSH (cm) = diameter at breast height for trees and shrubs and diameter at stump height for coffee (DSH_{40cm}) and khat (DSH_{10cm}).

The below ground biomass for enset was calculated by Ref. [32] as Eq 8

$$BGB = 7 \times 10^{-6} \times DSH^{4.083};\ R2 = 0.69 \quad (8)$$

Where BGB (kg dry matter/plant) = belowground biomass, DSH (cm) = diameter at stump height (DSH_{40cm}).

Finally, total biomass carbon stock was calculated by summing up of the individual carbon pools following Eq. (9) [35].

$$TC = AGC + BGC \quad (9)$$

Where TC is total carbon, AGC is aboveground carbon and BGC is belowground carbon.

1.5.3. Biomass carbon stock and sequestration potential

By multiplying biomass carbon by a factor of 3.67, the above- and below-ground biomass carbon stocks of the two land use types were transformed into CO2 equivalents [36].

1.5.4. Statistical analysis

Prior to data analysis, residuals from plots for the species diversity index variable, wood and enset density, stem number, DBH, basal area, and biomass carbon were examined for normal distribution and homogeneity. The impact of changing land use on species richness, density, basal area, and biomass carbon in the two land use types was examined using the generalized linear model (GLM). The difference between the means of two land use types in terms of wood density, basal area, above and below-ground biomass, carbon stocks, and carbon dioxide equivalent was examined using a one-way analysis of variance (ANOVA). At P 0.05, differences were declared significant. The relationship between woody species and enset density, diameter, basal area, and height with biomass carbon stock was also examined using the Spearman correlation test. The Statistical Package for Social Sciences (SPSS) version 20 was used to

Table 3
List of the recorded woody species and enset scientific name, families, life form and their uses.

Scientific name	Family	Life form	Origin	Uses
Albizia gummifera(J.F.Gmel.)	Fabaceae	Tree	Ind	Bh, *Cm*, Sh
Azadirachta indica A	Meliaceae	Tree	Int	Lf, Med,Fw
Casimiroa edulus	Rutaceae	Tree	Int	Fod,In
Catha edulis(Vahl) Forssk.ex Endl.	Celastraceae	Shrub	Ind	In, Med,
Celtis africa Burm.	Cannabaceae	Tree	Ind	Fw, Lf
Coffea arabica	Rubiaceae.	shrub	Ind	In, Med,
Cordia africana Lam.	Boraginaceae	Tree	Ind	Sh, Fw,*Cm*,Tm
Croton macrostachyus Del.	Euphorbiaceae	Tree	Ind	Sh,Sf,Fw
Dendrocnide sinuata	Urticaceae	shrub	Ind	Fw,Lf
Enset ventricosum(Welw.)	Musaceae	Hebaceous	Ind	Fd,Fod,In,Med,Sf
Eucalyptus camaldulensis	Myrtaceae	Tree	Int	*Cm*, In, Fw
Euphorbia abyssinica	Euphorbiaceae	Tree	Int	Fen, Med
Ficus vasta Forssk.	Moraceae	Tree	Ind	FW, CM, Tm
Fragaria ananassa	Rosaceae	shrub	Ind	Fod,In
Grevillea robusta A	Proteaceae	Tree	Int	Fw, *Cm*, Tm
Juniporous procera	Cupressaceae	Tree	Ind	Tim, *Cm*,Fw
Malus pumila	Rosaceae	shrub	Int	Fod,In
Mangifera indica L.	Anacardiaceae	Tree	Int	Fod,In
Milletia ferruginea (Hochst.) Bak.	Fabaceae	Tree	End	Fw, *Cm*, Sf
Moringa oleifera	Moringaceae	Tree	Int	Fd,Fod,Fw,In,Med
Olea Africana	Oleaceae	Tree	Ind	Fw,Med, Sh
Persea americana	Lauraceae	Tree	Int	Fod,In
Podocarpus falcatus (Thunb.) Mirb.	Podocarpaceae	Tree	Ind	Tim, *Cm*,Fw
Psidium guajava L.	Myrtaceae	shrub	Int	Inc,Fod
Ricinus communis	Euphorbiaceae	shrub	Ind	Med
Spathodea campanulata	Bignoniaceae	Tree	Ind	*Cm*,Fw
Vernonia amygdalina Del.	Asteraceae	shrub	Ind	Med,Fd
Vernonia auriculifera Hiern.	Asteraceae	shrub	Ind	Med,Fd

Cm = construction materials; Fd = fodder; Fod = food; Fw = fuel wood; In = income; Lf = life fence; Med = Medicinal; Sf = soil fertility; Sh = shade; Tm= Timber; Int = introduced; Ind = indigenous; End = endemic.

conduct the analyses.

2. Result

2.1. Floristic composition of woody species and enset

In the homegardens and khat land use types, a total of 27 woody species from 21 families were identified (Table 3). Despite the differences in plot densities, the enset plant was found in both forms of land use. Trees made up 67 % of the woody species, while shrubs made up 33 %. There was no dominant family among the 21 plant families that were spread equally across the agroforestry systems under study. Of the species that were discovered, 7 % were found solely in khat, 52 % were found only in homegardens, and the remaining 41 % were found in both khat and homegardens.

For a variety of reasons, farmers incorporate woody species into their farms. Among these include the use of woody species as supplies of building materials and fuel wood, as fodder for animals, as shade for coffee, as a live fence, as food, as a source of revenue, as soil fertility, and for their medicinal properties (Table 3). Woody species are made up of both native (including endemic and indigenous) and invasive species. About 33 % of woody species were introduced, while 67 % of those that were recorded were native (Table 3). Enset, is indigenous species although categorized as the only herbaceous species in this study. The outcome demonstrated the study area's agroforestry systems' ability to conserve native vegetation.

2.2. Woody species diversity and enset

The homegarden had almost twice as many species as the khat, a newly emerging land use (Table 4). Shannon diversity was two times lower in the khat land use types than it was in the home gardens. Compared to the homegardens, Khat land use type featured the least variety of woody species. For the homegardens, the mean Evenness (E) index value was higher than for the khat land use type. For homegardens and khat, the mean evenness values were 0.876 and 0.539, respectively. In terms of woody species composition and enset, there was a 57 % similarity between the two land use groups (Table 4).

2.3. Woody species structure

2.3.1. Importance value index (IVI)

In the bhomgardens, *Enset ventricosum* was the most significant plant, followed by *Coffea arabica, Cordia africana Lam, Persea americana, Eucalyptus camaldulensis, and Grevillea robusta.* The most valuable woody species in the khat field was *Catha edulis,* which was followed by *Coffea arabica, Enset ventricosum, Croton macrostachyus Del, and Cordia africana Lam (Table 5)*. The fast-growing woody species, *Grevillea robusta* and *Eucalyptus camaldulensis* were kept alive because of their importance as building materials, fuel wood, and sources of income. On the other hand, Catha edulis (Vahl) Forss, Persea americana, and Coffea arabica were kept as revenue sources. In the research region, enset ventricosum is a perennial multipurpose food crop whose leaf serves as a significant source of animal feed.

2.3.2. Number of stems and basal area

The results of the inventory showed that the two forms of land use had different stem densities (Table 6). In comparison to the homegardens, khat had a much greater stem density (2339.3 + 208.5 stem ha-1). In comparison to khat land use categories, woody species documented from homegardens had a greater basal area (84.0 + 16.4 m2 ha-1).

2.4. Carbon stocks and carbon dioxide emission reduction

In comparison to the khat land use types, homegardens had significantly higher carbon stocks in the belowground (17.14 + 2.3 Mg C ha-1) and total biomass (33.32 + 6.46 Mg C ha-1) (Table 7). The enset plant's tendency to store more biomass in the root (corm) than the pseudo stem may have contributed to the homegardens' somewhat greater below-ground biomass carbon than above-ground carbon levels. In a same vein, homegardens stored significantly more CO_2e in their below-ground (62.92 + 13.78 Mg CO2e ha-1) than khat land use types.

In comparison to homegardens, the above-ground, below-ground, and total biomass carbon reported in khat land use types were reduced by 18 %, 63 %, and 42 %, respectively (Table 7). The two land use categories had an average biomass carbon record of 26.84 + 3.94 Mg C ha^{-1}. About 24 % of the biomass carbon stock in homegardens comes from enset and coffee, while 51 % comes from Grevillea and Eucalyptus species (Fig. 2). In the homegardens, other non-fruit plants and shrubs and fruit trees and shrubs make up

Table 4
Species richness, Shannon, Simpson diversity, Evenness and similarity of woody species and enset in homegardens and khat land use types.

Land use types	Species richness	indexes			
		Shannon	Simpson	Equitability	Sørenson
Homegardens	26	2.82	0.902	0.876	0.57
Khat	14	1.38	0.557	0.539	

Table 5
Importance value index (IVI, %) of two land use types in Wondo Genet district.

Scientific name	Homegardens	Khat
Albizia gummifera(J.F.Gmel.)	1.9	1.79
Azadirachta indica A	6.2	–
Casimiroa edulus	1.8	–
Catha edulis(Vahl) Forssk	18.5	131.0
Celtis africa	–	1.8
Coffea arabica	35.3	49.5
Cordia africana Lam.	27.1	15.7
Croton macrostachyus Del.	15.8	22.7
Dendrocnide sinuata	4.1	–
Enset ventricosum(Welw.)	55.4	46.0
Eucalyptus camaldulensis	20.0	–
Euphorbia abyssinica	6.0	–
Ficus vasta Forssk.	2.2	–
Fragaria ananassa	5.0	3.3
Grevillea robusta A	19.3	5.4
Juniporous procera	4.6	–
Malus pumila	2.9	–
Mangifera indica L.	8.9	–
Milletia ferruginea (Hochst.)	13.7	5.1
Moringa oleifera	1.8	
Olea africana	–	3.0
Persea americana	24.8	9.7
Podocarpus falcatus (Thunb.)	4.7	–
Psidium guajava L.	4.2	3.1
Ricinus communis	3.2	–
Spathodea campanulata	9.2	–
Vernonia amygdalina Del.	4.6	6.9
Vernonia auriculifera Hiern	2.6	–

"—" indicate absence.

Table 6
Mean (±SE) number stems (stems ha^{-1}) and basal area of woody species (m^2 ha^{-1}).

Land use types	Density (stems ha^{-1})	Basal area (m^2 ha^{-1})
Homegardens	788.5 ± 89.5^b	84.0 ± 16.3^a
Khat	2339.3 ± 208.9^a	22.3 ± 3.3^b
Mean	1513.4 ± 150.4	55.2 ± 8.9
p-value	0.000	0.000

Different letters along the column indicate differences and similar letters indicate non-significant differences among land use types ($p < 0.05$).

Table 7
Mean (±SE) below and above ground biomass carbon stock in the two land use types of Wondo Genet Woreda, Southern Ethiopia.

Land use types	Mg C ha^{-1}			Mg CO_2e ha^{-1}	
	Above ground	Below ground	Total	Above ground	Below ground
Homegardens	16.18 ± 4.29^a	17.14 ± 3.75^a	33.32 ± 6.46^a	$59.39 + 15.75^a$	$62.92 + 13.78^a$
Khat	13.17 ± 3.09^a	6.27 ± 1.08^b	19.45 ± 4.03^b	$48.36 + 11.36^a$	$23.02 + 3.98^b$
Mean	14.78 ± 2.70	12.06 ± 2.09	26.84 ± 3.94	54.23 + 9.91	44.27 + 7.66
P-value	0.58	0.009	0.007	0.058	0.000

Different letters along the column indicate differences and similar letters indicate non-significant differences among land use types ($p < 0.05$).

roughly 17 % and 8 % of the carbon stock, respectively. With regard to the khat land use type, khat make up roughly 43 % of the total biomass carbon stock, while other non-fruit trees, fruit trees, Grevillea, and Eucalyptus make up approximately 24 %, 15 %, and 10 % of the total biomass carbon stock, respectively. About 8 % of the biomass carbon stock in khat land use types is made up of enset and coffee.

2.5. Correlation of above and below ground biomass with plant density and structures

Table 8 displays the relationships between diameter (cm), basal area (m2 ha-1), and height (m) and above- and below-ground biomass carbon. With R values of 0.501 and 0.504, respectively, plant density and basal area had a weakly significant positive

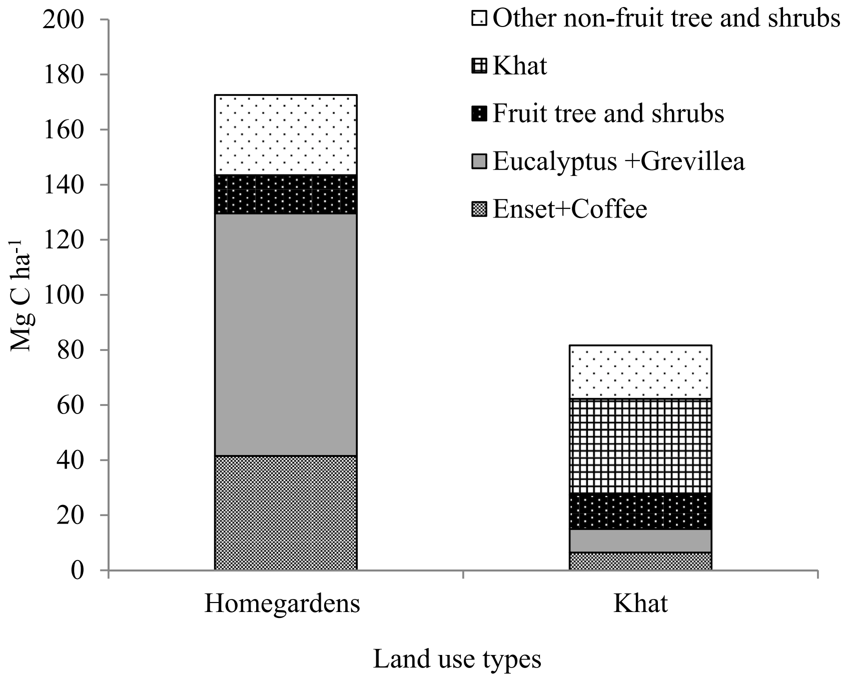

Fig. 2. Woody species contribution to total biomass carbon stocks for the two land use types in the study area.

Table 8
Spearman correlations of above and below ground carbon with plant height, diameter at breast height, basal area, and plant height.

	plant density	Diameter	Basal area	Height	AGC	BGC
plant density	1					
DBH	0.066	1				
Basal area	0.679[a]	0.759[a]	1			
Height	−0.022	0.195[a]	0.137[b]	1		
AGC	0.501[a]	0.219[a]	0.504[a]	0.196[a]	1	
BGC	0.628[a]	0.689[a]	0.917[a]	0.181[a]	0.728[a]	1

[a] Correlation is significant at the 0.01 level.
[b] Correlation is significant at the 0.05 level.

connection with the above-ground biomass carbon. On the other hand, there was a significant positive association between below-ground biomass carbon and plant density, diameter, and basal area. These imply the necessity of protecting old-growth and large woody species in order to maintain a significant carbon pool and biodiversity.

3. Discussion

3.1. Diversity of woody species and enset

According to this research, Wondo Genet's traditional enset-coffee-based homegarden supports a higher density of woody species than the khat land use type (Table 4). More niches for native tree species are provided by the presence of cash crop coffee (Coffea arabica), legume tree (Millettia ferruginea), timber tree (Cordia africana), and fuel wood tree (Vernonia amygdalina) in homegardens. The total number of woody species recorded in the current study (25) was lower than the 90 woody species reported from non-khat hotspot areas of South-Central Ethiopian homegardens [37], the 32 woody species recorded in traditional agroforestry systems of the Wolaytta zone in southern Ethiopia (38), the 108 species recorded in the Arbegona district of Southern Ethiopia [38], and the 100 species reported in the agroforestry practices of Yem special district, southern Ethiopia [39]. In comparison to homegardens, the number of documented woody species was more than half lower in the khat land use type. When compared to other research, the home gardens showed a lesser diversity of woody species. This may be because farmers are thinned down trees to cultivate khat, which is converted from enset and coffee [9].

The Shannon diversity index (2.82) recorded in the homegardens of this study was higher than Shannon's index of other studies reported in the mid-highlands of Yirgacheffee district of southern Ethiopia (2.2) [37], homegarden agroforestry of Shashemene district (2.22) [40], homegarden agroforestry systems of Southern Tigray (1.3) [41] and traditional agroforestry systems of Wolaytta zone in southern Ethiopia [38]. Except for the homegarden agroforestry systems of southern Tigray, the Shannon diversity index measured from the khat land use type (1.38) was 51 % lower than the homegardens of this study and other studies described in this discussion. The Simpson diversity index and equity figures recorded in the homegardens were also higher than those reported in other studies from traditional agroforestry systems in the Wolayitta Zone [38], homegarden agroforestry systems of the Shashemene district [37] and homegarden agroforestry systems of southern Tigray [41]. However, the decline in woody species richness by 46 %, Shannon's index by 51 %, and Simpson variety index by 38 % in response to khat expansion at the expense of homegardens may pose a threat to the Wondo Genet landscape's ability to conserve biodiversity (Table 4).

3.2. Important value index and local use

The presence of highest Important Value Index (IVI) of Coffea Arabica, Persea americana, and Eucalyptus camaldulensis from woody species and Enset ventricosum from herbaceous species in the homegardens might be because of the higher preference of the farmers for those species in their farms. On the other hand, in khat land use types, Catha edulis, Coffea arabica, Croton macrostachyus Del, and Cordia africana Lam had higher IVI from woody species and Enset ventricosum from herbaceous species. The presence of Enset ventricosum in both land use types indicated its valuable role for the farmers. Farmers maintained woody species and enset for multiple uses, such as construction, fodder, food, food, fuel wood, income, life fence, medicine, shade, and soil fertility improvement (Table 3). Previous research has shown a connection between species' IVI values and their significance for various purposes (39). Other studies have shown a connection between greater IVI and the economic importance of woody species [42]. Other studies have shown a connection between greater IVI and the economic importance of woody species [43], as well as the ecological need of species' life strategies [44].

In addition, introduced species such as *Eucalyptus camaldulensis* and *Grevillea robusta* are becoming more and more valuable in homegardens (Table 5), which may endanger native woody species because farmers tend to keep more of the two quickly growing species in response to constraints on farmland brought on by rising population pressure. As farmers replace multipurpose woody species with khat or other quickly growing woody species like Eucalyptus and Grevillea robusta, the Wondo Genet landscape may become homogenized as a result of this trend. An increasing trend of Eucalyptus expiation from 5000 ha in the 1890s to 896,240 ha in 2011, by roughly 1.5 % per year in Ethiopia was reported [45]. In wolo zone of northern Ethiopia, eucalyptus plantation area coverage increased 6022 ha in 2003–7930 ha in 2019, an increase by 24 % [46], from 832 ha in 1999–2692 ha in 2021, an increase in area coverage by 69 % in Northwestern Ethiopia [47]. Typical biological attributes that attract farmers to plant Eucalyptus include its fast-growing nature, outcompeting most native tree species, its coppicing ability, ease of management, market demand, and its ability to grow well on degraded lands [48].

The stem density in homegardens was substantially lower than khat, and the earlier gardens had a larger basal area (Table 6). The presence of many individual khat plants per unit area is related to the observed increased stem density in the khat land use type. On the other hand, the presence of more completely grown and matured woody species and enset was linked to the observed increased basal area in the homegardens.

3.3. Biomass carbon stock and carbon dioxide equivalent

The southern Ethiopian homegarden agroforestry systems are known for their capacity to store carbon. The total carbon stock found in the khat land use type was 42 % lower than in the home gardens (Table 7), suggesting that the agro-ecosystem's capacity to sequester carbon has decreased as a result of the growth of khat. The outcome was consistent with a previous study that found a three times greater annual loss of soil carbon in areas of southeast Ethiopia converted to khat monocropping [49] and a decrease in soil organic carbon stock of up to 30.2 % as a result of the substitution of enset-coffee-based homegardens by khat in the same study area [11]. The replacement of indigenous multifunctional trees and their contribution to carbon storage in the Wondo Genet environment was demonstrated by a larger biomass carbon stock contribution of Grevillea and Eucalyptus in homegardens (Fig. 2). Earlier study reported contribution of Eucalyptus plantations in carbon sequestration and climate change mitigation potential [50]. A total of 100 Mg C ha-1 and 36 Mg C ha-1 biomass carbon stock were reported from a eucalyptus plantation in central and southern Ethiopia respectively [51,52], and the total above ground biomass carbon of 145 Mg C ha^{-1} and belowground biomass carbon of 25 Mg C ha-1 from eucalyptus plantation in Bangladesh [53]. In Indian eucalyptus plantations, net yearly carbon sequestration rates of 6 Mg C ha^{-1} compared to 2 Mg C ha^{-1} for moderately developing teak forests were recorded [54]. For an Italian eucalyptus plantation, an average of 55 mg C ha-1 and 14 mg C ha-1 in the above- and below-ground biomass, respectively were reported [55]. The average 111 Mg C ha^{-1} total biomass carbon stack was recorded from eucalyptus plantation in Kenya [56]. This suggests that eucalyptus plants have the ability to sequester carbon while displacing indigenous multifunctional trees.

In comparison to homehardens, the khat land use type's capacity to reduce carbon dioxide emissions was lower in the above-ground and underground by 18.6 % and 63.0 %, respectively. This suggests that the Wondo Genet landscape's ability to reduce emissions has decreased as a result of the monoculture khat expansion, which increased greenhouse gas emissions and contributed to climate change. In accordance with this, a previous study [39] estimated that Ethiopian land use change was responsible for 27205.08 Mg of CO2e emissions.

4. Conclusion

The study found that compared to nearby khat land use type, homegardens retained better species richness, basal area, diversity of woody species, and enset. The most economically and ecologically beneficial woody species, like C. africana, M. ferruginea, P. americana, and E. ventricosum, are less common in nearby khat land use types and are therefore best preserved in homegardens. Compared to the khat land use type, homegardens had increased above- and below-ground biomass carbon stocks and reduced carbon dioxide emissions. The Wondo Genet landscape may lose some of its capacity to conserve biodiversity and mitigate climate change as a result of the current trend of homegarden system modifications toward the monocropping of khat. In light of these findings, we came to the conclusion that homegardens are crucial for biodiversity preservation and climate change mitigation. They complement the khat land use and serve to mitigate the loss of woody species and drop in carbon stock that result from the expansion of khat. The approach for biodiversity protection must therefore include raising awareness and increasing the capacity of household in the densely populated Wondo Genet area.

Declarations

Author contribution statement

Beyene Teklu Mellisse: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper. Motuma Tolera: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper. Ararsa Derese: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Funding statement

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Ethical approval

The research work was approved by Hawassa University, Wondo Genet College of Forestry and Natural Resources Research and Ethical Review Board (RERB). All respondents were informed and their willingness to allow the researchers to their farm field for species inventory was verbally agreed as part of the ethical consent process.

CRediT authorship contribution statement

Beyene Teklu Mellisse: Writing – review & editing, Writing – original draft, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Motuma Tolera:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Conceptualization. **Ararsa Derese:** Methodology, Investigation, Formal analysis, Conceptualization.

Declaration of AI and AI-assisted technologies in the writing process

During the preparation of this work the author(s) used QuillBot service in order to improve the language and readability. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication. This declaration does not apply to the use of basic tools for checking grammar, spelling, references etc.

The data associated with this study were not deposited into a publicly available repository Data will be made available on request.

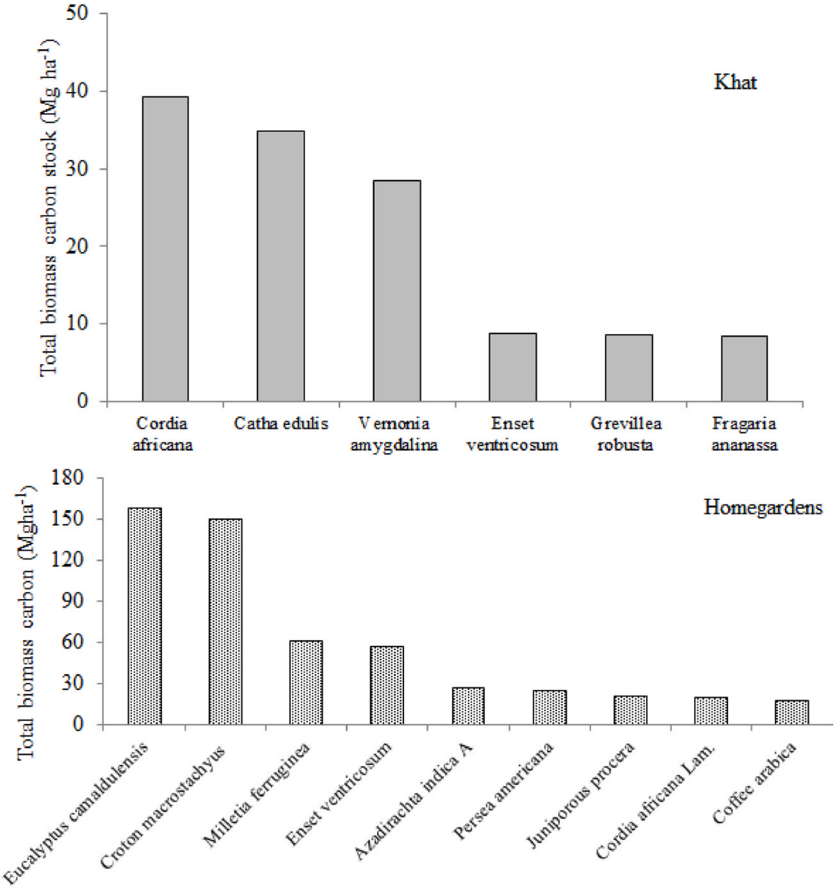

Fig. A1. Total carbon biomass contribution of major species in khat and homegardens. .

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.

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