Structure, composition, and species diversity of trees and shrubs on farms in Makueni and Kiambu County

A report on tree inventory in Kiambu and Makueni county

Shem Kuyah, Caroline Njoki, Denis Wakaba, Catherine W. Muthuri

With technical support from:

Damaris Mwikali
John Kamau
Eva Kerubo Nyaenya
Reuben Pillah

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1. Introduction

This report describes methods used during tree inventory on 36 and 26 farms in Kiambu and Makueni, respectively. It identifies the dominant locations where trees are situated on farms and describes species richness, species diversity, tree density, the proportion of fruit trees on farms, and the regeneration status of trees and shrubs on farms. The report also presents summaries of basic tree attributes measured in different land use types, including diameter at breast height (DBH) and collar diameter (CD) for individual trees. Findings from the study help to understand the composition, diversity, and distribution of tree species on farms in the study area, which is required for designing interventions needed for biodiversity conservation, food security, and programs that reward land users for maintaining trees in the landscape. The list of species and their sizes provide a sampling frame for the selection of trees for the development of allometric equations through destructive sampling.

2. Methodology

2.1 Description of the study sites

Tree inventory was conducted in Makueni and Kiambu counties in Kenya. Makueni is located in southeastern Kenya between latitudes 1°35'S and 3°00'S and longitudes 37°10'E and 38°30'E. Makueni covers an area of 8,008.7 km^2 and stretches from 600 m above sea level in lower areas to 1,900 m above sea level in higher regions (Government of Makueni County 2018). Soils in Makueni are predominantly sandy to sandy loam, with very low organic matter content (between 0.43 and 1.87%) and low nutrient content (NAAIAP and KARI 2014).

Makueni is largely arid and semi-arid with mean annual temperatures ranging from 20 °C to 25 °C and variable precipitation. The onset, amount, and duration of rain in Makueni vary considerably. Long-term (1961-2012) and short-term (2015-2019) mean annual rainfall in Makueni are 280 and 283.8 mm during the short rain season (March to May), and 294 and 389.4 mm during the long rain season (October to January), respectively (Nkurunziza et al. 2022). Rainfall also varies spatially; low-lying areas receive between 250 and 400 mm per year, while high areas receive between 800 and 900 mm per year. Erratic rainfall, frequent droughts, and longer dry spells make growing crops a risky business.

Kiambu County is located in central Kenya between latitudes 00°25'S and 10°20'S and longitude 36°31'E and 37°15'E. The county occupies a total area of 2,543.5 km^2, which varies in elevation from 1,200-1,360 m above sea level in the lower midland zone, 1,300 to 1,500 m in the upper midland zone, 1,500 to 1,800 m in the lower highland zone, and 1,800 to 2,550 m in the upper highland zone (County Government of Kiambu 2017). Rainfall in the county is bimodal, received between April and June (long rain season) and September and December (short rain season). Rainfall in the area varies with altitude, ranging from 600 mm per year in semi-arid areas (Kiganjo, Ndarugu, and Ngenda in Gatundu South sub-county) to 2000 mm per

year in humid and sub-humid areas (Githunguri, Komothai, and Ngewa in Githunguri sub-county). Similar to rainfall, the mean temperature in Kiambu varies from 7 °C in the upper highland areas to 34 °C in the lower midland zones and an average of 26 °C across the county.

Agriculture is a major economic activity in Kiambu, and a leading sector for employment, food security, and income. Small-scale mixed farming with trees and livestock keeping dominates the landscape; there are also patches of commercial large-scale farms. Agriculture comprises of cash crops such as tea (*Camellia sinensis*), coffee (*Coffea arabica*), and pineapples (*Ananas comosus*) in the upper and lower highlands; dairy farming; horticultural crops; and staples such as maize (*Zea mays*), beans (*Phaseolus vulgaris*), peas (*Pisum sativum*) and potato (*Solanum tuberosum*). Tea is often integrated with avocado (*Persea americana*) trees, while coffee is planted with bananas (Musa spp.), Macadamia spp., *Grevillea robusta,* and other shade trees. The average household farm size is about 0.36 ha among smallholder farmers and 69.5 ha among large-scale farmers (County Government of Kiambu 2017). The small parcels are attributed to population pressure that leads to the subdivision of land into smaller units.

2.2 Procedure for Selection of Farms

A multistage sampling procedure with simple random selection was used to choose households for the study. Multistage sampling has previously been used on farmland trees in Ethiopia (Endale et al. 2017). This involved selection of two administrative locations (sub-counties) in each county (Wote-Nzui and Wote in Makueni, and Githunguri and Gatundu South in Kiambu), and then wards from which households were selected. To have a representative sample, farmers were randomly selected from six wards (Kiambu, Komothai, Githunguri, Kiganjo, Ndarugu, Ngenda, Ngewa) in Kiambu and four sub-wards (Kilala, Nziu, Ukia, and Wote) in Makueni. These wards/sub-wards were selected because they represent diverse ecological conditions (e.g. semi-arid, sub-humid, humid), different farming systems (e.g. subsistence, commercial production; small-scale, large-scale production), and access to different markets (rural, peri-urban). The wards in Kiambu were purposively selected based on elevation, dominant agricultural production systems, and land size; while those in Makueni were selected based on climate and scale of production. Tree inventory covered an elevation range between 1610.4 and 2138.3 m above sea level in Kiambu, and between 1050.4 and 1651.4 m above sea level in Makueni.

Before the inventory, a reconnaissance survey was conducted to identify the above representative units (wards, sub-wards, and villages), familiarize with the landscape and retool the inventory team. The reconnaissance survey involved transect walks, formal discussions with stakeholders, and informal discussions with selected farmers. Sub-country agriculture and forest officers assisted in identifying farmers during the reconnaissance. A stratified sampling method was then used to select households for the baseline survey and tree inventory. Stratification was based on administrative locations (wards). Farms for conducting the inventory were randomly selected from the baseline sample within the wards, based on the

distance from the road, and ensuring a minimum distance of 1 km from each farmer. This was done to increase the variability of the tree species recorded. This approach allowed the team to capture a representative sample from all farmer groups and to assess variations in the composition and proportion of fruit trees on farms.

Tree inventories were conducted on the cultivated land of farmers and a socio-economic households survey was carried out. We defined cultivated land as the area used for growing crops recurrently or permanently, including land that was (at the time of the survey) fallowed but would be used for cultivation in the following season or year. A total of 36 households were selected randomly from the households interviewed, comprising seven or eight households in each of the four wards in Makueni, and six households in each ward in Kiambu. Inventories were conducted on the main parcel where the homestead is situated. The socio-economic survey captured the total land (area and the number of parcels) owned by the farmer. However, it was not possible to conduct a complete tree inventory of all trees on all land parcels owned by the farmer because of resource and time limitations.

2.3 Description of land use categories

Farm surveys identified eight major land use types signifying areas that harbor trees on farms in Kiambu and Makueni. These include:

1. Homestead: the farm parcel that is near the house, including its surrounding yards. The homestead has perennial woody plants in addition to small crop fields, but unlike the main crop production area, it is purely managed by family labor. Trees within the kitchen garden and in the compound were counted under the homestead.
2. Cropland: the farmland area where trees or shrubs are mixed with annual crops. It is often situated outside the homestead and used as the main crop production area.
3. Orchard: an area of land where fruit trees are grown. Mango (*Mangifera indica*) and citrus spp. orchards were common in Makueni while avocado orchards were mainly found in Kiambu. Macadamia plantations were counted under orchards.
4. Perennial-crop systems: production systems involving plantation crops such as coffee, tea, and pineapple in commercial systems. Commercial coffee and tea plantations were mainly documented in Kiambu County.
5. Woodlots: an area dedicated to small-scale production of wood. Woodlots were mainly found in Kiambu.
6. Grazing land: an area set aside for grazing. The grazing land had scattered trees but no crops or evidence of crops from the previous season.
7. Boundary: trees on the boundary, for example, live fence or trees on farm borders.
8. Soil conservation structures. Strips of trees are planted along or in combination with grasses to control runoff and soil loss, or trees are planted on the edges of terraces to stabilize the soil.

2.4 Tree measurement

All trees in each land use type were identified and recorded. Where possible, both local and scientific names were identified in the field with the help of a taxonomist, a field guidebook (Maundu and Tengnäs 2005), and a plant identification app. Diameter at breast height (1.3 m above the ground) and collar diameter (30 cm above the ground) were measured on trees with DBH 2.5 cm or height ≥2 m using a regular measuring tape. The threshold of 2.5 cm DBH was chosen because the traditional forestry practice of measuring only trees with DBH>5 cm compromises allometry parameters (Sileshi et al. 2022). Procedures for measuring trees with anomalies were applied when taking DBH of leaning trees, trees on the slope, trees with swellings at breast height, forked trees, and multi-stemmed trees (see ACIAR project output 3.2. A protocol for establishing allometric equations for estimation of biomass in fruit trees). In addition, the dimensions of the crown (the longest extent across the crown and the diameter perpendicular to it) were measured to estimate the canopy area of trees in orchards and cropland. This parameter was not determined for trees in homesteads, boundary planting, hedgerows, and woodlots as they tend to have intersected canopies that make it difficult to distinguish canopy extensions. The trees and shrubs encountered were grouped into three growth stages based on height and diameter: seedlings (height < 1 m), saplings (height > 1 m and < 2 m), and trees (DBH >2.5 cm or height >2 m). The number of saplings and seedlings was counted in each of the land use types. The area of the land use type where the trees were measured was determined by walking around it with a GPS device. Measurement of the area allowed comparison of diversity, abundance, and carbon stocks among land use types identified in the farms.

The land use on which the trees are situated was documented and geo-referenced. Grouping of trees into different land use types was preferred to minimize the edge effect (Gebre et al. 2019), for example, allowing trees on the boundary to be counted under that land use type. Tree inventory in orchards or large grazing land or woodlots was achieved by installing 30 m x 30 m plots on the land use type and measuring all trees within the plot. The outer row of the orchard was always left out when establishing a plot to avoid overestimation of biomass due to the edge effect. Trees on the edge tend to grow better than those inside the plot due to better sunlight conditions. Geolocations of the land use types allow for comparison with remotely sensed imagery, and for building a spatial illustration of the typology of land uses.

2.5 Data Management and A Analysis

2.5.1 Data cleaning

Data was cleaned to (1) correct spelling errors (e.g. species names), (2) remove multiple entries of species due to synonyms (e.g. *Cyphomandra betacea* and *Solanum betaceum*; *Thuja orientalis* and *Platycladus orientalis*), (3) rectify false categories relating to names that appear twice when a software that distinguishes between letter case or spaces before or after letters

is used, and (4) to fill in missing information (such as land use type area where this not captured in the field; scientific names of species that were identified by local or common names).

During data cleaning, individual trees were classified as "fruit trees" or "other trees", and native or exotic based on existing literature. Whether the tree was a "fruit tree" or "other tree" was determined by checking the products and services of the species listed in the Agroforestry Database 4.0 (Orwa et al. 2009) and the field guide on Useful trees and shrubs for Kenya (Maundu and Tengnäs 2005). A tree was considered a "fruit tree" if its fruits are eaten fresh or cooked, or processed into an edible product. Fruit trees listed include those trees whose fruits are usually eaten in normal times or only in an emergency. Trees whose leaves, flowers, and flower buds are eaten as vegetables were not listed as fruit trees. Trees documented in the inventory were also checked if they appear in the review and appraisal on the status of indigenous fruits in Eastern Africa (Chikamai et al. 2004). The trees were then grouped as exotic and native to Africa based on the origin as described by Orwa et al. (2009) and Maundu and Tengnäs (2005). Trees were counted as native if they were indigenous to a least one country in Africa; for example, *Delonix regia* is exotic to Kenya but native to Zambia (Orwa et al. 2009).

2.5.2 Data analysis

Species diversity indices (species richness, abundance, and Shannon-Weiner diversity index) and stand characteristics (stem density, mean DBH, mean CD, and distribution of individuals in different diameter classes) were calculated across sites and for each land use type. Shannon diversity index was used to determine species diversity via analysis of the number of species in the land use and the distribution of a given species within the sample. First, the total number of species per given land use type were calculated. Shannon diversity index was then calculated to show the relative proportion of a particular species in the land use as $= -\Sigma pi \times ln(pi)$, where pi is the proportion of the entire community made up of species i. Higher Shannon diversity index values suggest higher diversity of species in the land use; a value of zero suggests that the land use has only one species. The relative frequency was calculated as the percentage of the frequency of one species over the total of all frequencies recorded.

The diameter was obtained from girth measurements by dividing the circumference by π (3.14). Tree density was calculated as the number of trees per unit area (stems/hectare). The diameter of multi-stemmed trees or trees that fork around or just below 1.3 m was calculated as the square root of the sum of squares of individual stems i.e. $D_O = \sqrt{(d_1^2 + d_2^2 + d_3^2 + \ldots d_n^2)}$, where D_O is the overall diameter, and $d_1, d_2, d_3 \ldots d_n$ are the diameter measurements of individual stems. Trees with a diameter >2.5 cm were grouped into six diameter classes (<10 cm, 10-20, 30-40, 40-50, and >60 cm) for analysis of population structure.

The regeneration status of tree species was established from the number of seedlings, saplings, and mature trees. Regeneration was considered (1) good when seedlings > than saplings > mature trees; (2) fair when seedlings > saplings ≤ mature trees; (3) poor when there were

saplings but no seedlings; (4) none when only mature trees were found and no seedlings or saplings; and (5) new when only saplings or seedlings were present, with no mature trees.

3.1 Composition and Diversity of trees on farms

3.1.1 Species Richness, diversity, and Abundance in Kiambu

A total of 99 species belonging to 39 families and 84 genera were documented on five major and two minor land use types in Kiambu. This included 82 tree species with 2488 individuals, 54 sapling species with 1111 individuals, and 38 seedling species with 788 individuals (Table 1). One individual tree was identified by genus name while 8 individual trees were recorded as unknown; these were removed from the analysis. The three dominant woody plant families in terms of the number of individuals were Proteaceae, Lauraceae and Myrtaceae, cumulatively accounting for 68% of the total number of woody plants across growth stages; 78% of the total all mature trees, and 59% of all saplings documented in Kiambu. In terms of species richness, Fabaceae (10 species), Myrtaceae (8 species), Euphorbiaceae (8 species) and Rutaceae (8 species) were the most dominant families, jointly accounting for 34% of the total number of species across growth stages. Lauraceae was represented by one species (*P. americana*), although it was the second dominant family in terms of number of individuals. Half of all woody plant species documented were native to Africa, although the corresponding number of individuals were very few (12%, n=4388). When the data was disaggregated into different growth stages, 47% of the mature tree species and 42% of the species of saplings and seedlings were native to Africa. In terms of abundance, exotic woody plants dominated the landscape; with 90, 89 and 79% of the total number of mature trees, saplings and seedlings inventoried, respectively.

Table 1 The abundance, species richness and Shannon diversity index in different land use types in Kiambu.

Growth stage	Land use type	No. of Households	No. of individuals	Species richness	Shannon index
Trees	Cropland	30	1090	43	1.92
	Homestead	34	434	57	3.03
	Orchard	7	119	13	1.41
	Tree-crop systems	10	203	21	2.21
	Woodlot	13	548	23	1.52
	All land use types	36	2488	82	2.51
Saplings	Cropland	29	485	31	2.16
	Homestead	17	98	29	3.00
	Orchard	3	27	8	1.64
	Tree-crop systems	10	200	10	1.49
	Woodlot	10	296	21	1.83
	Across land use types	36	1111	54	2.71
Seedlings	Cropland	16	308	22	2.11
	Homestead	14	144	25	2.23

	Orchard	3	89	9	1.53
	Tree-crop systems	8	119	13	1.86
	Woodlot	5	119	16	3.25
	Across land use types	36	788	38	2.53
All growth stages	Cropland	31	1883	52	2.15
	Homestead	35	667	68	3.21
	Orchard	7	235	17	1.73
	Tree-crop systems	10	522	24	2.14
	Woodlot	13	963	37	2.01
	Across land use types	36	4389	99	2.75

Shannon diversity index for seedlings, saplings and mature trees in Kiambu was 2.53, 2.71 and 2.51, respectively (Table 1). When the data was disaggregated to land use, species diversity for mature trees was highest in the homestead and the lowest in orchards (Figure 1). A similar trend was observed for saplings with a value of 3.00 and 2.23 in homegardens. Woodlots had the highest Shannon diversity index for seedlings; perennial-crop systems and orchards had the lowest sapling and seedlings diversity (Table 1). Species richness also varied across the land use types (Figure 1). When all land use types were aggregated, the number of trees species per household ranged from 3 to 33. Homesteads and croplands had the highest number of species in general and for the different growth stages (Figure 1, Table 1). These were also the most dominant land use types in Kiambu, found on 31 (cropland) and 35 (cropland) of the farms visited. Orchards had a narrow range of species for seedlings, saplings and mature trees (Figure 1). Species diversity on farm was disaggregated per land use type to account for preferences for particular species on certain land use types, for example fruit trees on orchards.

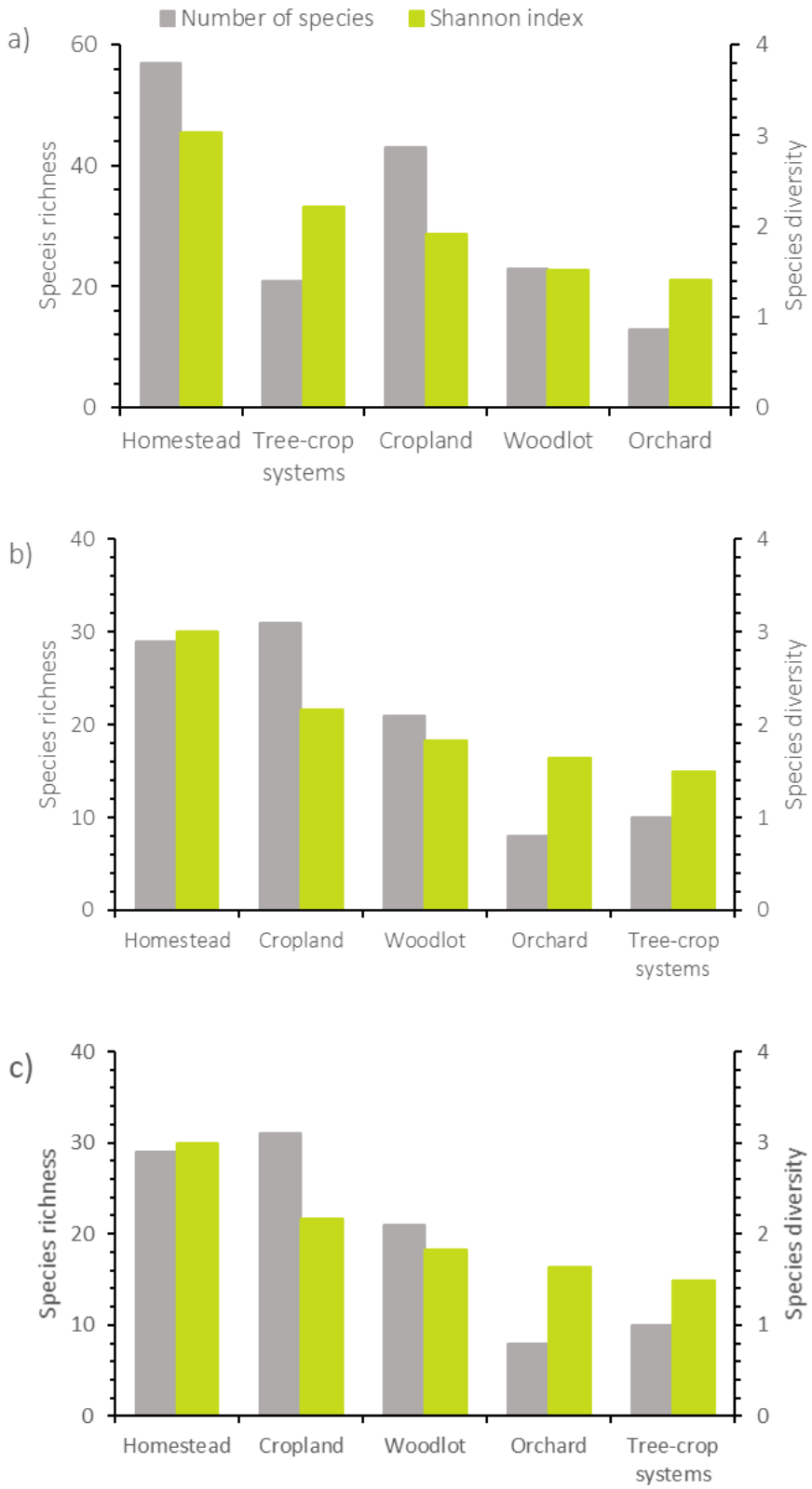

Figure 1 Species richness and diversity in different land use in Kiambu for mature trees (a), saplings (b) and seedlings (c).

The abundance of trees of farms varied considerably across the 36 farms in Kiambu, and ranged from four species with 10 individuals in one farm to above 100 individuals in 10 farms (Table *3*). When all growth stages were aggregated, *G. robusta*, Eucalyptus spp., and *P. americana* were the most abundant tree species cumulatively accounting for 61% of the total number of individuals documented (Appendix 1). For mature trees, *G. robusta* (30%), Eucalyptus spp. (21%) and *P. americana* (19%) cumulatively accounted for 70% of the individuals documented in Kiambu. *Grevillea robusta* (47%) and *P. americana* (22) dominated croplands; *P. americana* (21%), *Eucalyptus saligna* (15%) and *G. robusta* (10%) dominated homesteads; *P. americana* (62%) and *Macadamia integrifolia* (13%) dominated orchards; *G. robusta* (26%) and *P. americana* (26%) dominated perennial-tree-crop systems; woodlots were dominated by Eucalyptus spp. (76%). Twenty-seven species were represented by one individual and therefore considered rare (Appendix 1).

When saplings were considered, Eucalyptus spp. (22%), *P. americana* (18%) and *G. robusta* (15%) were the dominant species, accounting for 68% all individuals recorded. *P. americana* (31%) and *G. robusta* (29%) dominated cropland; *P. americana* (13%) and *C. papaya* (10%) dominated homestead; *P. americana* (44%) and *S. betaceum* (19%) dominated orchards; *S. betaceum* (51%) and Eucalyptus spp. (21%) dominated perennial tree-crop systems; woodlots were dominated with Eucalyptus spp. (65%).

When seedlings were considered, *P. americana* accounted for about one-third of the individuals recorded and documented in Kiambu. *Persea americana* dominated croplands (41%), orchards (43%), perennial tree crop systems (46%), and homestead (30%); *Ricinus communis* dominated homestead (31%); woodlots were dominated by *Bridelia micrantha* (22%), *Croton macrostachyus* (13%), Eucalyptus spp. (13%), and *G. robusta* (13%). Trees on (internal) farm boundaries were composed of *G. robusta* (n=106). Two species with one (*Acacia mearnsii*) and three individuals (*G. robusta*) were documented on soil conservation structures.

3.1.2 Species Richness, diversity, and Abundance in Makueni

One hundred species belonging to 34 families and 69 genera were documented on seven land use types in Makueni. This included 98 mature tree species with 1893 individuals, 14 saplings species with 177 individuals, and 5 seedlings species with 123 individuals (Table 2). Three individuals belonging to two species were identified to genus level (Araucaria and Cadaba) while 12 individuals belonging to one species were recorded as unknown; these were removed from the analysis. Rutaceae (19%), Proteaceae (17%), Fabaceae (13%), and Anacardiaceae (12%) were the dominant plant families in terms of a number of individuals, collectively accounting for 62% of the trees recorded in Makueni; 85% of the saplings stems belonged to Rutaceae (27%), Euphorbiaceae (24%), Proteaceae (18%) and Myrtaceae (17%); seedlings were mainly composed of individuals from Lauraceae (69 stems) and Rutaceae (52 stems) family. In terms of species richness, Fabaceae was the most dominant family with 24 species. Proteaceae was represented by *G. robusta* and accounted for 18% of all mature trees documented in

Makueni. Close to two-thirds (62%) of the species documented in Makueni are native to Africa; and constituted 30% (n= 2197) of individuals documented. A similar trend was observed on mature trees (when the data was disaggregated into different growth stages), 38% of the species were native to Africa and contributed 68% of the individuals documented in Makueni.

Table 2 The abundance, species richness, and Shannon diversity index in different land use types in Makueni.

Growth stage	Land use type	Number of Households	Number of individuals	Species richness	Shannon index
Trees	Boundary	3	40	8	1.46
	Cropland	9	205	43	2.94
	Grazing land	10	264	43	2.85
	Homestead	26	708	79	3.29
	Orchard	18	488	9	1.30
	Soil conservation structures	6	87	13	1.79
	Woodlot	4	101	7	0.91
	Across land use types	26	1893	98	3.29
Saplings	Cropland	2	12	2	0.29
	Grazing land	1	40	4	0.88
	Homestead	8	71	9	1.65
	Orchard	6	37	3	0.96
	Soil conservation structures	1	7	2	0.41
	Woodlot	1	10	1	0.00
	Across land use types	14	177	14	2.21
Seedlings	Cropland	1	2	1	0.00
	Orchard	3	121	4	0.76
	Across land use types	4	123	5	0.84
All growth stages	Boundary	3	40	5	1.46
	Cropland	9	217	43	2.95
	Grazing land	10	311	45	2.86
	Home garden	26	781	80	3.24
	Orchard	18	646	10	1.54
	Soil conservation structures	6	94	13	1.94
	Woodlot	4	111	7	0.85
	Across land use types	26	2193	99	3.29

Shannon diversity index for mature trees in Makueni was 3.29, respectively (Table 2). When the data was disaggregated to land use, Shannon diversity index and species richness were highest in the homestead, but comparable in grazing land and cropland (Figure 2). The two indices were lowest in woodlots. A similar trend was observed for saplings, which had high Shannon diversity in homestead and monospecific stands of *G. robusta* in woodlots. The number of species in orchards and croplands was also narrow (Figure 2). Homesteads host the

largest number of individuals in Makueni; it is also the most common land use type in Makueni, found on all households surveyed; followed by orchards.

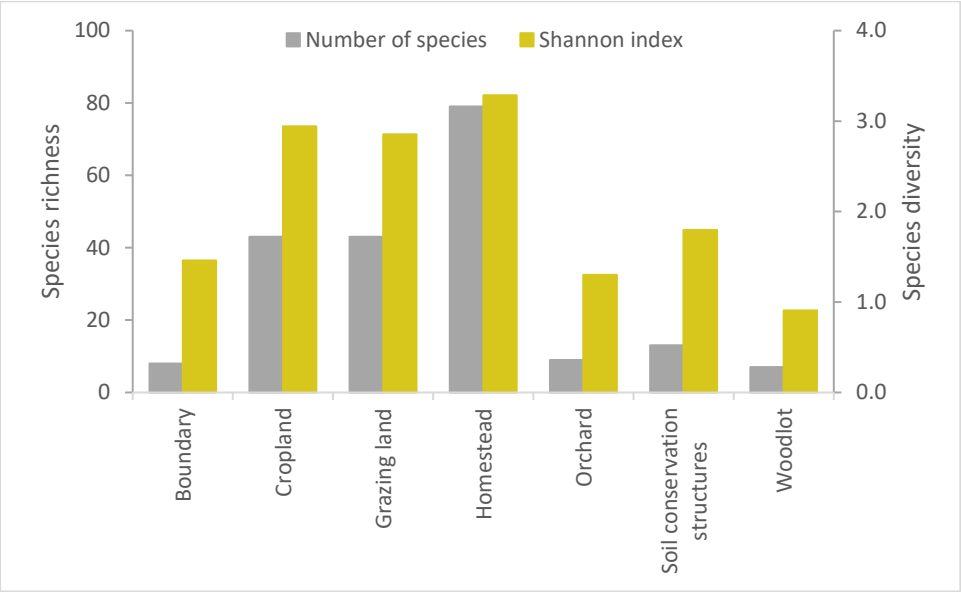

Figure 2 Species richness and diversity in different land use in Makueni for mature trees.

The abundance of trees on farms varied across the 26 households surveyed in Makueni, and ranged from 24 to 178 trees, with an average of 85 trees per farm (Table 4). When all growth stages were aggregated, *G. robusta* (17%), *P. americana* (11%), and *Citrus sinensis* (10%) were the most abundant tree species cumulatively accounting for 37% of the total number of individuals documented (Appendix 2). These species accounted for 40% of the mature trees (individuals) documented in Makueni. *Grevillea robusta* dominated homestead (24%), cropland (25%), woodlots (75%), and boundaries (50%); *Terminalia brownii* dominated grazing land (27%), *C. sinensis* dominated orchards (40%) while mango was the most common species on soil conservation structures 39%. Twenty-four species were represented by one individual and therefore considered rare (Appendix 2). Among this was *Catha edulis*, represented by only one sapling. We did not expect to find *C. edulis* in Makueni.

When saplings were considered, *G. robusta* (18%), *Croton megalocarpus* (15%), *Citrus limon* (14%), *Callistemon salignus* (14%), and *Citrus sinensis* (10%) were the dominant species, accounting for 62% all individuals recorded. Orchards and cropland were mainly composed of citrus saplings; homesteads were dominated by *C. salignus* (35%) and *G. robusta* (27%); grazing land was dominated by croton spp. (88%) while woodlots mainly had *G. robusta*. Seedlings were mainly found in orchards and comprised of citrus spp. (52%) and *P. americana* (69%). Homestead had the highest species richness (9 species) with 75 individuals for saplings. Grazing land was the second most diverse land use type with 4 species with 40 individuals. The only sapling in the woodlot was *G. robusta*; Citrus spp., were found mainly in orchards. Seedlings were mainly found in homesteads (*G. robusta*) and in orchards (*Citrus aurantium*, *C. limon*, *C. sinensis* and *P. americana*).

3.2 Proportion of fruit trees

3.2.1 Fruit trees on farms in Kiambu

Thirty-four percent of woody species identified to the species level in Kiambu were fruit tree; the rest (66%) are other use groups. Table 3 shows the proportion of fruit trees on farms in Kiambu. A total of 31 fruit tree species belonging to 22 botanical families were identified from the 36 farms surveyed in Kiambu. The majority (58%) of the fruit tree species encountered were exotic and had the largest number of individuals (95%, n=841). The rest (13 species) were native to Africa, represented by only 5% of the stems recorded.

Table 3 The proportion of fruit trees on farms in five wards in Kiambu County.

		All trees		Fruit trees		The proportion of fruit trees (%)		Number of native species	
Ward	Household ID	No. of species	No. of trees	No. of species	No. of trees	No. of species	No. of trees	No. of species	No. of trees
Githunguri	KGIHH01	6	78	3	18	50	23	1	1
	KGIHH04	22	144	9	33	41	23	12	31
	KGIHH05	11	44	4	7	36	16	2	2
	KGIHH02	9	124	5	13	56	10	1	1
	KGHH03	9	35	3	6	33	17	3	12
Kiganjo	KKIHH04	8	77	5	37	63	48	1	2
	KKIHH05	7	23	4	10	57	43	2	4
	KKIHH01	12	86	7	59	58	69	3	8
	KKIHH02	13	113	9	86	69	76	3	18
	KKIHH03	10	63	5	24	50	38	2	10
	KKIHH06	11	54	4	9	36	17	3	4
	KKIHH07	6	62	3	29	50	47	1	1
Komothai	KKOHH01	4	32	1	2	25	6	1	1
	KKOHH03	7	19	3	4	43	21	3	7
	KKOHH05	3	16	1	2	33	13		
	KKOHH02	11	27	6	17	55	63	5	7
	KKOHH04	8	147	2	19	25	13	3	6
	KKOHH06	21	78	7	19	33	24	15	26
Ndarugu	KNGHH06	5	37	4	35	80	95	1	1
	KNGHH05	4	42	3	7	75	17		
	KNGHH04	7	114	3	22	43	19	1	4
	KNGHH01	11	71	3	4	27	6	4	9
	KNGHH03	7	106	3	38	43	36	1	1
	KNGHH02	11	67	5	17	45	25	3	4
Ngenda	KNDHH06	16	109	8	74	50	68	5	5
	KNDHH01	12	116	6	27	50	23	5	11
	KNDHH02	5	50	3	32	60	64	1	1
	KNDHH03	7	47	5	14	71	30		
	KNDHH04	4	34	3	33	75	97		

	KNDHH05	14	143	5	59	36	41	5	9
Ngewa	KNWHH02	4	10	3	9	75	90		
	KNWHH03	7	66	4	9	57	14	1	2
	KNWHH05	7	89	3	11	43	12	1	1
	KNWHH01	16	68	5	15	31	22	8	11
	KNWHH04	12	28	6	10	50	36	3	7
	KNWHH06	33	103	15	41	45	40	14	40

Figure 3 shows the frequency and abundance of fruit tree species recorded in Kiambu. *Persea americana* was the most common fruit tree, found in all 36 farms with 469 individuals, followed by *M. integrifolia* (found in 13 farms with 120 individuals). Both avocado and macadamia fruits are exotic to Africa, and yet were located in almost all land use types in Kiambu. Other common species were *S. betaceum*, *E. japonica* and mango, with 51, 42 and 31 individuals found in five of the six land use types. *Podocarpus falcatus* was the most frequent native fruit tree species, with 12 individuals encountered on 3 farms.

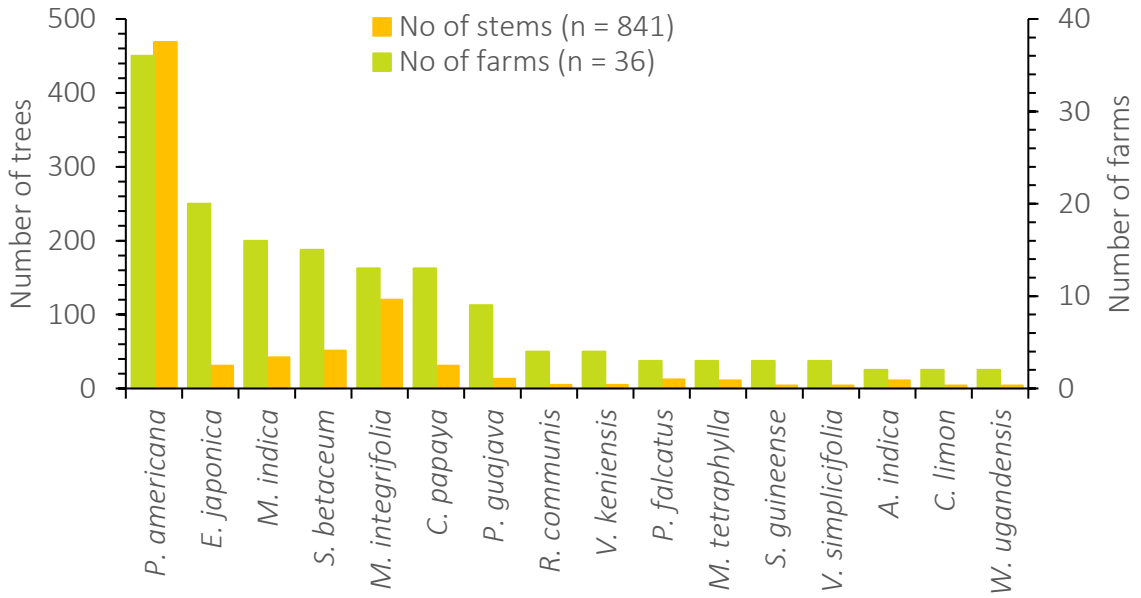

Figure 3 The distribution of fruit tree species and the corresponding number of individual stems per species recorded on farms in Kiambu County. The graph represents those species that were found in two or more farms and had a minimum of four individuals across the farms

3.2.2 Fruit Tree Diversity in Makueni

Table 4 shows the proportion of fruit trees on farms in Makueni. A total of 41 fruit tree species belonging to 22 botanical families were identified from the 26 farms in Makueni. Fruit tree species make up 40% of all woody species (and also mature trees) identified at the species level in Makueni. The majority (62%) of the fruit tree species are native to Africa but have the least number of individuals (32%, n=1896). The rest (37 species) were exotic to Africa and accounted for over two-thirds (68%) of the individual stems recorded. A similar trend was

observed with mature fruit trees: more species (61%) are native, but have very few stems (12%); few (39%) exotic species dominate (88%) the landscape.

Table 4 The proportion of fruit trees on farms in two wards (four sub-wards) in Makueni County

Sub-ward	Household	All trees		Native trees		Fruit trees		The proportion of fruit tree	
		No of species	No of stems	No of species	No of stems	No of species	No of stems	% species	% stems
Kilala	UKIHH01	12	126	5	42	5	82	42	65
	UKIHH02	6	47	1	3	4	42	67	89
	UKIHH03	13	79	5	30	6	31	46	39
	UKIHH04	18	96	8	45	8	32	44	33
	UKIHH05	10	57	1	1	4	33	40	58
Nziu	WNZHH01	13	84	6	27	7	49	54	58
	WNZHH02	10	39	3	5	5	30	50	77
	WNZHH03	11	75	6	18	4	48	36	64
	WNZHH04	17	130	11	78	6	52	35	40
	WNZHH05	4	10	1	3	2	4	50	40
Ukia	UUKHH01	17	52	12	37	6	15	35	29
	UUKHH02	11	50	8	33	4	18	36	36
	UUKHH03	16	76	9	41	8	33	50	43
	UUKHH04	16	108	10	55	3	31	19	29
	UUKHH05	8	24	5	21	4	4	50	17
	UUKHH06	21	69	10	40	9	27	43	39
	UUKHH07	14	40	12	34	5	9	36	23
	UUKHH08	6	31	2	5	4	26	67	84
	UUKHH09	16	128	8	87	5	23	31	18
Wote	WWOHH01	28	81	17	55	14	27	50	33
	WWOHH02	19	46	11	20	6	16	32	35
	WWOHH03	28	76	14	42	18	42	64	55
	WWOHH04	15	98	2	27	8	58	53	59
	WWOHH05	28	144	19	103	6	38	21	26
	WWOHH06	13	86	7	63	5	17	38	20
	WWOHH07	17	46	4	16	9	24	53	52

Mangifera indica was the most common fruit tree, found in all 23 farms of the 26 farms, followed by *C. sinensis*, found in 14 farms (Figure 4). Mango (29%) and orange (25%) account for over half (54%) of the fruit trees documented in Makueni. Mango was found in all land use types except woodlots. *Vachellia tortilis* was the most frequent native fruit tree, found in nine farms with 28 individuals, followed by *Azanza garckeana* and *Senegalia senegal* (Figure 4).

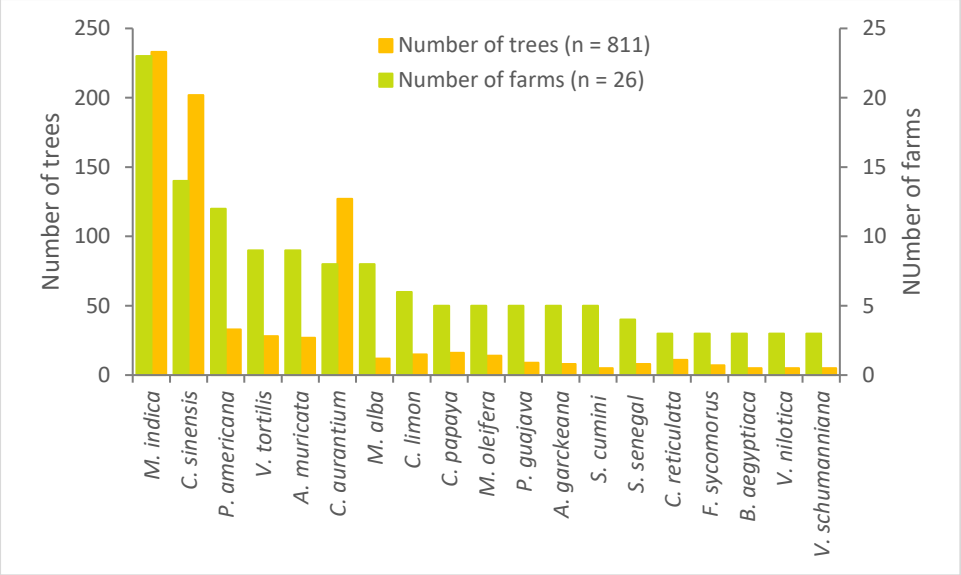

Figure 4 The distribution of fruit tree species and the corresponding number of individuals per species recorded on farms in Makueni County. The graph represents those species that were found in three or more farms and had a minimum of five individuals across the farms.

3.3 Stand characteristics

3.3.1 Population Structure in Kiambu

The distribution of DBH showed variable patterns for different land use types. Larger items (>60 cm) had lower frequency across all land use types; smaller stems (<10 cm) had high frequency in orchards and perennial tree-crop systems (Figure 5). There was relatively high frequency in the 20-30 cm diameter class on the boundary, <10 and 10-20 cm on cropland and homestead, and lower diameter class (<10 cm) orchards and perennial tree-crop systems (Figure 5). A similar pattern was observed with collar diameter (Appendix 3).

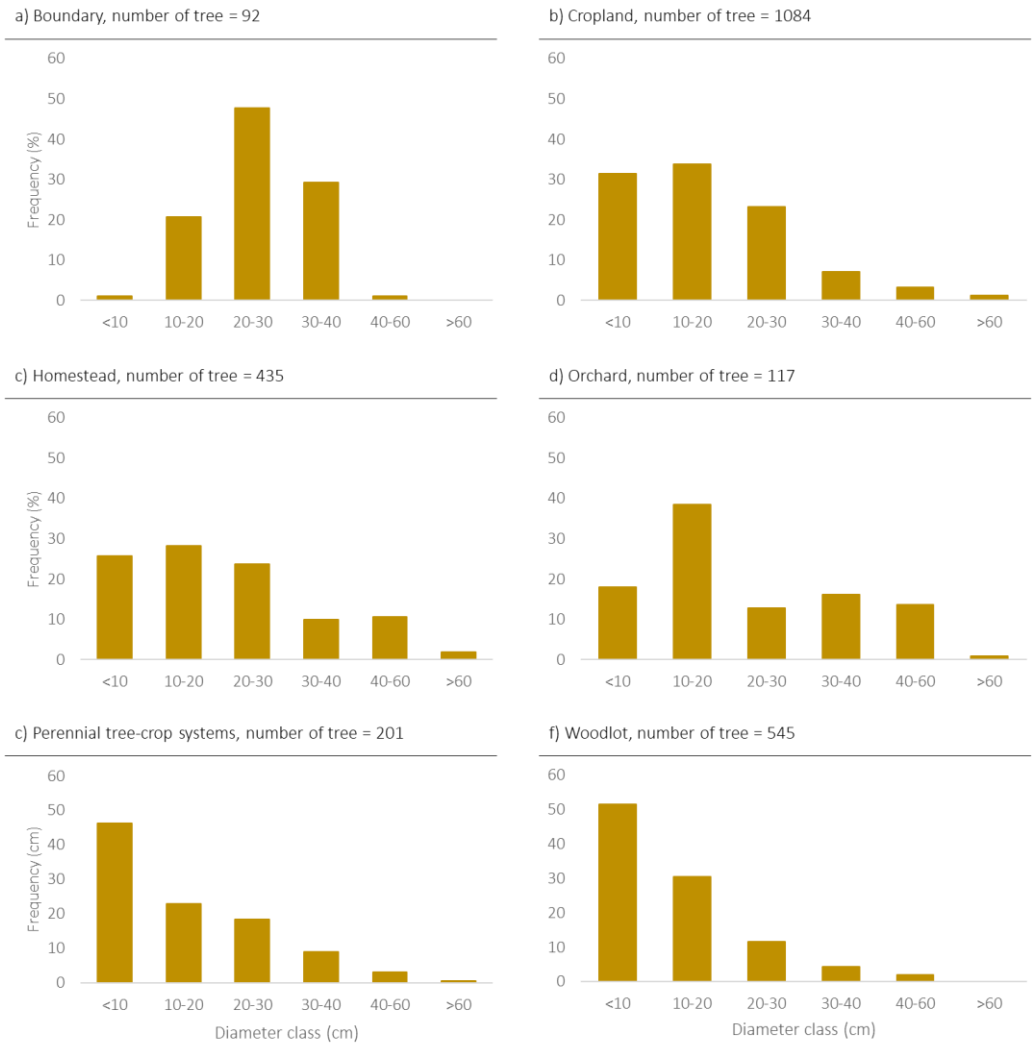

Figure 5 The distribution pattern of trees of different diameters at breast height on different farm locations in Kiambu.

Tree density varied across the different land use types. As expected, tree density was high in woodlots (385 trees/ha) and orchards (237 trees/ha) and low in cropland and homesteads (Table 5). The species with high density were *G. robusta* in cropland and perennial tree-crop systems, Eucalyptus spp. in woodlots, and avocado trees in orchards and homesteads.

Table 5 Descriptive summary of mature trees documented farms in Kiambu. The number of households (HH), the area of each land use type across the farms (ha), and the number of individuals per hectare are provided.

Land use type	No of HH	Area (ha)	No of trees	Tree density	Collar diameter			Diameter at breast height		
					Mean±SD	Min	Max	Mean±SD	Min	Max
Boundary	4	na	92	na	28.8±9.5	2.7	60.5	25.6±7.5	8.5	48.4
Cropland	31	12.43	1089	88	20.0±13.2	3.1	136.9	17.5±12.0	1.5	90.8
Homestead	35	4.70	433	92	24.4±15.6	2.9	93.6	21.6±14.7	2.3	85.3
Orchard	7	0.50	118	237	24.3±15.2	3.3	66.3	22.8±14.9	2.5	61.4
Perennial tree-crop systems	10	1.84	203	110	17.1±13.2	2.9	72.6	15.3±12.0	2.4	62.7
Terraces	1	na	5	na	23.3±7.8	9.3	27.5	20.1±7.6	6.6	24.6

Woodlot	13	1.39	548	395	15.4±10.7	2.8	65.7	13.3±9.5	2.5	55.7

3.3.2 Population Structure in Makueni

The distribution of DBH across different land use types is shown in Figure 6. There were a few larger stems (DBH>50cm) in the landscape. On the contrary, the frequency of smaller stems <10 am and between 10-20 cm was high. All land use types, except perennial tree-crop systems, had the highest frequency of stems with DBH between 10-20. A similar pattern was observed with collar diameter (Appendix 4).

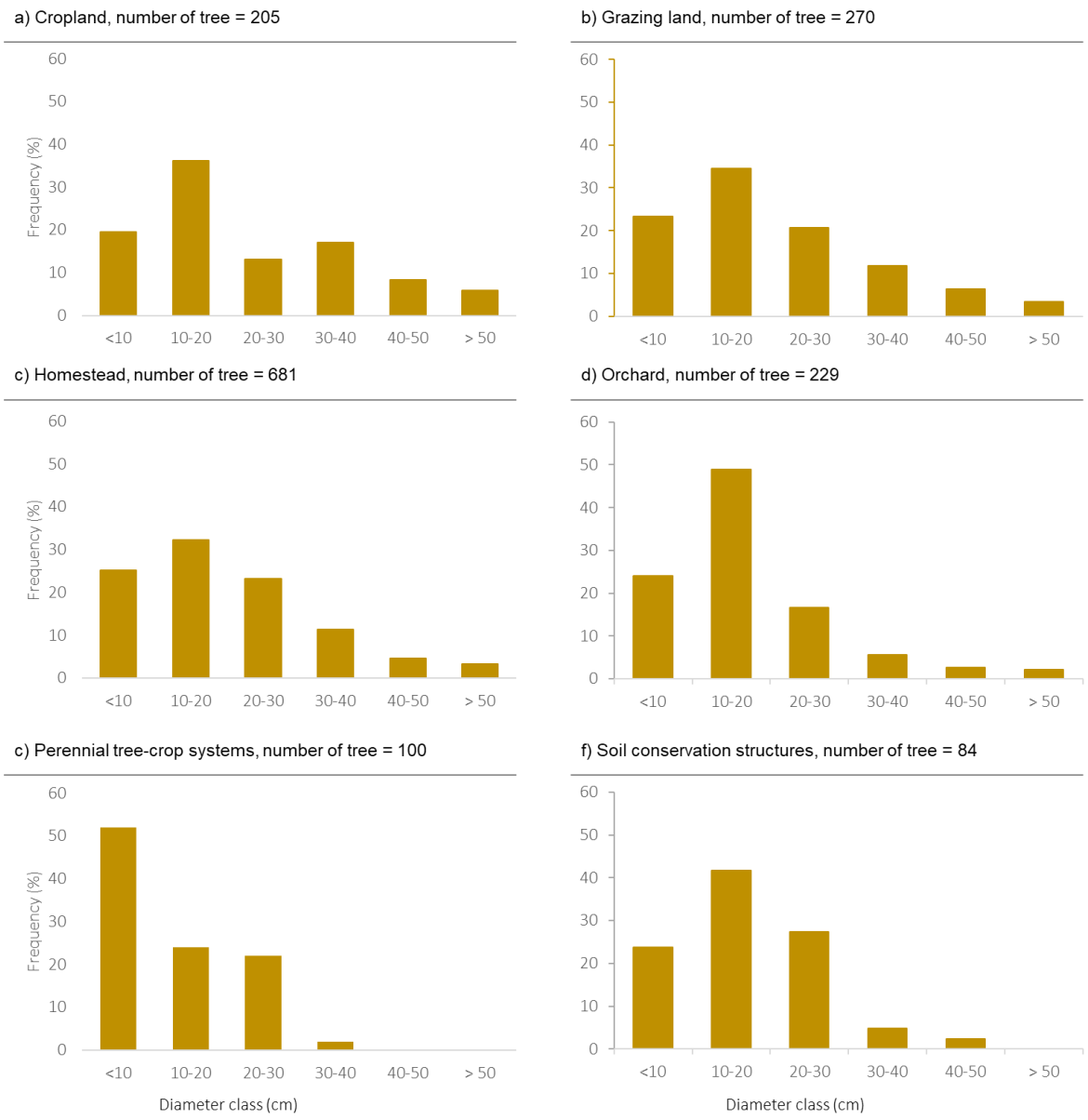

Figure 6 The distribution pattern of trees of different diameters at breast height on different farm locations in Makueni.

Stand characteristics for mature trees documented in Makueni is shown in Table 6. Tree density has not been calculated because of missing information on the land use area for

Makueni. This will be collected during the biomass sampling exercise. The abundance of trees in different land use types has been described in section 4.1.

Table 6 Descriptive summary of mature trees documented farms in Makueni. The number of households (HH) that included trees in the land use type is provided

Land use type	No of HH	Collar diameter (cm)				Diameter at breast height (cm)			
		Count	mean±SD	min	max	Count	mean±SD	min	max
Boundary	3	39	24.2±7. 9	11.3	46.2	34	21.6±6.5	8.8	36.1
Cropland	9	205	27.2±18.2	3.5	108.2	205	23.2±16.1	2.4	97.0
Grazing land	10	269	23.7±15.1	2.9	104.7	270	20.5±13.4	2.7	84.4
Homestead	26	710	23.0±14.5	2.6	96.6	681	20.0±13.5	1.8	100.9
Orchard	18	482	17.0±8.9	4.1	58.9	229	17.1±10.8	2.8	63.3
Soil cons. structures	6	85	19.4±9.6	2.9	48.0	84	17.1±9.4	1.8	48.5
Woodlot	4	65	9.6±4.3	3.1	28.5	100	12.6±7.8	2.0	31.2

3.4 Regeneration status of fruit trees

In Kiambu, the proportion of seedlings relative to the total population of fruit trees was highest followed by trees and saplings (Figure 7). The regeneration of dominant fruit tree species and other trees adapted to sub-humid and dryland ecosystems was good to fair (Appendix 5). Five species showed good regeneration while 16 species had limited regeneration or no regeneration (Appendix 5). Four species (*Ficus sycomorus*, *Casimiroa edulis*, *Morus alba*, *Punica granatum*) could be considered new arrivals in the farms inventoried as they were only represented by seedlings.

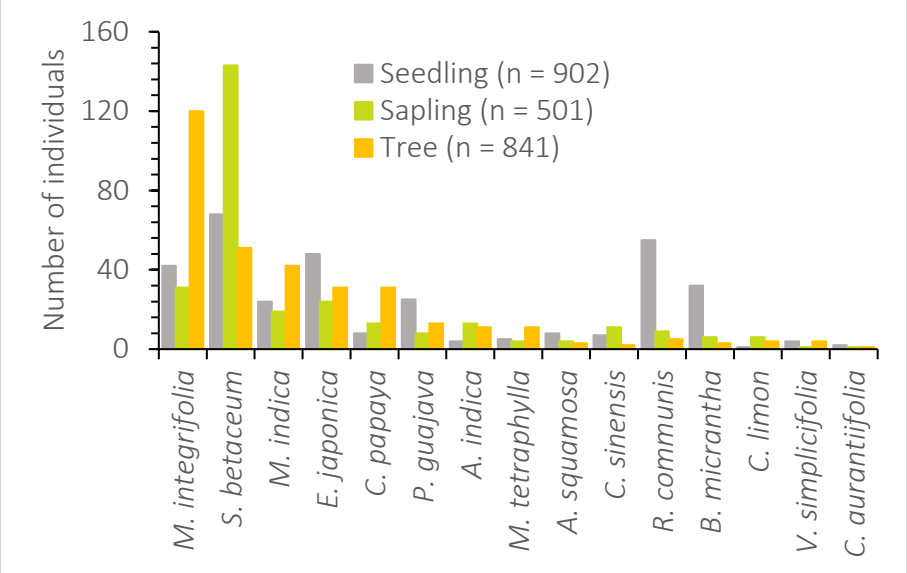

Figure 7 Regeneration patterns of fruit tree species in Kiambu County. The graph does not include *P. americana*, which was represented by 266 seedlings, 202 saplings, and 469 mature trees.

In Makueni, the proportion of mature trees relative to the total population of fruit trees (n= 983) was highest (83%), followed by saplings (12%) and seedlings (5%). Regeneration of fruit trees was poor and limited to five exotic species: *P. americana*, *C. limon*, *C. sinensis*, *C. aurantium,* and *P. guajava* (Appendix 6).

Low populations of native species in both counties coupled with poor representation of seedlings and saplings point to a compositional shift that has favored exotic species. The absence of seedlings of some species could be attributed to their characteristic poor seed germination and establishment, especially in dryland ecosystems. There is a need to establish the conservation status of species with no regeneration, as these can be exterminated if they are susceptible to climate change.

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Appendices

Appendix 1 List of all species documented in Kiambu in decreasing order of relative proportion of seedlings, saplings, and mature trees. NO refers to the number of individuals while % refers to the relative proportion (%).

NO	Scientific name	Botanical family	Seedling		Sapling		Mature trees		All stages	
			NO	%	NO	%	NO	%	NO	%
1	*Grevillea robusta*	Proteaceae	53	7	165	15	760	30	978	22
2	*Persea americana*	Lauraceae	266	34	202	18	469	19	937	21
3	*Eucalyptus sp*	Myrtaceae	25	3	190	17	212	9	427	10
4	*Eucalyptus saligna*	Myrtaceae			53	5	302	12	355	8
5	*Solanum betaceum*	Solanaceae	68	9	143	13	51	2	262	6
6	*Macadamia integrifolia*	Proteaceae	42	5	31	3	120	5	193	4
7	*Acacia mearnsii*	Fabaceae	24	3	49	4	56	2	129	3
8	*Commiphora eminii ssp. zimmermannii*	Burseraceae			36	3	75	3	111	3
9	*Eriobotrya japonica*	Rosaceae	48	6	24	2	31	1	103	2
10	*Ricinus communis*	Euphorbiaceae	70	9	14	1	10		94	2
11	*Mangifera indica*	Anacardiaceae	24	3.04	19	1.70	42	1.69	85	1.93
12	*Cupressus lusitanica*	Cupressaceae			27	2.42	35	1.40	62	1.41
13	*Prunus africana*	Rosaceae	6	0.76	10	0.90	38	1.52	54	1.23
14	*Carica papaya*	Caricaceae	8	1.01	13	1.17	31	1.24	52	1.18
15	*Croton macrostachyus*	Euphorbiaceae	30	3.80	11	0.99	6	0.24	47	1.07
16	*Psidium guajava*	Myrtaceae	25	3.17	8	0.72	13	0.52	46	1.05
17	*Bridelia micrantha*	Phyllanthaceae	32	4.06	6	0.54	3	0.12	41	0.93
18	*Azadirachta indica*	Meliaceae	4	0.51	13	1.17	11	0.44	28	0.64
19	*Ehretia cymosa*	Boraginaceae	6	0.76	9	0.81	6	0.24	21	0.48
20	*Citrus sinensis*	Rutaceae	7	0.89	11	0.99	2	0.08	20	0.45
21	*Macadamia tetraphylla*	Proteaceae	5	0.63	4	0.36	11	0.44	20	0.45
22	*Albizia gummifera*	Fabaceae	4	0.51	4	0.36	10	0.40	18	0.41
23	*Podocarpus latifolius*	Podocarpaceae	1	0.13			15	0.60	16	0.36
24	*Annona squamosa*	Annonaceae	8	1.01	4	0.36	3	0.12	15	0.34
25	*Podocarpus falcatus*	Podocarpaceae			1	0.09	12	0.48	13	0.30
26	*Callistemon viminalis*	Myrtaceae					11	0.44	11	0.25
27	*Casuarina equisetifolia*	Casuarinaceae			1	0.09	10	0.40	11	0.25
28	*Citrus limon*	Rutaceae	1	0.13	6	0.54	4	0.16	11	0.25
29	*Filicium decipiens*	Sapindaceae			4	0.36	7	0.28	11	0.25
30	*Juniperus procera*	Cupressaceae			1	0.09	10	0.40	11	0.25
31	*Solanum mauritianum*	Solanaceae	4	0.51	4	0.36	3	0.12	11	0.25
32	*Calliandra calothyrsus*	Fabaceae			2	0.18	8	0.32	10	0.23
33	*Croton megalocarpus*	Euphorbiaceae	1	0.13	1	0.09	8	0.32	10	0.23
34	*Vepris simplicifolia*	Rutaceae	4	0.51	1	0.09	4	0.16	9	0.20
35	*Alchornea cordifolia*	Euphorbiaceae			8	0.72			8	0.18
36	*Callistemon citrinus*	Myrtaceae					8	0.32	8	0.18
37	*Sesbania sesban*	Fabaceae	1	0.13	4	0.36	3	0.12	8	0.18
38	*Pinus patula*	Pinaceae		0.00			7	0.28	7	0.16
39	*Senna spectabilis*	Fabaceae	3	0.38			4	0.16	7	0.16

40	*Phoenix reclinata*	Arecaceae			2	0.18	4	0.16	6	0.14
41	*Jacaranda mimosifolia*	Bignoniaceae			1	0.09	4	0.16	5	0.11
42	*Senna didymobotrya*	Fabaceae	5	0.63					5	0.11
43	*Thuja orientalis*	Cupressaceae			3	0.27	2	0.08	5	0.11
44	*Vitex keniensis*	Verbenaceae					5	0.20	5	0.11
45	*Warburgia ugandensis*	Canellaceae			1	0.09	4	0.16	5	0.11
46	*Citrus aurantiifolia*	Rutaceae	2	0.25	1	0.09	1	0.04	4	0.09
47	*Duranta erecta*	Verbenaceae			1	0.09	3	0.12	4	0.09
48	*Malus pumila*	Rosaceae			3	0.27	1	0.04	4	0.09
49	*Markhamia lutea*	Bignoniaceae			2	0.18	2	0.08	4	0.09
50	*Syzygium guineense*	Myrtaceae					4	0.16	4	0.09
51	*Terminalia mantaly*	Combretaceae	1	0.13			3	0.12	4	0.09
52	*Trichilia emetica*	Meliaceae					4	0.16	4	0.09
53	*Bauhinia variegata*	Fabaceae					3	0.12	3	0.07
54	*Camellia sinensis*	Theaceae					3	0.12	3	0.07
55	*Ficus sycomorus*	Moraceae	1	0.13			2	0.08	3	0.07
56	*Senecio bayonnensis*	Asteraceae	1	0.13	2	0.18			3	0.07
57	*Vepris nobilis*	Rutaceae			3	0.27			3	0.07
58	*Bougainvillea spectabilis*	Nyctaginaceae			2	0.18			2	0.05
59	*Brugmansia suaveolens*	Solanaceae			1	0.09	1	0.04	2	0.05
60	*Clauseana aniseta*	Rutaceae			2	0.18			2	0.05
61	*Cordia africana*	Boraginaceae					2	0.08	2	0.05
62	*Delonix regia*	Fabaceae	2	0.25					2	0.05
63	*Dodonaea viscosa*	Sapindaceae	2	0.25					2	0.05
64	*Petrea volubilis*	Verbenaceae	1	0.13	1	0.09			2	0.05
65	*Schefflera actinophylla*	Araliaceae					2	0.08	2	0.05
66	*Solanum torvum*	Solanaceae					2	0.08	2	0.05
67	*Tecomaria capensis*	Bignoniaceae			2	0.18			2	0.05
68	*Trema orientale*	Cannabaceae					2	0.08	2	0.05
69	*Zanthoxylum usambarense*	Rutaceae			1	0.09	1	0.04	2	0.05
70	*Acacia melanoxylon*	Fabaceae					1	0.04	1	0.02
71	*Araucaria cunninghamii*	Araucariaceae					1	0.04	1	0.02
72	*Brachylaena huillensis*	Asteraceae			1	0.09			1	0.02
73	*Callistemon linearis*	Myrtaceae					1	0.04	1	0.02
74	*Casimiroa edulis*	Rutaceae	1	0.13					1	0.02
75	*Clerodendrum johnstonii*	Verbenaceae			1	0.09			1	0.02
76	*Cryptomeria japonica*	Cupressaceae	1	0.13					1	0.02
77	*Cussonia spicata*	Araliaceae					1	0.04	1	0.02
78	*Diospyros abyssinica*	Ebenaceae					1	0.04	1	0.02
79	*Dracaena steudneri*	Asparagaceae					1	0.04	1	0.02
80	*Ekebergia capensis*	Meliaceae					1	0.04	1	0.02
81	*Eucalyptus citriodora*	Myrtaceae					1	0.04	1	0.02
82	*Euphorbia candelabrum*	Euphorbiaceae					1	0.04	1	0.02
83	*Euphorbia kibwensis*	Euphorbiaceae					1	0.04	1	0.02
84	*Fraxinus pennsylvanica*	Oleaceae					1	0.04	1	0.02
85	*Hagenia abyssinica*	Rosaceae					1	0.04	1	0.02
86	*Kigelia africana*	Bignoniaceae					1	0.04	1	0.02

87	*Macaranga kilimandscharica*	Euphorbiaceae			1	0.09			1	0.02
88	*Melia azedarach*	Meliaceae					1	0.04	1	0.02
89	*Moringa oleifera*	Moringaceae					1	0.04	1	0.02
90	*Morus alba*	Moraceae			1	0.09			1	0.02
91	*Nerium oleander*	Apocynaceae					1	0.04	1	0.02
92	*Newtonia buchananii*	Fabaceae					1	0.04	1	0.02
93	*Olea europaea ssp. africana*	Oleaceae					1	0.04	1	0.02
94	*Olea capensis ssp. welwitschii*	Oleaceae					1	0.04	1	0.02
95	*Punica granatum*	Punicaceae	1	0.13					1	0.02
96	*Sambucus africana*	Caprifoliaceae					1	0.04	1	0.02
97	*Schinus telebrinthifolia*	Anacardiaceae					1	0.04	1	0.02
98	*Spathodea campanulata*	Bignoniaceae					1	0.04	1	0.02
99	*Vernonia amygdalina*	Asteraceae					1	0.04	1	0.02
100	*Acalypha sp*	Euphorbiaceae			1	0.09			1	0.02
101	*Unkown*	unknown	1	0.13	3	0.27	3	0.12	7	0.16

Appendix 2 List of species documented in Makueni in decreasing order of relative proportion. NO refers to number of individuals while % refer to the relative proportion (%).

SNO	Scientific name	Botanical family	Seedling		Sapling		Mature trees		All stages	
			NO	%	NO	%	NO	%	NO	%
1	*Grevillea robusta*	Proteaceae	2	1.6	32	17.7	334	17.50	368	16.63
2	*Mangifera indica*	Anacardiaceae					233	12.21	233	10.53
3	*Citrus sinensis*	Rutaceae	1	0.8	18	9.9	202	10.58	221	9.99
4	*Citrus aurantium*	Rutaceae	50	40.7	4	2.2	127	6.65	181	8.18
5	*Croton megalocarpus*	Euphorbiaceae			28	15.5	90	4.71	118	5.33
6	*Terminalia brownii*	Combretaceae			2	1.1	115	6.02	117	5.29
7	*Persea americana*	Lauraceae	69	56.1			33	1.73	102	4.61
8	*Senna siamea*	Fabaceae			14	7.7	74	3.88	88	3.98
9	*Croton macrostachyus*	Euphorbiaceae			15	8.3	63	3.30	78	3.52
10	*Cascabela thevetia*	Apocynaceae					42	2.20	42	1.90
11	*Citrus limon*	Rutaceae	1		26	14.4	15	0.79	42	1.90
12	*Senegalia polyacantha*	Fabaceae					35	1.83	35	1.58
13	*Callistemon salignus*	Myrtaceae			26	14.4	8	0.42	34	1.54
14	*Vachellia tortilis*	Fabaceae					28	1.47	28	1.27
15	*Annona muricata*	Annonaceae					27	1.41	27	1.22
16	*Combretum molle*	Combretaceae					25	1.31	25	1.13
17	*Melia azedarach*	Meliaceae			1		22	1.15	23	1.04
18	*Vachellia gerrardii*	Mimosaceae					22	1.15	22	0.99
19	*Jacaranda mimosifolia*	Kigelia africana			6	3.3	15	0.79	21	0.95
20	*Eucalyptus camaldulensis*	Myrtaceae			1	0.6	17	0.89	18	0.81
21	*Carica papaya*	Caricaceae					16	0.84	16	0.72
22	*Moringa oleifera*	Moringaceae					14	0.73	14	0.63
23	*Vachellia seyal*	Fabaceae					14	0.73	14	0.63
24	*Cassia abbreviata*	Fabaceae					13	0.68	13	0.59
25	*Euphorbia tirucalli*	Euphorbiaceae					13	0.68	13	0.59
26	*Casuarina equisetifolia*	Casuarinaceae					12	0.63	12	0.54
27	*Morus alba*	Moraceae					12	0.63	12	0.54
28	*Psidium guajava*	Myrtaceae			3	1.7	9	0.47	12	0.54
29	*Senna longiracemosa*	Fabaceae					12	0.63	12	0.54
30	*Calliandra calothyrsus*	Fabaceae					11	0.58	11	0.50
31	*Citrus reticulata*	Rutaceae					11	0.58	11	0.50
32	*Commiphora africana*	Burseraceae					11	0.58	11	0.50
33	*Combretum schumannii*	Combretaceae					9	0.47	9	0.41
34	*Cupressus lusitanica*	Cupressaceae					9	0.47	9	0.41
35	*Senegalia mellifera*	Fabaceae					9	0.47	9	0.41
36	*Azanza garckeana*	Malvaceae					8	0.42	8	0.36
37	*Combretum collinum*	Combretaceae					8	0.42	8	0.36
38	*Senegalia senegal*	Fabaceae					8	0.42	8	0.36
39	*Dalbergia melanoxylon*	Fabaceae					7	0.37	7	0.32
40	*Ekebergia capensis*	Meliaceae					7	0.37	7	0.32
41	*Ficus sycomorus*	Moraceae					7	0.37	7	0.32
42	*Terminalia mantaly*	Combretaceae					7	0.37	7	0.32
43	*Vachellia nilotica*	Fabaceae					7	0.37	7	0.32

44	*Araucaria sp*	Araucariaceae			3	1.7	3	0.16	6	0.27
45	*Ficus benjamina*	Moraceae					6	0.31	6	0.27
46	*Balanites aegyptiaca*	Balanitaceae					5	0.26	5	0.23
47	*Combretum zeyheri*	Combretaceae					5	0.26	5	0.23
48	*Kigelia africana*	Bignoniaceae					5	0.26	5	0.23
49	*Senna spectabilis*	Fabaceae					5	0.26	5	0.23
50	*Syzygium cumini*	Myrtaceae					5	0.26	5	0.23
51	*Vangueria schumanniana*	Rubiaceae					5	0.26	5	0.23
52	*Zanthoxylum chalybeum*	Rutaceae					5	0.26	5	0.23
53	*Azadirachta indica*	Meliaceae					4	0.21	4	0.18
54	*Casimiroa edulis*	Rutaceae					4	0.21	4	0.18
55	*Commiphora rostrata*	Burseraceae					4	0.21	4	0.18
56	*Markhamia lutea*	Bignoniaceae					4	0.21	4	0.18
57	*Tecoma stans*	Bignoniaceae					4	0.21	4	0.18
58	*Turraea mombassana*	Meliaceae					4	0.21	4	0.18
59	*Eriobotrya japonica*	Rosaceae					3	0.16	3	0.14
60	*Leucaena diversifolia*	Fabaceae					3	0.16	3	0.14
61	*Ormocarpum kirkii*	Fabaceae					3	0.16	3	0.14
62	*Polyalthia longifolia*	Annonaceae					3	0.16	3	0.14
63	*Spathodea campanulata*	Bignoniaceae					3	0.16	3	0.14
64	*Turraea robusta*	Meliaceae					3	0.16	3	0.14
65	*Vachellia xanthophloea*	Fabaceae					3	0.16	3	0.14
66	*Vangueria madagascariensis*	Rubiaceae					3	0.16	3	0.14
67	*Albizia amara*	Fabaceae					2	0.10	2	0.09
68	*Bridelia micrantha*	Phyllanthaceae					2	0.10	2	0.09
69	*Erythrina abyssinica*	Fabaceae					2	0.10	2	0.09
70	*Ficus vasta*	Moraceae					2	0.10	2	0.09
71	*Grewia bicolor*	Tiliaceae					2	0.10	2	0.09
72	*Hyphaene compressa*	Arecaceae					2	0.10	2	0.09
73	*Lannea schweinfurthii subsp. stuhlmannii*	Anacardiaceae					2	0.10	2	0.09
74	*Lonchocarpus eriocalyx*	Fabaceae					2	0.10	2	0.09
75	*Saraca asoca*	Fabaceae					2	0.10	2	0.09
76	*Tamarindus indica*	Fabaceae					2	0.10	2	0.09
77	*Alchornea cordifolia*	Euphorbiaceae					1	0.05	1	0.05
78	*Annona squamosa*	Annonaceae					1	0.05	1	0.05
79	*Bougainvillea spectabilis*	Nyctaginaceae					1	0.05	1	0.05
80	*Cadaba sp*	Capparaceae					1	0.05	1	0.05
81	*Catha edulis*	Celastraceae			1	0.6		0.00	1	0.05
82	*Commiphora eminii subsp. Zimmermannii*	Burseraceae					1	0.05	1	0.05
83	*Commiphora habessinica*	Burseraceae					1	0.05	1	0.05
84	*Delonix elata*	Fabaceae					1	0.05	1	0.05
85	*Euclea divinorum*	Ebenaceae					1	0.05	1	0.05
86	*Euphorbia compactum*	Euphorbiaceae					1	0.05	1	0.05
87	*Ficus elastica*	Moraceae					1	0.05	1	0.05
88	*Ficus thonningii*	Moraceae					1	0.05	1	0.05

89	*Grewia tembensis*	Tiliaceae					1	0.05	1	0.05
90	*Grewia villosa*	Hibiscus rosa-sinensis					1	0.05	1	0.05
91	*Hibiscus rosa-sinensis*	Malvaceae					1	0.05	1	0.05
92	*Leucaena leucocephala*	Fabaceae					1	0.05	1	0.05
93	*Nerium oleander*	Apocynaceae					1	0.05	1	0.05
94	*Psydrax schimperiana subsp. Schimperiana*	Rubiaceae					1	0.05	1	0.05
95	*Sclerocarya birrea*	Anacardiaceae					1	0.05	1	0.05
96	*Steganotaenia araliacea*	Apiaceae					1	0.05	1	0.05
97	*Trichilia emetica*	Meliaceae					1	0.05	1	0.05
98	*Vachellia lahai*	Fabaceae					1	0.05	1	0.05
99	*Vachellia stuhlmannii*	Fabaceae					1	0.05	1	0.05
100	*Vitex doniana*	Lamiaceae					1	0.05	1	0.05
101	*Ziziphus mucronata*	Rhamnaceae					1	0.05	1	0.05
102	*Unknown*	NA			1	0.6	12	0.63	13	0.59

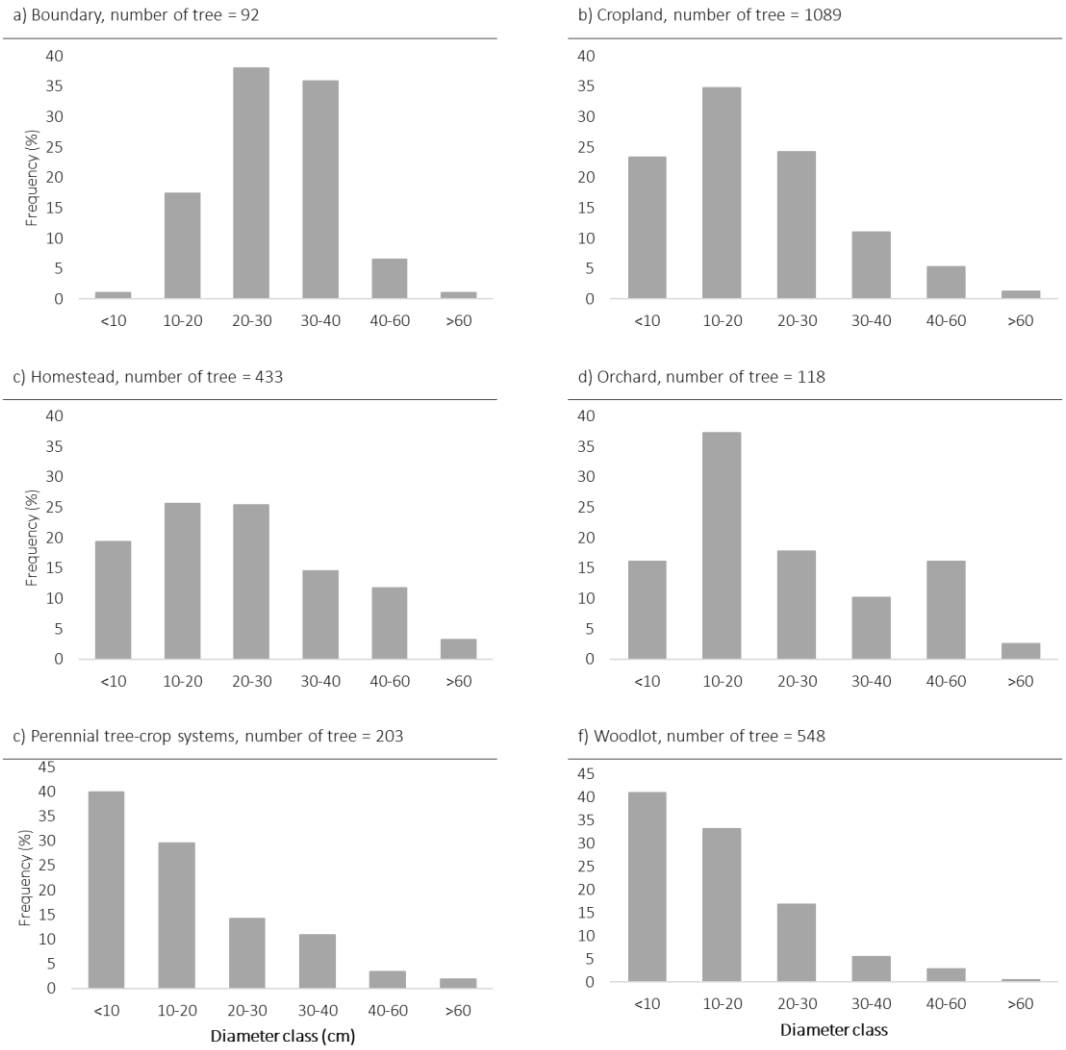
Appendix 3; LIST OF ENUMERATORS INVOLVED IN TREE INVENTORY

Kiambu: 20th -27th July 2022

Makueni: 21st -25th June 2022

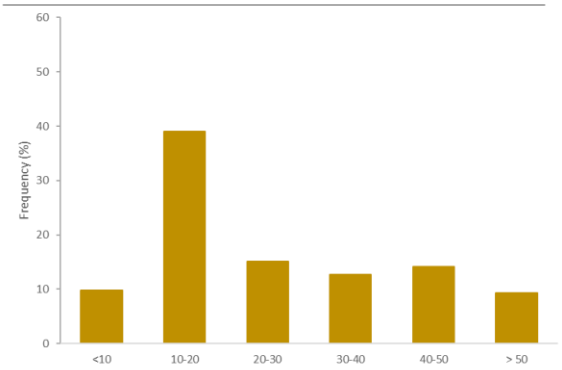
S/No	Name	County	Gender	Activity
1	Damaris Mwikali Nzyuko	Makueni	F	Tree Inventory
2	Muchoku John Kamu	Makueni	M	Tree Inventory
3	Omenye Reuben Pillah	Makueni	M	Tree Inventory
4	Eva Kerubo Nyaenya	Makueni	F	Tree Inventory
5	Muchoku John Kamau	Kiambu	M	Tree Inventory
6	Paul Ojwang Ajwang	Kiambu	M	Tree Inventory
7	Caroline Njoki	Kiambu	F	Tree Inventory
8	Violet Asiengo	Kiambu	F	Tree Inventory
9	Cornelius Kibet	Kiambu	M	Tree Inventory
10	Charlie Muigai	Makueni	M	Tree Inventory
11	James Kibe	Kiambu	M	Tree Inventory
12	Meshack Muthoka	Makueni	M	Tree Inventory

Appendix 3 The distribution pattern of trees of different collar diameter on different farm locations in Kiambu county

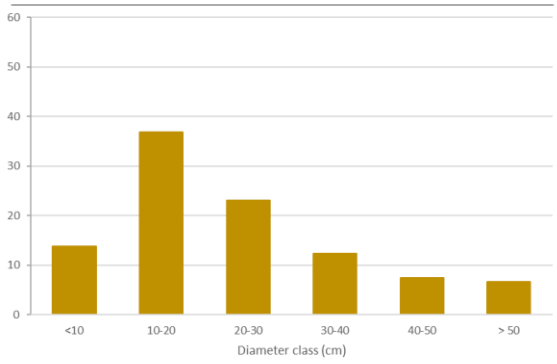


Appendix 4 The distribution pattern of trees of different collar diameter on different farm locations in Makueni county.

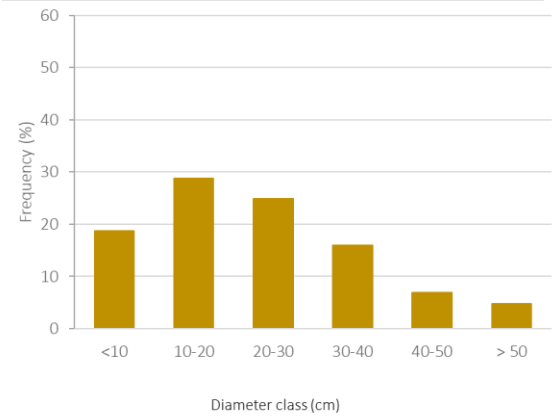
a) Cropland, number of tree = 205



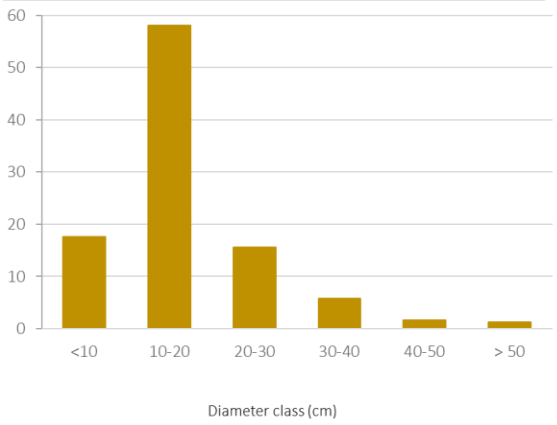
b) Grazing land, number of tree = 269



c) Homestead, number of tree = 710



d) Orchard, number of tree = 482



Appendix 5 Regeneration patterns of fruit tree species documented in Kiambu

Species	Seedling (n = 902)	Sapling (n = 501)	Tree (n = 841)	All fruit trees	Regeneration status
Persea americana	266	202	469	937	Fair
Macadamia integrifolia	42	31	120	193	Fair
Solanum betaceum	68	143	51	262	Good
Mangifera indica	24	19	42	85	Fair
Eriobotrya japonica	48	24	31	103	Fair
Carica papaya	8	13	31	52	Fair
Psidium guajava	25	8	13	46	Fair
Azadirachta indica	4	13	11	28	Fair
Macadamia tetraphylla	5	4	11	20	Fair
Annona squamosa	8	4	3	15	Good
Citrus sinensis	7	11	2	20	Fair
Ricinus communis	55	9	5	69	Good
Bridelia micrantha	32	6	3	41	Good
Citrus limon	1	6	4	11	Fair
Vepris simplicifolia	4	1	4	9	Fair
Citrus aurantiifolia	2	1	1	4	Good
Podocarpus falcatus		1	12	13	Poor
Warburgia ugandensis		1	4	5	Poor
Vitex keniensis			5	5	None
Syzygium guineense			4	4	None
Ficus sycomorus	1		2	3	None
Cordia africana			2	2	None
Solanum torvum			2	2	None
Trema orientale			2	2	None
Malus pumila		3	1	4	Poor
Ekebergia capensis			1	1	None
Moringa oleifera			1	1	None
Olea europaea ssp. africana			1	1	None
Sambucus africana			1	1	None
Schinus telebrinthifolia			1	1	None
Spathodea campanulata			1	1	None
Casimiroa edulis	1			1	New
Morus alba		1		1	New
Punica granatum	1			1	New

Appendix 6 Regeneration patterns of exotic (1-16) and native (17-42) fruit tree species documented in Makueni.

SNO	Species	Sapling	Seedling	Tree	All growth stages trees	Proportion, % (all trees)	Proportion, % (origin)	Regeneration status
1	*Mangifera indica*			233	233	24	24	None
2	*Citrus sinensis*	18	1	202	221	21	22	Fair
3	*Citrus aurantium*	4	50	127	181	13	18	Fair
4	*Persea americana*		69	33	102	3	10	Fair
5	*Annona muricata*			27	27	3	3	None
6	*Carica papaya*			16	16	2	2	None
7	*Citrus limon*	26	1	15	42	2	4	Fair
8	*Moringa oleifera*			14	14	1	1	None
9	*Morus alba*			12	12	1	1	None
10	*Citrus reticulata*			11	11	1	1	None
11	*Psidium guajava*	3		9	12	1	1	Fair
12	*Syzygium cumini*			5	5	1	1	None
13	*Azadirachta indica*			4	4	0	0	None
14	*Eriobotrya japonica*			3	3	0	0	None
15	*Polyalthia longifolia*			3	3	0	0	None
16	*Annona squamosa*			1	1	0	0	None
17	*Vachellia tortilis*			28	28	3	3	None
18	*Azanza garckeana*			8	8	1	1	None
19	*Senegalia senegal*			8	8	1	1	None
20	*Ficus sycomorus*			7	7	1	1	None
21	*Balanites aegyptiaca*			5	5	1	1	None
22	*Vachellia nilotica*			5	5	1	1	None
23	*Vangueria schumanniana*			5	5	1	1	None
24	*Casimiroa edulis*			4	4	0.4	0.4	None
25	*Vangueria madagascariensis*			3	3	0.3	0.3	None
26	*Bridelia micrantha*			2	2	0.2	0.2	None
27	*Ficus vasta*			2	2	0.2	0.2	None
28	*Grewia bicolor*			2	2	0.2	0.2	None
29	*Hyphaene compressa*			2	2	0.2	0.2	None
30	*Lannea schweinfurthii subsp. stuhlmannii*			2	2	0.2	0.2	None
31	*Spathodea campanulata*			2	2	0.2	0.2	None
32	*Tamarindus indica*			2	2	0.2	0.2	None
34	*Alchornea cordifolia*			1	1	0.1	0.1	None
35	*Euclea divinorum*			1	1	0.1	0.1	None
36	*Grewia tembensis*			1	1	0.1	0.1	None
37	*Grewia villosa*			1	1	0.1	0.1	None

38	*Kigelia africana*			1	1	0.1	0.1	None
39	*Sclerocarya birrea*			1	1	0.1	0.1	None
40	*Trichilia emetica*			1	1	0.1	0.1	None
41	*Vitex doniana*			1	1	0.1	0.1	None
42	*Ziziphus mucronata*			1	1	0.1	0.1	None

LIST OF ENUMERATORS INVOLVED IN TREE INVENTORY

Kiambu: 20th -29th July 2022

Makueni: 21st -25th June 2022

S/No	Name	County	Gender	Activity
1	Damaris Mwikali Nzyuko	Makueni	F	Tree Inventory
2	Muchoku John Kamu	Makueni	M	Tree Inventory
3	Omenye Reuben Pillah	Makueni	M	Tree Inventory
4	Eva Kerubo Nyaenya	Makueni	F	Tree Inventory
5	Muchoku John Kamau	Kiambu	M	Tree Inventory
6	Paul Ojwang Ajwang	Kiambu	M	Tree Inventory
7	Caroline Njoki	Kiambu	F	Tree Inventory
8	Violet Asiengo	Kiambu	F	Tree Inventory
9	Cornelius Kibet	Kiambu	M	Tree Inventory
10	Charlie Muigai	Makueni	M	Tree Inventory
11	James Kibe	Kiambu	M	Tree Inventory
12	Meshack Muthoka	Makueni	M	Tree Inventory
13	Samuel Ndungu	Kiambu	M	Tree Inventory
14	David Gathiga	Kiambu	M	Tree Inventory