# Agroforestry innovation by smallholders facing uncertainty: the case of clove-based cropping systems in Madagascar

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## Abstract

Clove production in the eastern coastal region of Madagascar is typical of an export crop grown by particularly vulnerable smallholders. Products from clove trees, along with vanilla, account for the largest proportion of Madagascar's agricultural exports. There is a marked contrast between the national economic stakes and the situation of smallholders hampered by fluctuating world market prices, a particularly erratic climate in this cyclone-prone area, and land fragmentation due to high demographic pressure. Clove trees were first introduced by French settlers and grown in monospecific plantations according to their development model. These clove plantations dominate the landscape but appear at first sight to be deteriorating, thus mobilizing R&D actors with the intention of improving the sector. What if it turned out, on the contrary, that farmers had gradually developed, over generations, diverse and diversified clove systems adapted to the prevailing uncertainty? This is what we wanted to test by implementing a method combining farmer surveys and field observations. We assumed that the density of associated and clove trees, the identification of species within these stands, and the clove tree growth status, reflected the past and present dynamics and the sought-after functions. In two Fenerive-Est villages, we analyzed findings from a sample of thirty clove plots, and revealed six different types of system in terms of vegetation structure, species combinations and ages. The trend was in favour of clove tree maintenance and renewal, but also diversification of associated tree species and uses of the underlying layers, to the detriment of the per-hectare clove tree density. The systems had also evolved according to the age of the clove trees. Interventions to improve clove production in Madagascar must be designed within the framework of these diversified, multifunctional and evolving systems, without overlooking other derivative components and products.

## 1. Introduction

The practice of cash cropping for export often has a major role to play in the economy of rural households in southern countries. Some of these productions find themselves wedged between, on one side, constraints imposed by market related factors (fluctuating purchase price), and on the other, the local context, such as land pressure resulting from a high demography combined with a return to the countryside by an impoverished urban population. Often the grower in search of resilience will respond to these situations with adaptation strategies that complexify and diversify existing cropping systems. Madagascar's clove production is an exemplary case of this type of problem. The east coast of Madagascar is characterised by its clove trees (*Syzygium aromaticum* L.), shaping the landscape and generating income for its smallholders from the production and export of cloves and essential oil. Clove trees, which were introduced and imposed in the early twentieth century by the French colonial administration, were planted over time by the farmers in all the non-flooded areas, transforming them into the mainstay of diversified agroforestry systems. However, in the context of growing global demand for clove products, and in the light of the importance of these exports for Madagascar[1], the productivity and sustainability of clove trees within these systems is an issue (Danthu et al., 2014).

The primary objective of this study was to determine the characteristics of these original and little known clove systems, as well as their temporal dynamics, as a preliminary to their evaluation. The aim was to indicate possible avenues of intervention to existing farmers. Our study sought to identify the diversity of clove based cropping systems from a quantitative typology constructed using cluster analyses. It was our assumption that it would be possible to disassociate the relevant types based on the overall structure of the tree stands, its clove trees composition, as well as the species diversity of the associated trees. We analysed the correspondence of the structural types thus defined, considering, on the one hand, the species composition of the associated trees describing their uses, and on the other, the agricultural uses of the lower stratum. Finally, we described the evolutionary patterns that emerged from a comparative analysis of types according to the age composition of the relevant clove tree stand.

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[1] Currently, Madagascar is the second largest producer of cloves and clove essential oil after Indonesia, and the first world exporter since the 1990s (Danthu et al., 2014; Danthu et al., 2020). Clove represented on average 7.3% of the value of total exports from Madagascar over the period 2007/2012 (Danthu et al., 2014). While agricultural products are Madagascar's first export item, since 2000, the place of first Malagasy agricultural product exported has been occupied alternately by vanilla or clove depending on world prices; due to its very high price, vanilla has been number one since 2015 (Gouzien et al., 2016; FAOStat, 2020).

## 2. Context

Clove trees, which originate from the Molucas, also known as the Spice Islands, in eastern Indonesia, are currently grown and farmed all along the east coast of Madagascar, concentrated in the *Analanjirofo* region in Taomasina Province. In this region, our study concentrated on the coastal lowlands of Fenerive-Est (Fenoarivo Atsinanana) (17°N, 49°E), where the clove tree was introduced in the early twentieth century at the start of French colonisation, following its acclimation and its extension on the Ile Sainte Marie, a little before the 1830s (Leroy, 1946).

The climate is humid subtropical without a marked dry season. Average annual rainfall reaches 2700 mm and the average temperature 24°C. Located in an inter-tropical convergence zone, it experiences unstable, rainy conditions from January to March, causing cyclones of variable intensity. The landforms are hilly with elevations ranging from 50 to 600 m altitude, standing on an ensemble of hard metamorphosed sedimentary rock, on an igneous basement (Serpantié et al., 2007). Soils are mainly ferralitic, desaturated and highly eroded on hill slopes (tanety), while in the lowlands the soils are hydromorphic, formed by a diversity of colluvial deposits. From the 17$^{th}$ century, the primal forest appears already to have been receding, supplanted by the *savoka* (regrowth of vegetation that develops after slash and burn as secondary forest), dominating the landscape (Kiener, 1963; Dandoy, 1973). A rare coastal shelter to the north of Tamatave and a historical commercial exchange zone with Alaotra Lake, the area is a densely populated and long-established settlement (Dandoy, 1973). The district of Fenerive-Est had a population density in 2009 estimated at 273 inhabitants per km$^2$, more than twice as much as the regional average (124 inhabitants per km$^2$) (INSTAT and ICF Macro, 2010). The population is homogeneous, for the most part of Betsimisaraka ethnicity.

In the past, agriculture was based on a system of hillside slash-and-burn (tavy), based on rainfed rice cultivation, flooded rice cultivation in the lowlands, and zebu breeding. Perennial crops for export were introduced and developed by the French settlers, starting with coffee trees (*Coffea canephora*) and then clove trees. More robust than coffee trees, which were confined to the lower slopes, grown in shade and then wiped out by disease, clove trees also benefited from a higher value for their products on the global market. From the 1930s, they progressively gained ground in all the non-flooded areas, supplanting coffee plantations and dominating the landscape from the 1980s (Dandoy, 1973; Danthu et al., 2014). The current clove plots come from a few monospecific colonial plantations, which have since been dismantled and redistributed, as well as from plantations of indigenous populations established from seeds or seedlings brought back by the men employed in the clove plantations on Sainte Marie Island. Promoted by the colonial administration, clove trees spread in gardens close to the houses, in shaded coffee plantations at the bottom of the slopes, on hillsides in the *savoka*, all without any external chemical input. This extension of the clove plantations, accompanied by a strong population growth multiplied by ten between 1955 and 2009 (CEMUBAC, 1967), reshaped profoundly the local agrarian system. We observed indeed the virtual disappearance of forest areas, the eradication of the slash-and-burn system and consequently of the areas devoted to rainfed rice in rotation with long-term fallow, the reduction of grazed areas, and finally the saturation of the lowlands occupied by irrigated rice in a more or less controlled manner (Lobietti, 2013). An average farm consisted of a family of four people farming 2.5 hectares (maximum 5 ha) including 0.35 ha of irrigated rice fields (maximum 2 ha), owned 2 zebus and 154 clove trees (Fourcin, 2014). The sale of clove tree products became the main source of income for the area's farmers (Fourcin, 2014).

Since the 1980s, clove growing was disrupted in a number of ways. Plantations were destroyed by the passing of successive cyclones, as well as the development of *andretra* (lepidoptera *Chrysotypus mabilianum* Viette) (Dubois and Ranaivosoa, 1966), a clove tree miner against which farmers have no means of control. At the same time, farmers were confronted with the volatility of world prices for cloves and essential oil, adding to the interannual variability in clove production observed in Madagascar (Maistre, 1964). In addition, the acreage of farms continued to decrease due to the land fragmentation through inheritance. Among the major adaptations was the increasing share of essential oil in farmers' income, product of the distillation of the leaves in artisanal stills which were multiplied from 1965 onwards (Dandoy, 1973). But it was not the only one. We hypothesized in this article that because of this agrarian history, which placed the clove tree as the first cash crop in the region, the clove based cropping systems are diverse and diversified, making it possible to reconcile several functions at plot level through original combinations of trees and crops.

## 3. Material and methods

### *3.1. Study site and sampling*

The study was carried out in two villages (fokontany) of Fenerive-Est district: Ambodihazinina, in the rural commune of Ambatoharanana, and Mahavanona in the rural commune of Ambodimanga II. We travelled through the areas of the selected villages using transects to cover all types of land use. We interviewed different ‘key persons’ (the village chief, the oldest farmers) to characterize the diversity of existing clove systems (age of clove trees, diversity of structures and species compositions of associated trees). We then selected thirty plots belonging to different farmers to represent this plot diversity. In each plot, a quadrat of 1024 $m^2$ (32 m x 32 m) - as homogeneous and representative of the plot as possible in terms of the clove stand and associated tree communities - was established.

### *3.2. Collected data*

We used the classic agroforestry system characterization indicators described by Sonwa et al. (2017). In order to adapt our analysis for systems with a potentially cultivable lower stratum, we completed them with indicators measuring *in situ* the rate of soil cover by tree crowns (Jennings et al., 1999).

### *3.2.1. Characterization of the structures of clove systems and their tree species compositions*

All non-clove trees (and assimilated) with a trunk diameter greater than five cm were inventoried. Species were identified (vernacular and scientific names), if necessary by comparison with reference specimens from the Malagasy national herbariums TAN (Botanical and Zoological Park of Tsimbazaza, Antananarivo) and TEF (Forest and Fish Research Department of FOFIFA, Antananarivo). On the basis of the work of botanists (Perrier de la Bâthie, 1931-1932; Decary, 1963), the origin of tree species was specified according to the two following classes: native for endemic (exclusively Malagasy) and indigenous (with an area of presence extending beyond Madagascar) species; exotic for introduced species. Forest tree species were distinguished from fruit tree species, according to the main use of tree products reported by the farmers surveyed. The degree of biodiversity of clove systems was estimated from the diversity of associated tree species in the systems. This was done by combining primary data such as species composition of the systems and different metrics i.e. species richness (number of different species), the relative abundance of each species (the numerical importance of individuals of a species relative to the total number of individuals, expressed as a percentage) and the Shannon-Wiener index (Krebs, 1985; Santini et al., 2017). The basal area of each associated tree, i.e. its cross-section, was calculated on the basis of the trunk diameter at breast height (DBH), at 1.3 m for adult trees and 0.5 m height for juvenile trees. Identical measurements were carried out on clove trees more than three years old. For multi-stem trees (coffee and clove trees), all trunks were taken into account. The total basal area of a stand is the sum of the basal areas of all individuals in the stand. The canopy height of clove and associated trees was measured using an 8 m long graduated pole and a dendrometer for larger trees. The projection range of a tree was calculated by measuring the diameter of its crown in two perpendicular directions from a place vertical to the deciduous crown boundary. The projection range of the crown of the tree was estimated by calculating the area of the ellipsoid corresponding to the two axes. For a plot, the rate of soil cover by tree crowns (clove and associated trees), expressed as a percentage, is the ratio of the plot area to the sum of the crown projection ranges of each inventoried tree (Nouvellet et al., 2006).

*3.2.2. Determination of ages of clove plots and clove trees*

The age of the clove plots, determined according to the year in which the first clove trees were planted, was estimated roughly by interviewing farmers. In the light of the difficulty in obtaining accurate information regarding the age of the older clove trees in the stand, we simply distinguished, through questioning, the clove trees aged over 15 years from those between 3 and 15 years. We continued the analysis using DBH of clove tree trunks, concentrating on the largest trunk for multi-stemmed individuals, which account for 33.3% of the clove trees in our entire sample. This was the variable we selected as the age indicator of the clove trees in the stand. A data set produced by the *Centre technique horticole de Tamatave* (CTHT) indicating the DBH of forty clove trees aged between 6 and 50 years, completed by Arimalala et al. (2019) in the same study zone as our own, enabled us to obtain a correspondence between four classes of DBH and four classes of clove tree age. These turned out to be compatible with our study results on clove trees of less than 15 years (table 1). For each plot, we calculated the distribution in percentage of cloves trees in the four classes of DBH defined in this manner.

*3.2.3. Characterization of the agricultural uses of the lower stratum*

Individuals of semiperennial cultivated species were counted. The presence of annual species was recorded and grazing practices were studied.

This data was gathered during 2013 and 2014.

*3.3. Surveys of farmers*

From interviews with thirty owner-farmers, it was possible to ascertain the management practices of clove plots and their variations over time, as well as the uses of trees and crops in association with the clove trees. The interview process took place between 2013 and 2016.

*3.4. Statistical analysis*

The approaches we used to build the typology combined multivariate analysis and cluster analysis applied to similar systems (Deheuvels et al., 2012). We first carried out a principal component analysis (PCA) based, on the one hand, on the structure of the tree vegetation, distinguishing the relative importance and the age of the clove stand, and, on the other hand, on the species diversity of the associated trees. A hierarchical clustering was subsequently performed on the first two principal components, defining our types of clove based cropping systems (Husson et al., 2010).

The characteristics of the types of clove systems defined thus were compared using analysis of variance (ANOVA), to which we submitted the measured variables according to a normal distribution. In the case where a significant difference was highlighted by the Fisher test (at $p < 5\%$), Tukey's HSD test was used. In the other cases, we used the Kruskal-Wallis test, followed by Dunn's multiple comparison with p-values adjusted by the Benjamini-Hochberg method.

All statistical analyses were performed using R software (version 3.5.0, 2018).

## 4. Results

### 4.1. *Characterization of clove based cropping systems : multistrate, rich in tree species and providing a diversity of products*

From our sample of thirty plots, we identified 595 clove tree individuals and 463 associated tree individuals. On average, the clove trees were 3.8 m high (the highest was 7.8 m), with a crown of 3.4 m in diameter. Associated trees averaged 5.1 m in height and had a crown of 3 m in diameter. Few of the associated trees measured were taller than 8 m, allowing them to outweigh the clove trees. These included individuals of the species *Mangifera indica* (some reaching 25 m in height), *Albizia chinensis*, *Artocarpus heterophyllus*, *Cocos nucifera*, *Grevillea banksii*, *Harungana madagascariensis*, *Eucalyptus robusta*, *Litchi chinensis*, *Nephelium lappaceum* and *Artocarpus altilis*.

Within the entire sample of plots, we identified 41 different associated tree species, of which 5 remained undetermined, designated only by their vernacular name (table 2). Of these 41 species, 68.3% were forest species, but the count of associated trees individuals showed that 56.2% of the trees present were fruit species. The five species the most highly represented of the trees inventoried were in decreasing order: *Coffea canephora, Mangifera indica*, *Grevillea banksii*, *Bombacopsis glabra*, then in equal numbers, *Cocos nucifera* and *Artocarpus heterophyllus* (figure 1). Although *Litchi chinensis* trees were well valorized by the sale of fruit, partly for export, they were only the 15th most common tree in our sample. Conversely, the coffee trees (*Coffea canephora*), which made up the greatest proportion of the trees associated with the clove trees, were no longer planted but renewed from preserved offshoots. Coffee production was not well valorized, mainly exploited for personal consumption, as were mangoes.

Under the clove and associated trees, we found plants of the local bamboo species (*Nastus capitatus*) used as firewood and building materials, banana stems (*Musa paradisiaca*), pineapple plants (*Ananas comosus*) and sugar cane (*Saccharum officinarum*), basis of traditional alcoholic drinks. We also found vanilla lianas (*Vanilla planifolia*), using as supports trees *Bombacapsis glabra, Dracaena reflexa, Erythroxylum ferrugineum* and also *Phylloxylon xylophylloides.* Within this lower stratum, it was also possible to find rainfed rice alternating between cassava and fallow periods of 1 to 3 years, fallow which the farmers often used for grazing their zebu herds.

## *4.2. Determination of six types of clove based cropping system*

### *4.2.1. A quantitative structural typology*

To build the typology, five explanatory variables were chosen: total tree density (clove and associated trees) (dT), Shannon-Wiener index (SI), total basal area of tree stands (clove and associated trees) (baT), share of clove trees in the total basal area of tree stands (pCba) and finally mean basal area of each clove tree (mbaC). Added to which was one illustrative variable: the share of clove trees between 5 and 15 years old (pCag). This variable allowed us to separate the young plots from the others, comprising more than 85 % of the clove trees aged under 15 years.

The first two dimensions from the PCA expressed 79.45% of the total inertia (figure 2a). The variable which contributed the most to axis 1 was the share of clove trees in the total basal area of tree stands (pCba). Amongst the other variables which contributed distinctly to this axis, we found the total tree density (dT) and the Shannon index (SI), correlated negatively to the mean basal area of each clove tree (mbaC); therefore, axis 1 also brought the plots into contrast according to their species diversity. The variable which contributed the most to axis two was the total basal area of tree stands (baT).

Structured around these two axes, the factorial plan divided into four parts corresponding to the four main systems identified: system A ‘clove agroforestry system’(7 plots), with significant development of the trees present, rich in associated tree species but fairly poor in clove trees; system B ‘diversified clove parkland’ (7 plots), with low tree development, a diversity of associated tree species and a fairly low clove component; system C ‘simple clove parkland’ (9 plots), with low tree development, few associated tree species and a high clove component; and finally system D ‘clove plantation’ (7 plots), with high tree development dominated by clove trees (figure 2b).

Distinguishing the young clove trees enabled us to extract a YA type (plots 15, 18, 26) from system A, and a YB type (plots 19, 21, 24, 30) from system B, allowing us to establish six different types.

#### *4.2.2. Correspondence between structural types, species composition of associated trees and growth status of clove trees*

The rate of soil cover by the crowns of clove and associated trees showed significant differences between the six defined types, with the 'parkland' types (B, YB and C) presenting the lowest values (table 3). The coverage rate of the crowns determines the amount of light that filters through to the soil, which therefore has an impact on the potential agricultural uses for the lower stratum. Indeed, rice and cassava crops were observed only in types B and C, with the exception of YB, 'young diversified clove parkland' (table 4).

Where the species composition of associated trees was concerned, there were significant differences between the types in terms of numbers of fruit and forest trees (table 3). Indeed, the analysis of species present and their representative numbers in the associated tree stand illustrated the existence of marked differences between the types (figure 1, table 2 and table 4). In particular, a fruit component similar to the forest component was observed in types A 'agroforestry system' and C 'simple clove parkland', while fruit trees dominated in the other types, in the exception of type YB 'young diversified clove parkland' where forest trees prevailed.

Regarding the clove tree stand, the mean basal area per individual clove tree presented significant inter-type differences (table 3). The percentage distribution of clove trees according to the four classes of DBH was indeed quite different according to the types of systems (table 4): the more the system had a large clove component, the more the high DBH category was represented, indicating the presence of older individuals.

We will now describe the elements by clove system type, assembling all their components.

### *4.3. Characterization of each type of clove based cropping system*

#### *4.3.1. 'Clove agroforestry system' type A*

Type A consisted of plots which were characterized by a total high density of trees per hectare (cloves and associated trees), significantly higher than other types (table 3). This raised value came firstly from the associated trees, the density of which was the highest of all types; the density of clove trees was intermediary. This high representation of numbers of individuals of associated trees was expressed by a significantly greater Shannon index than the others, which went hand in hand with a greater number of species per plot than the others types. Within the tree stands, the mean basal area of each clove tree had an intermediary value and the mean basal area of each associated tree was statistically similar to that of the other types. It was expressed by an intermediary total basal area of tree stands per hectare in comparison to other types, with an equally intermediary share of clove trees. The basal aera of the associated tree stand was significantly higher than that of the other types.

The number of associated fruit trees were virtually equivalent to the number of forest trees (table 4).

The three species the most highly represented of the trees inventoried were in decreasing order: *Bombacopsis glabra, Artocarpus heterophyllus* and *Streblus dimepate* (table 2*)*.

In accordance with the significantly raised soil coverage rate by the crowns of the associated trees and cloves trees (table 3), valorization of the lower stratum was not recorded in plots of this type (table 4). However, a high presence of vanilla lianas was observed, using the trunks of *Bombacopsis glabra* as supports.

Regarding the clove trees, they were primarily found in the category DBH<15 cm (47.8% of individuals), and in the category 20 cm<DBH<29 cm (26.9% of individuals) (table 4), indicating a relatively young clove tree stand.

#### *4.3.2. 'Young clove agroforestry system' type YA*

Young plots of type A presented similar characteristics to type A plots. Consistent with their young age, these plots distinguished themselves by the mean basal area of the clove tree individuals, which was among the lowest of all types. The share of clove trees in the total basal area of tree stands per hectare was therefore lower.

Moreover, in this system type, the population of associated trees consisted primarily of fruit trees with a frequency of 68%. The three species the most highly represented of the trees inventoried were in decreasing order: *Coffea canephora, Mangifera indica* and *Cocos nucifera*, all three fruit species. The most represented forest species was *Afzelia bijuga*, in 4$^{th}$ position.

As with type A plots, the soil coverage rate of associated and clove trees crowns was distinctly high, significantly higher than the other types. Accordingly, in the lower stratum of this type of plot only a few bamboo stems and bananas trees were present.

#### *4.3.3. 'Diversified clove parkland' type B*

Type B encompassed plots with a low total density of trees per hectare. This combined the significantly lowest density of clove trees of all the types with an intermediary density of the associated trees. The Shannon index and the number of species of associated trees per plot were fairly high, identical to the plots of type YA, slightly lower than those of type A. The mean basal area of clove tree individuals was fairly low, identical to plots of type A. The mean basal area of each associated tree was on average very low, without a significant difference. The total basal area per hectare of the resulting tree stands was among the lowest of all types, with an intermediary share of clove trees.

In this type of plot, the fruit trees dominated the associated trees stand, with a frequency of 64.2%. But the forest species were also well represented. The three species the most highly represented of the trees inventoried were in decreasing order: *Nephelium lappaceum*, *Ficus tiliifolia*, then in equal numbers *Cocos nucifera*, *Coffea canephora* and *Albizia chinensis* (table 2).

Consistent with a low to intermediary soil coverage rate by the crowns of all the trees, the lower stratum was observed to be well valorized in these plots. Rice, cassava, pastured fallows, as well as banana trees, sugar cane and even vanilla lianas were grown.

Where the clove trees were concerned, they were found mostly in the category 20 cm<DBH<29 cm (43.2% of individuals) then in the category DBH<15 cm (35.4% of individuals), which revealed individuals of a young age, fairly close to that observed in type A plots.

#### *4.3.4. 'Young diversified clove parkland' type YB*

The young plots extracted from type B presented similar characteristics to the plots of this type, with a nonetheless greater clove tree density of intermediary value in relation to the other types. In the same manner as type YA, they were distinguishable by their low mean basal area of the clove tree individuals. The share of clove trees in an already low total basal area of tree stands per hectare was therefore lower.

The plots of this type were distinguishable by the forest trees which predominated the associated tree stand with a high frequency of 72.2%. The three species the most highly represented of the trees inventoried were *Grevillea banksii,* followed by *Harungana madagascariensis*, and then in equal numbers *Mangifera indica* and *Artocarpus altilis*.

In the same manner as plots of type B, the soil coverage rate by the crowns of all the trees was low to intermediate in these plots. However, the lower stratum was not greatly exploited, to avoid damaging the young clove trees; only a few pineapple plants were observed, serving as protection and as a barrier against grazing.

#### *4.3.5. 'Simple clove parkland' type C*

Type C consisted of plots with a total density of trees per hectare (clove and associated trees) that was significantly the lowest of all types. It combined a density of associated trees which was also significantly the lowest of all types, with an intermediary clove tree density value. Correspondingly, the Shannon index and the number of tree species per plot were significantly the lowest of all the types. The mean basal area of the clove tree individuals was significantly one of the highest. Within the plots with the lowest total basal area of tree stands per hectare, similar to type B, the share of clove trees was among the highest.

The number of associated fruit trees were virtually equivalent to the number of forest trees. The three species the most highly represented of the trees inventoried were *Coffea canephora* in greatest numbers, followed by *Citrus reticulata* and *Ravenala madagascariensis*.

Consistent with a significantly low soil coverage rate by crowns of clove and associated trees, a high valorization of the lower stratum was observed with crops of rice and cassava, as well as cattle grazing. Bamboo stems were also observed.

Regarding the clove trees, they were primarily within the higher DBH categories between 20 and 29 cm (43.2% of individuals) then > 29cm (27.4%), indicating older individuals. Clove trees younger than 15 years were nevertheless well represented (21.3%).

#### *4.3.6. 'Clove plantation' type D*

Type D consisted of plots with a total density of trees per hectare of an intermediary value comparable with the other types. These combined the significantly highest density of clove trees of all the types, with a density of associated trees of intermediate value. The Shannon index and the number of tree species per plot were in the low range of an intermediate level. The mean basal area of clove tree individuals was among the highest of all types, identical to type C plots. The mean basal area of the associated trees was higher on average relative to the others, showing no significant difference. The total basal area per hectare of the resulting tree stands was significantly the highest of all types, with a share of clove trees among the highest, similar to type C plots.

Fruit trees dominated the stand of associated trees of this plot type with a frequency observed at 67.5%. The three most represented associated tree species in terms of number of individuals inventoried were *Coffea canephora* the most dominant, then *Cinnamomum verum* and *Mangifera indica.* The mangoes observed were old, isolated individuals, of a large mean basal area; coffee and cinnamon trees, however, were small in size but large in number, a sign in the case of cinnamon of a major exploitation.

The soil coverage rate of the crowns of all trees was of intermediary value. Valorization of the lower stratum was not observed.

Where the clove trees were concerned, distribution within the categories of DBH was observed to be fairly close to that of type C: 37.5% between 20 and 29 cm, 24.1% over 29 cm, and 28.7% of clove trees were under 15 years.

# 5. **Discussion**

## *5.1. Species diversity and agricultural uses of clove systems*

As a consequence of the species diversity of their vegetation, the clove based cropping systems characterised here fulfil a number of functions. In fact, they serve several local and export sectors (cloves, essential oils of clove and cinnamon, bark of cinnamon, coffee, vanilla, lychee), produce fruit, some of which are key foodstuffs (jack fruit and bread fruit), firewood, softwood timber, building materials for housing; rice and cassava; or forage...While in terms of income, the sale of clove products are the economic mainstay of the farmers (>50% of total income), who juggle with one or other of the products according to price, the conditions of that year's production and budgetary needs, the other derivatives from the clove plots, nonetheless, fulfil an important adjustment role (Lobietti, 2013; Fourcin, 2014; Mariel, 2016). As for the zebu that graze under the clove trees, they constitute agricultural savings (Fourcin, 2014). These systems also provide a variety of ecosystemic services, such as the conservation of tree species. The agricultural productions are managed without chemical fertilisers or phytosanitary products. The type B system ‘diversified clove parkland’, characterized by a low density of clove trees, is the one capable of accommodating the greatest number of functions, combining species diversity of trees and diversity of uses of the lower stratum.

Particular consideration should be given to the biomass energy these systems supply for operating the stills required for the development of the clove essential oil sector, a big consumer of firewood (Simanjuntak, 2014; Rougier, 2015). When considering all the components of clove based cropping systems, including bamboo and sugar cane, they can represent a major source of biomass energy.

### *5.2. Coexistence of different types of clove system*

At the village level, a mosaic of different identified clove system types could be observed. Village-scale studies at several sites in the Analanjirofo region, (in particular, in the rural commune of Ambatoharanana, which is part of our study), showed that this mosaic of systems exists everywhere, and that within them types B and C 'diversified or simple clove parkland' predominate (Michels et al., 2011; Herimandimby, 2014; Leydet, 2015; Mariel, 2016). The key to the spatial distribution of the different systems remains unknown, not independent of the characteristics of the physical environment, amongst them cyclone paths.

This diversity of clove systems can be found at the level of farms, as confirmed by Lobietti (2013) and Fourcin (2014). At this level, the combination of different types of systems is tied in, but not exclusively so, with the history of each plot inherited. The structure of the clove based cropping systems is influenced in equal measure by other factors including the size of the exploited rainfed area, the area of flooded rice fields and the size of the zebu herd. Type A 'clove agroforestry system' was practised by those farmers who either had access to a lot of agricultural land (≥ 3 ha in rainfall), combining it with other types of clove systems, or else those who had access to little land, choosing to diversify tree species (fruit trees, in particular) within a constricted area. In case of low availability of flooded rice fields (<0.2 ha), farmers gave priority to types B and C 'diversified or simple clove parkland', allowing the growing of rainfed rice in the lower stratum despite very low productivity (Fourcin 2014); grazing needs played a similar role.

In a context where the surface area of farms tends to decrease with inheritance, types A, and especially B and C should develop.

### 5.3. *Temporal dynamics*

It was evident from questioning farmers that remodelling was possible. The trends that emerged from our enquiries inclined towards a reduction in the density of clove trees over time in the oldest of inherited plots, transforming type D plots ‘clove plantations’ into type C ‘simple clove parkland’. These trends corresponded to the clove trees distribution observed in the different categories of DBH according to clove system types (table 4). In fact, the most developed of the clove trees, therefore the oldest, were highly represented in type C ‘simple clove parkland’ plots and D ‘clove plantations’, indicating that these plots would have been established prior to the 1960s. Type D plots ‘clove plantation’ would be old plantations maintained by progressive renewal of the clove trees, as shown by the presence of a substantial number of young clove tree individuals in the stands (table 4). Type C plots ‘simple clove parkland’ would have emerged from old type D ‘clove plantations’ in which the destroyed or ageing clove trees would not have been replaced, leaving room to introduce bamboo plants, annual crops or grazing. This dynamic follows on from the conclusions of Arimalala et al. (2019). It corresponds also to the data from earlier publications indicating that clove plantations in the 1950s presented densities exceeding 250 clove trees per hectare (Maistre, 1955), which corresponds to the current average density of our type D system (263.7 clove trees per hectare).

The distribution of clove trees in the categories of DBH of type A’clove agroforestry’ plots and B ‘diversified clove parkland’ would suggest that these systems are more recent. Therefore, the recently created plots (< 15 years) were only found in these two types. Yet according to what the farmers said and what we found, these plots are not necessarily intended to remain this way, notably the type YB ‘young diversified clove parkland’ plots. As a matter of fact, these were highly composed of established *Grevillea banksia* trees, a fastgrowing forest species used in the past for shading coffee plantations, destined to be cut down once the clove trees reach maturity and become less sensitive to light. Enriched with fruit trees, these plots may remain type B plots or shift towards type C 'simple clove parkland'. In the same way, plots of type YA 'young clove agroforestry systems' may become plots of type B 'diversified clove parkland'. None of the type D plots 'clove plantation' are likely to be reproduced.

Figure 3 represents the different transitions possible between the different clove systems. Our results showed a double dynamic, articulating a spatial extension of clove trees with a decrease in clove tree densities per unit area, both by the loss of clove trees in old plots and by the creation of newer systems with fewer clove trees per area (types A and B). This regression in clove tree densities in the systems was accompanied by the integration of different associated plant species, either strictly tree based and high density (type A), or creating opportunities for crops in the spaces remaining between the trees (types B and C). The young plantations encountered were all rich in associated tree species.

Our results also demonstrated that clove trees aged between 5 and 15 years could be found in all the clove system types, in varying proportions (table 4). This allows for progressive renewal of the clove tree stand. The farmers achieve this mainly by transplanting the regrowths that arise from fruits that have dropped from clove trees, studied by Leydet (2015). Conversely, the presence of large, and therefore old clove trees, in all the clove system types demonstrates that it has been possible to build young plots in place of the old ones after they have been destroyed, mainly by cyclones, which tallies with what the farmers report.

### *5.4. Typology criteria*

The clove systems studied cover a large panoply of agroforestry systems, ranging from, on the one hand, complex systems close to the cocoa based systems described, for instance, in Cameroon by Sonwa et al. (2017), Jagoret et al. (2011, 2018) and in Costa Rica by Deheuvels et al. (2012); on the other, near monospecific orchards; through cropped tree parklands or pastures, similar to the agroforestry parklands in Sub-saharan Africa (Boffa, 1999; Smektala et al., 2005). Focusing on the most complex clove systems, the mean Shannon index measured for type A, i.e. two (table 3), is lower than the value obtained by Jagoret et al. (2011) for complex cocoa agroforests in Cameroon with similar methods, i.e. 2.64; while the mean tree species richness of type A, i.e. 11.3, is quite close to the value found in Cameroon by Jagoret et al. (2018), i.e. 10. However, the average measured total basal area of tree stands for type A, i.e. 13.7 $m^2 ha^{-1}$, with a clove share of 50.1%, is much lower than that obtained in Cameroon, i.e. 26.4 $m^2 ha^{-1}$, with a cocoa share of 33.5% (Jagoret et al., 2018), showing that the cummunities of trees concerned in the two situations are quite different.

The indicators chosen to differentiate the types of clove system appear relevant. Each type defined corresponds effectively to an array of associated tree species and specific uses of the lower stratum. We are therefore in a position where we could assess the productivity of each type, provided that we knew the level of production of each component, which is not the case. The level of production of clove trees (cloves and essential oil), of associated trees and crops, should effectively be studied, and according to each identified system. The interactions between associated plant species and their impact on the agricultural performance of these systems should be analysed. The analysis of the correspondence between age, DBH and level of production of clove trees should be pursued, distinguishing between types of systems and methods of technical management of clove trees.

## 6. Conclusion

The clove tree is the pillar of a variety of systems and dynamics created by the farmers over time, tailored to suit their situations and objectives. The trend observed is at once, a spatial extension of the clove trees, a decline in clove tree densities per unit area, an integration of different types of associated plant species and a diversification of the uses and functions of the planted areas. Farmers have thus achieved a diversification of clove systems at village, farm and plot scales. The demographic context of the region, which reduces the surface area of farms over successive inheritances, is inclined to encourage a diversity of species and uses to the detriment of the clove tree component. As long as new space remains, the loss of clove tree density in the systems can be compensated for at the village scale. But this spatial extension is already reaching its limits. At the current time, clove production is inseparable from the diversified and multifunctional systems that integrate it, and any intervention to improve it should be designed within the framework of these systems. The other components of these systems must also be the subject of research and intervention with farmers: there is a great deal of room for improvement in the production of fruits, rainfed rice and fodder resources. Better valorisation of all the products derived from these systems also offers other possible avenues of intervention, not forgetting the tree species conservation service. Particular attention should be given to the production of biomass energy from these diversified systems, a crucial resource to support the development of the clove essential oil sector.

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**References**

Arimalala N., Penot E., Michels T., Rakotoarimanana V., Michel I., Ravaomanalina H., Roger E., Jahiel M., Leong Pock Tsy J.M., Danthu P**.,** 2019. Clove based cropping systems on the east coast of Madagascar: how history leaves its mark on the landscape. *Agroforestry systems* 93 (4), 1577-1592. https://doi.org/10.1007/s10457-018-0268-9

Boffa J.M., 1999. Agroforestry parklands in sub-Saharan Africa. *Cahier FAO Conservation* 34, FAO, Rome, 230 p.

Centre scientifique et médical de l'Université libre de Bruxelles (CEMUBAC), 1967. *Madagascar : cartes de densité et de localisation de la population*. Sous la direction de Gourou P., CEMUBAC, ORSTOM, 28 p., tabl., cartes. https://docplayer.fr/42452088-Madagascar-cartes-de-densite-et-de-localisation-de-la-population-etablies-par-le-sous-la-direction-de-pierre-gourou.html

Dandoy G., 1973. *Terroir et économie villageoise de la région de Vavatenina (Côte orientale malgache).* Paris : ORSTOM, 95 p. (Atlas des Structures Agraires à Madagascar). http://www.documentation.ird.fr/hor/fdi:06660

Danthu P., Penot E., Ranoarosoa K.M., Rakotondravelo J.C., Michel I., Tiollier M., Michels T., Normand F., Razafimamonjison G., Fawbush F., Jahiel M., 2014. The clove tree of Madagascar: a success story with an impredictable future. *Bois et forêts des tropiques* 320 (2), 83-96. http://bft.cirad.fr/revues/notice_fr.php?dk=574435

Danthu P., Simanjuntak R., Fawbush F., Leong Pock Tsy J.M., Razafimamonjison G., Abdillahi M.M., Jahiel M., Penot E., 2020. The clove tree and its products (clove bud, clove oil, eugenol): prosperous today but what of tomorrow's restrictions? *Fruits* 75 (5), 224–242. https://doi.org/10.17660/th2020/75.5.5

Decary R., 1963. Plantes introduites à Madagascar et toponymie. *Journal d'Agriculture et de Botanique Appliquée* 10, 204-218. https://doi.org/10.3406/jatba.1963.2706

Deheuvels O., Avelino J., Somarriba E., Eric Malezieux E., 2012. Vegetation structure and productivity in cocoa-based agroforestry systems in Talamanca, Costa Rica. *Agriculture, Ecosystems and Environment* 149, 181– 188. http://doi.org/10.1016/j.agee.2011.03.003

Dubois J., Ranaivosoa H., 1966. *Chrysotypus mabilianum* Viette, chenille mineuse du giroflier (*Andretra*)—biologie et lutte mécanique. *L'Agronomie Trop* 21, 823–836.

FAOStat., 2020. Food and agriculture data. http://www.fao.org/faostat/en/#home (accessed October 27, 2020).

Fourcin C., 2014. *Contribution du giroflier à la sécurité alimentaire des ménages agricoles* *dans la région de Fénérive-Est, Madagascar. Modélisation économique et analyse prospective*. Montpellier SupAgro, Montpellier (France), Mémoire de fin d'études, 153 p. **https://web.supagro.inra.fr/pmb/opac_css/index.php?lvl=notice_display&id=89995**

Gouzien Q., Penot E., Jahiel M., Danthu P., 2016. *Le Girofle : poids dans l'économie malgache et place de Madagascar dans le marché mondial.* Document de travail AFS4FOOD 18. 17 p. http://agritrop.cirad.fr/582468

Herimandimby H., 2014. *Organisation spatiale et évolution en 50 ans des girofliers de la côte est malgache, dans la commune Ambatoharanana Région Analanjirofo, District de Fénérive-Est*. Mémoire de fin d'études, Master Géosphère, Université de la Réunion, 53 p.

Husson F., Josse J., Pagès J., 2010. *Principal component methods – hierarchical clustering - partitional clustering: why would we need to choose for visualizing data?* Technical Report, Agro Campus Ouest, 17 p. http://www.agrocampus-ouest.fr/math

Institut National de la Statistique (INSTAT) et ICF Macro, 2010. *Enquête démographique et de santé à Madagascar 2008-2009*. Antananarivo, Madagascar : INSTAT et ICF Macro, 280 p. http://instat.mg

Jagoret, P., Michel-Dounias, I., Malézieux, E., 2011. Long-term dynamics of cocoa agroforests: a case study in central Cameroon. *Agrofor. Syst*. 81 (3), 267–278. https://doi.org/10.1007/s10457-010-9368-x

Jagoret P., Todem Ngnogue H., Malézieux E., Michel I., 2018. Trajectories of cocoa agroforests and their drivers over time: lessons from the Cameroonian experience. *European journal of agronomy* 101, 183-192. https://doi.org/10.1016/j.eja.2018.09.007

Jennings S., Brown N., Sheil D., 1999. Assessing forest canopies and understorey illumination: canopy closure, canopy cover and other measures. *Forestry* 71 (1), 59-73. https://doi.org/10.1093/forestry/72.1.59

Kiener A., 1963. Le « tavy » à Madagascar. *Bois et Forêts des Tropiques* 90, 9-16. https://doi.org/10.19182/bft1963.90.a18888

Krebs C.J., 1985. Species diversity. In: Krebs CJ (ed) *Ecology: the experimental analysis of distribution and abundance.* Harper and Row, New York, 507–534.

Leroy J.F., 1946. Le Giroflier et les Plantes à parfums. *Rev. Int. Bot. Appliquée Agric. Trop*. 26, 425–429. https://doi.org/10.3406/jatba.1946.1984

Leydet C., 2015. *Evaluation de la dynamique de plantation/replantation en girofliers par les petits producteurs malgaches*. Montpellier SupAgro, Montpellier (France), Mémoire de fin d'études, 120 p. **https://web.supagro.inra.fr/pmb/opac_css/index.php?lvl=notice_display&id=91508**

Lobietti M., 2013. *Analyse des systèmes girofliers à Fénérive-Est, Madagascar : dynamiques spatiales, trajectoires et stratégies paysannes*. Montpellier SupAgro, Montpellier (France), Mémoire de fin d'études, 114 p.

https://afs4food.cirad.fr/en/content/download/4454/33850/version/1/file/Lobietti%2C+syst+giroflier+Fenerive.pdf

Maistre J., 1955. Le giroflier à Madagascar et Zanzibar. *Agron Trop* 10, 413–448.

Maistre J., 1964. Le clou de girofle. *Les plantes à épices*. G.-P. Maisonneuve & Larose, Paris, 77–124.

Mariel J., 2016. *Analyse des systèmes agroforestiers du territoire de Vavatenina à Madagascar. Stratégies de mise en valeur, perceptions paysannes et résilience*. AgroParisTech, Montpellier (France), mémoire de fin d'études, 47 p. http://agritrop.cirad.fr/591617/1/Juliette_Mariel_Memoire_BioGET.pdf

Michels T., Bisson A., Ralaidovy V., Rabemananjar H., Jahiel M., Malézieux E., 2011. Horticultural agroforestry systems in the humid tropics: analysis of clove tree-based systems in Madagascar. *Acta Hortic* 894, 161–167. https://doi.org/10.17660/ActaHortic.2011.894.17

Nouvellet Y., Kassambara A., Besse F., 2006. Le parc à karités au Mali : inventaire, volume, houppier et production fruitière. *Bois et forêts des tropiques*, 287 (1), 5-20. https://agritrop.cirad.fr/530562/1/document_530562.pdf

Perrier de la Bâthie H., 1931-1932. Les plantes introduites à Madagascar. *Revue de Botanique Appliquée et d'Agriculture Coloniale* 121, 719-729; 122, 833-837; 123, 920-923; 124, 991-999; 125, 48-52; 126, 128-133; 127, 213-220; 128, 296-301; 129, 372-383; 130, 462-468; 131, 530-543.

Rougier C., 2015. *Impact environnemental de la collecte de bois de chauffe pour la production d'huile de girofle dans le district de Fénérive-Est, Madagascar*. AgroParisTech, Montpellier (France), mémoire de fin d'études, 98 p. https://infodoc.agroparistech.fr/index.php?lvl=notice_display&id=186707

Santini L., Belmaker J., Costello M.J., Pereira H.M., Rossberg A.G., Schipper A.M., Ceaușu S., Dornelas M., Hilbers J.P., Hortal J., Huijbregts M.A.J., Navarro L.M., Schiffers K.H., Visconti P., Rondinini C., 2017. Assessing the suitability of diversity metrics to detect biodiversity change. *Biological Conservation* 213, 341–350. http://dx.doi.org/10.1016/j.biocon.2016.08.024

Serpantié G., Toillier A., Carrière S., 2007. À l'est de Madagascar, le relief structure le paysage. In Serpantié G., Rasolofoharinoro, Carrière S. (éd. sc.) : *Transitions agraires, dynamiques écologiques et conservation : le « corridor » Ranomafana-Andringitra,* Madagascar, Paris, Ird-Cite, 17-26. http://horizon.documentation.ird.fr/exl-doc/pleins_textes/divers09-03/010042175.pdf

Simanjuntak R., 2014. *Analyse technico-économique de la filière amont de production d'essence de girofle à Fénérive-Est, Madagascar : de la feuille à l'alambic*. AgroCampusOuest, Angers (France), mémoire de fin d'études, 36 p. https://pdfs.semanticscholar.org/00f9/df42113c677f62234445cfd6d08153be48d1.pdf?_ga=2.87206480.956394070.1570450793-554854986.1570450793

Smektala G., Peltier R., Sibelet N., Leroy M., Manlay R., Njiti C.F., Ntoupka M., A. Njiemoun A., O. Palou et Tapsou, 2005. Parcs agroforestiers sahéliens : de la conservation à l'aménagement. *VertigO* Volume 6 Numéro 2. http://doi.org/10.4000/vertigo.4410

Sonwa D.J., Weise S.F., Nkongmeneck B.A., Tchatat M., Janssens M.J.J., 2017. Structure and composition of cocoa agroforests in the humid forest zone of Southern Cameroon. *Agroforestry systems* 91(3), 451-470. http://dx.doi.org/10.1007/s10457-016-9942-y

## Figure captions

**Figure 1.**

Number of associated trees (and assimilated) per species with relative abundance> 1% , and breakdown by type of clove system (30 plots, east coast of Madagascar)

A : clove agroforestry system ; YA : young clove agroforestry system ; B : diversified clove parkland ; YB : young diversified clove parkland ; C : simple clove parkland ; D : clove plantation.
*Ind* ( ) : undetermined species (*local name*)

**Figure 2.**

**(a)** Correlation plots of variables with PCA (30 plots, east coast of Madagascar)

Black : explanatory variables ; Blue : illustrative variable. dT : total tree density (clove and associated trees) trees ha-1 ; SI : Shannon-Wiener index ; baT : total basal area of tree stands (clove and associated trees) $m^2$ $ha^{-1}$ ; pCba : share of clove trees in the total basal area of tree stands % ; mbaC : mean basal area of each clove tree cm2 ; pCag : share of clove trees between 5 and 15 years old %.

**(b)** Identification of the four main clove systems (30 plots, east coast of Madagascar).

System A : clove agroforestry system ; System B : diversified clove parkland ; System C : simple clove parkland ; System D : clove plantation. Plots surrounded by a circle : share of clove trees between 5 and 15 years old > 85 %

**Figure 3.**

Figure 3. Average densities of different tree stands by type of clove system and possible transitions from one type to another (30 plots, east coast of Madagascar)

A : clove agroforestry system ; YA : young clove agroforestry system ; B : diversified clove parkland ; YB : young diversified clove parkland ; C : simple clove parkland ; D : clove plantation.

**Table 1**. Correspondence between clove trees ages and clove trunks DBH, based on data from CTHT and Arimalala et al. (2019) on the east coast of Madagascar

| DBH classes (cm) | Age classes (years) |
|---|---|
| < 15 | < 15 |
| [15 ; 20] | [15 ; 30] |
| ]20 ; 29[ | ]30 ; 50] |
| ≥ 29 | > 50 |

DBH : diameter at breast height

**Table 2**. Tree (and assimilated) species inventoried and relative abundance by type of clove system (%) (30 plots, east coast of Madagascar)

| Scientific name | Local name | Common name | Family | Group | Ori-gin | Local main uses | Types of clove system | | | | | | All plots |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | A (4) | YA (3) | B (3) | YB (4) | C (9) | D (7) | (30) |
| *Albizia chinensis* (Osbeck) Merr., 1916 | albizia | albizia | Fabaceae | FO | exotic | Firewood, shading | 1,6 | 3,9 | 9,4 | | 10,5 | 1,4 | 3,5 |
| *Albizia gummifera* (J.F.Gmel.) C.A.Sm., 1930 | sambalahy | fleur de paon | Fabaceae | FO | native | Firewood, shading | 1,6 | | | | | | 0,4 |
| *Albizia lebbeck* (L.) Benth., 1844 | bonara | bois noir | Fabaceae | FO | exotic | Firewood, shading, vanilla tutor | 4,1 | 3,9 | 1,9 | | 2,6 | | 2,4 |
| *Annona muricata* L., 1753 | voantsokina | corossolier | Annonaceae | FR | exotic | Self-consumed fruits | | | | 1,4 | | 4,1 | 0,9 |
| *Artocarpus altilis* (Parkinson) Fosberg, 1941 | soanambo | arbre à pain | Moraceae | FR | exotic | Self-consumed fruits | 1,6 | | | 8,3 | | 2,7 | 2,2 |
| *Artocarpus heterophyllus* Lam., 1789 | ampalibe | jacquier | Moraceae | FR | exotic | Self-consumed fruits | 10,6 | 5,8 | 5,7 | | | | 4,8 |
| *Bombacopsis glabra* Pasq. 1868 | pistache-be | pistache arbuste | Malvaceae | FR | exotic | Fruits, vanilla tutor | 19,5 | | 3,8 | | | | 5,6 |
| *Cinnamomum verum* J.Presl, 1825 | kanelina | cannelier | Lauraceae | FO | exotic | Firewood, bark | | 2,9 | | | | 17,6 | 3,5 |
| *Citrus reticulata* Blanco, 1837 | citrus | mandarinier | Rutaceae | FR | exotic | Self-consumed fruits | 4,1 | 1,0 | 3,8 | 1,4 | 13,2 | 6,8 | 4,1 |
| *Cleistanthus capuronii* Leandri | rahiny | lohindry | Phyllanthaceae | FO | native | Firewood | | | | | 2,6 | | 0,2 |
| *Cocos nucifera* L., 1753 | cocotier | cocotier | Arecaceae | FR | exotic | Self-consumed fruits | 1,6 | 9,7 | 9,4 | 2,8 | 7,9 | | 4,8 |
| *Coffea canephora* Pierre ex A.Froehner, 1897 | caféier | caféier | Rubiaceae | FR | exotic | Self-consumed fruits, vanilla tutor | 4,1 | 21,4 | 9,4 | 2,8 | 26,3 | 37,8 | 15,6 |
| *Croton mongue* Baill., 1861 | mongy | molanga | Euphorbiaceae | FO | native | Firewood | | 1,0 | | | | | 0,2 |
| *Dracaena reflexa* Lam., 1786 | hasina | bois de chandelle | Asparagaceae | FO | native | Vanilla tutor | 4,1 | | | | | 1,4 | 1,3 |
| *Dypsis fanjana* Beentje | fanjana | fougère arborescente | Arecaceae | FO | native | . | | | | 2,8 | | | 0,4 |
| *Erythroxylum ferrugineum* Cav. | menahy | menahy | Erythroxy-laceae | FO | native | Vanilla tutor | 0,8 | | | | | | 0,2 |
| *Eucalyptus robusta* sm. | kininina | eucalyptus | Myrtaceae | FO | exotic | Lumber | 0,8 | | | 6,9 | | | 1,3 |
| *Ficus tiliifolia* Baker | voara | gonda | Moraceae | FO | native | Firewood, vanilla tutor | 2,4 | 1,0 | 15,1 | 1,4 | 2,6 | 2,7 | 3,5 |
| *Gliricidia sepium* (Jacq.) Kunth ex Walp., 1842 | gliricidia | gliricidia | Fabaceae | FO | exotic | Forage, hedge, shading | | 1,0 | | | | | 0,2 |
| *Grevillea banksii* R.Br., 1810 | grevilea | grevillea de Banks | Proteaceae | FO | exotic | Firewood, shading | | 5,8 | | 38,9 | | | 7,3 |
| *Harungana madagascariensis* Lam. ex Poir., 1804 | harongana | bois harongue | Hypericaceae | FO | native | Firewood | 6,5 | 1,0 | | 12,5 | 2,6 | 2,7 | 4,5 |
| *Intsia bijuga* (Colebr.) Kuntze, 1891 | hintsina | faux teck | Fabaceae | FO | native | Lumber | 5,7 | 7,8 | 1,9 | 6,9 | | | 4,5 |
| *Jatropha curcas* L., 1753 | valavelona | jatropha | Euphorbiaceae | FO | exotic | Firewood, oil | | | 1,9 | | | | 0,2 |
| *Litchi chinensis* Sonn., 1782 | litchi | litchi | Sapindaceae | FR | exotic | Fruits sold and self-consumed | 1,6 | 5,8 | 7,5 | 1,4 | | 1,4 | 3,0 |
| *Macaranga obovata* Boivin ex. Baill. | mankaranana | macaranga | Euphorbiaceae | FO | native | Lumber | 0,8 | | | | 5,3 | | 0,6 |
| *Mangifera indica* L., 1753 | manga | manguier | Anacardiaceae | FR | exotic | Self-consumed fruits | 4,1 | 19,4 | | 8,3 | 5,3 | 9,5 | 8,6 |
| *Melia azedarach* L., 1753 | voandelaka | margousier | Meliaceae | FO | exotic | shading | | | 1,9 | | | | 0,2 |
| *Nephelium lappaceum* L., 1767 | litchi chinois | ramboutan | Sapindaceae | FR | exotic | Fruits sold and self-consumed | | 3,9 | 20,8 | | | | 3,2 |
| *Persea americana* Mill., 1768 | zavoka | avocatier | Lauraceae | FR | exotic | Self-consumed fruits | | | 3,8 | 1,4 | | 2,7 | 1,1 |
| *Phylloxylon xylophylloides* (Baker) Du Puy, Labat & Schrire | arahara | arahara | Fabaceae | FO | native | Timber, vanilla tutor | 0,8 | | | | | | 0,2 |
| *Psidium cattleianum* Sabine, 1821 | goavier | goyavier de chine | Myrtaceae | FR | exotic | Fruits, wood, vanilla tutor | 4,9 | 1,0 | | | | 1,4 | 1,7 |
| *Ravenala madagascariensis* Sonn., 1782 | ravinala | arbre du voyageur | Strelitziaceae | FO | native | lumber, fiber, drink | | 1,0 | | | 13,2 | | 1,3 |
| *Streblus dimepate* (Bureau) C.C.Berg | odipa- | dipaty | Moraceae | FO | native | Firewood | 10,6 | | | 1,4 | | 2,7 | 3,5 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | so/tsopatika | | | | | | | | | | | | |
| *Syzygium cumini (L.) Skeels, 1912* | voarotro | jamblon | Myrtaceae | FO | exotic | Firewood | | | | | 2,6 | | 0,2 |
| *Syzygium malaccense* (L.) Merr. & L.M.Perry, 1938 | makoba | Jambosier rouge | Myrtaceae | FR | exotic | Self-consumed fruits | 1,6 | | | | | 1,4 | 0,6 |
| *Trema orientalis* (L.) Blume, 1852 | angezoka | bois d'Andrèze | Cannabaceae | FO | native | Firewood | 0,8 | | | | | | 0,2 |
| . | hazomanjary | . | Euphorbiaceae | FO | . | Firewood | 1,6 | | | | | | 0,4 |
| . | fankamamo | . | Fabaceae | FO | . | Firewood | | 1,0 | | | | | 0,2 |
| . | menefelana | . | . | FO | . | Firewood | | 1,9 | | | | | 0,4 |
| . | ranomainty | . | . | FO | . | Firewood | 3,3 | | 3,8 | 1,4 | 5,3 | 2,7 | 2,4 |
| . | beloha | . | . | FO | . | Firewood | 0,8 | | | | | 1,4 | 0,4 |

( ) : number of plots

FO : forest tree species ; FR : fruit tree species

A : clove agroforestry system ; YA : young clove agroforestry system ; B : diversified clove parkland ; YB : young diversified clove parkland ; C : simple clove parkland ; D : clove plantation.

**Table 3**. ANOVA (F) or Kruskal-Wallis (H) results and mean values for 19 variables for the types of clove system identified by PCA and cluster analysis (30 plots, east coast of Madagascar)

| Variables | F or H value | Types of clove system | | | | | | Overall mean |
|---|---|---|---|---|---|---|---|---|
| | | A (4) | YA (3) | B (3) | YB (4) | C (9) | D (7) | (30) |
| Total tree density (clove and associated trees) trees $ha^{-1}$ = (dT)[a] | 16,5*** | 512,8 d | 491,6 cd | 299,6 ab | 336,9 b | 214,9 a | 366,9 bc | 342,5 |
| Clove tree density trees $ha^{-1}$ | 2,9* | 212,5ab | 159,5ab | 127,0a | 161,1ab | 179,1ab | 263,7b | 193,7 |
| Associated tree density trees $ha^{-1}$ | 13,2*** | 300,3 c | 332,0 c | 172,5 ac | 175,8 bc | 35,8 a | 103,2 ab | 148,8 |
| Share of clove trees in total tree density % | 19,3** | 43,0 ab | 31,5 a | 41,7 ab | 48,3 ab | 83,2 c | 72,0 bc | 61,2 |
| Shannon-Wiener index = (SI)[a] | 8,8*** | 2,0 c | 1,9 bc | 1,7 bc | 1,1 abc | 0,5 a | 1,0 ab | 1,1 |
| Number of associated tree species | 19,2** | 11,3 c | 9,3 bc | 7,0 bc | 4,5 abc | 2,1 a | 4,3 ab | 5,4 |
| Number of associated fruit tree species | 15,6** | 4,3 b | 5,3 b | 3,3 ab | 2,3 ab | 1,0 a | 2,4 ab | 2,6 |
| Total basal area of tree stands (clove and associated trees) $m^2$ $ha^{-1}$ = (baT)[a] | 6,2*** | 13,7 ab | 14,7 ab | 7,5 a | 5,2 a | 10,8 a | 17,9 b | 12,1 |
| Basal area of clove tree stand $m^2$ $ha^{-1}$ | 17,0*** | 6,8 ab | 1,6 a | 4,6 ab | 1,7 a | 10,1 b | 15,3 c | 8,3 |
| Basal area of associated tree stand $m^2$ $ha^{-1}$ | 21,1*** | 6,9 b | 13,1 b | 2,9 ab | 3,5 ab | 0,7 a | 2,6 ab | 3,8 |
| Share of clove trees in the total basal area of tree stands % = (pCba)[a] | 24,4*** | 50,1 ab | 15,1 a | 61,5 ab | 30,8 a | 93,8 c | 84,7 bc | 66,3 |
| Mean basal area of each clove tree $cm^2$ = (mbaC)[a] | 6,4*** | 317,3 ab | 112,6 a | 381,7 ab | 99,0 a | 585,4 b | 637,9 b | 429,4 |
| Mean basal area of each associated tree $cm^2$ | ns | 284,6 | 412,6 | 166,0 | 248,1 | 252,3 | 683,8 | 364,1 |
| Share of clove trees between 5 and 15 years old % = (pCag)[a] | 18,3** | 47,8 ab | 86,3 b | 35,4 ab | 94,6 b | 21,3 a | 28,7 a | 44,2 |
| Rate of soil cover by tree crowns (clove and associated trees) % | 18,4** | 45,2 bc | 70,3 c | 32,8 abc | 28,7 ab | 25,4 a | 44,2 bc | 38,1 |
| Mean height of clove trees m | ns | 3,7 | 2,8 | 3,5 | 3,1 | 4,1 | 4,4 | 3,8 |
| Mean height of associated trees m | ns | 4,9 | 5,2 | 4,7 | 7,0 | 4,1 | 5,4 | 5,1 |
| Mean crowns diameter of clove trees m | ns | 3,4 | 2,3 | 3,2 | 2,5 | 3,8 | 3,9 | 3,4 |
| Mean crowns diameter of associated trees m | ns | 2,9 | 3,7 | 3,3 | 3,3 | 2,6 | 2,9 | 3,0 |

[a] : variables of PCA.

( ) : number of plots. ****p* <0,001 ; ***p* <0,01 ; **p* <0,05 ; NS : non significant.

Values in the same line with the same letters are not significantly different at *p* <0,05

A : clove agroforestry system ; YA : young clove agroforestry system ; B : diversified clove parkland ; YB : young diversified clove parkland ;

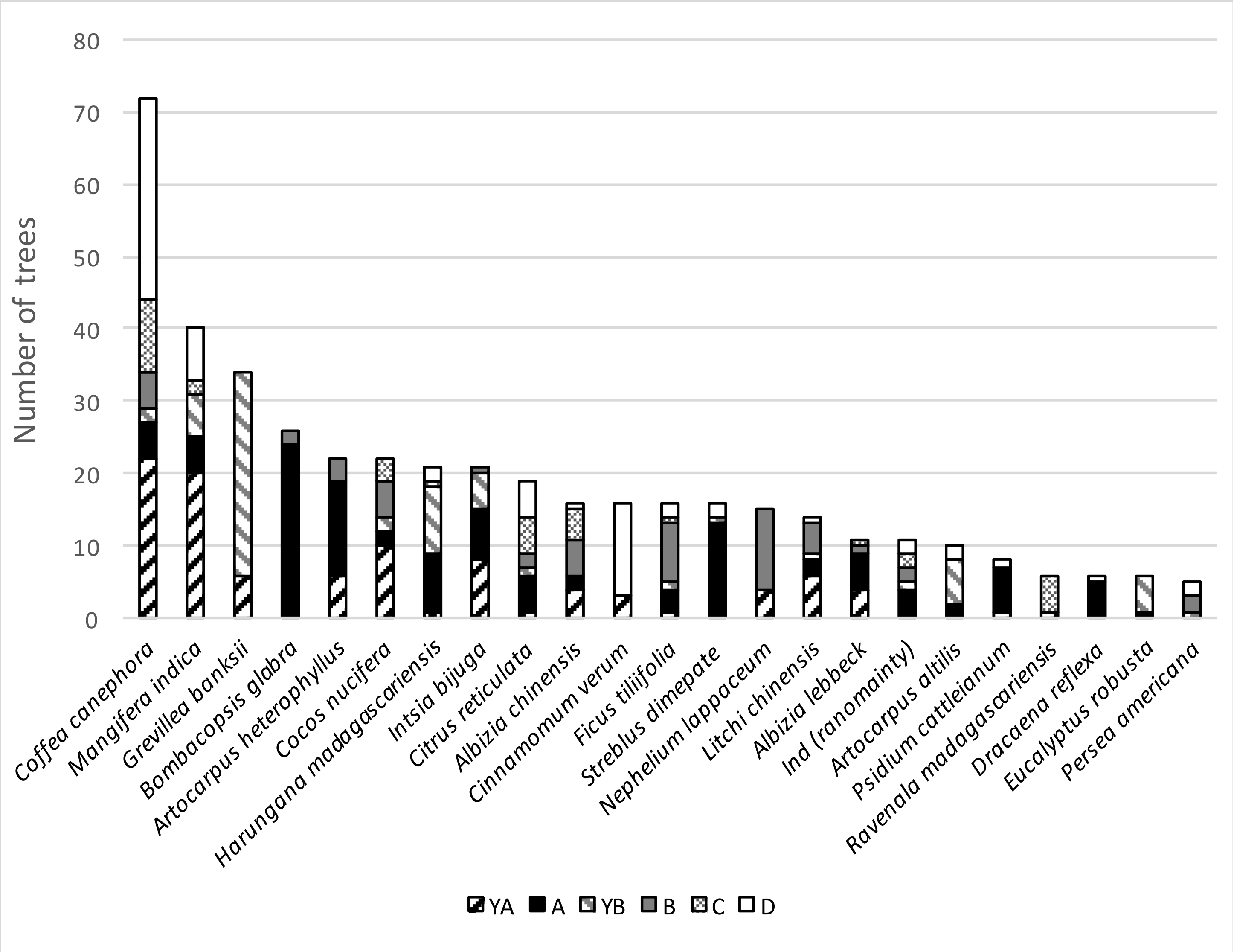
C : simple clove parkland ; D : clove plantation.

**Table 4**. Details on stands composition and agricultural uses of the lower stratum in the types of clove system (30 plots, east coast of Madagascar)

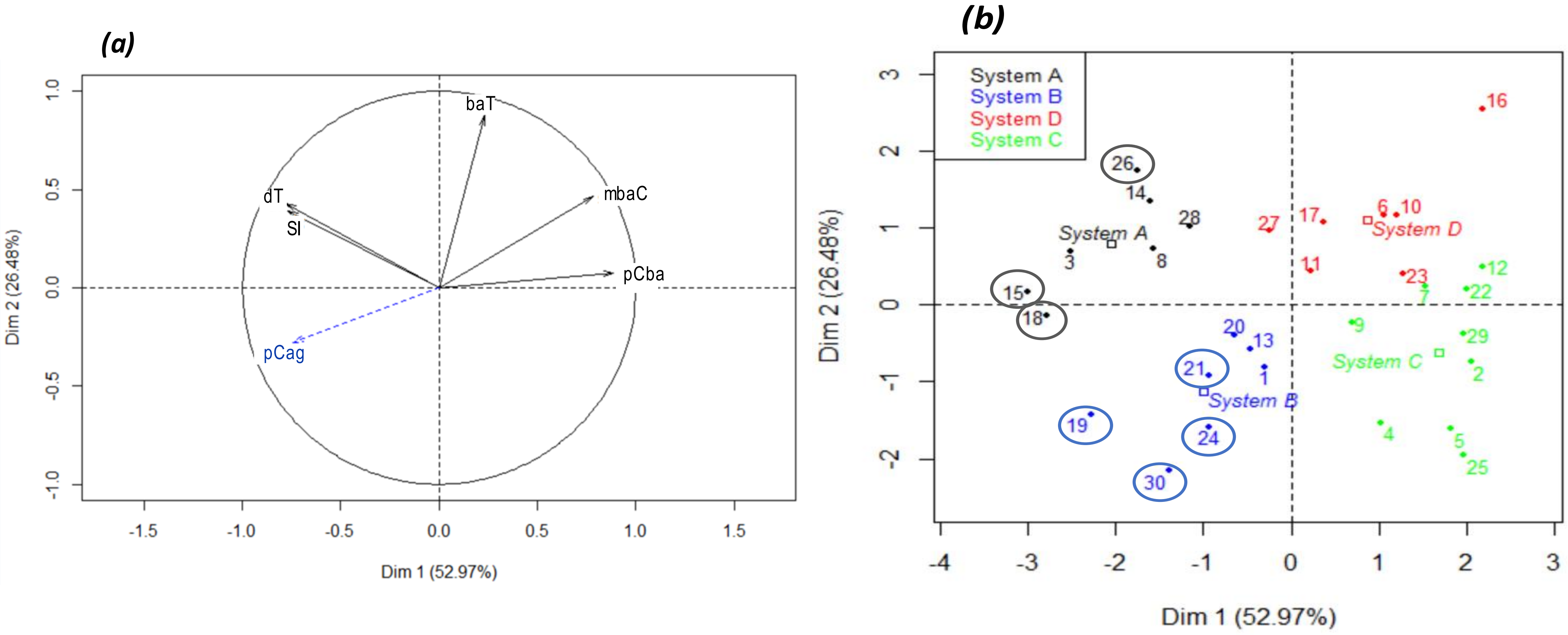
| | | Types of clove system | | | | | |
|---|---|---|---|---|---|---|---|
| | | A | YA | B | YB | C | D |
| Associated trees | Mean fruit tree density trees ha-1 | 161,1 | 225,8 | 110,7 | 48,8 | 18,9 | 69,7 |
| | Mean forest tree density trees ha-1 | 139,2 | 106,3 | 61,8 | 127,0 | 17,0 | 33,5 |
| | Share of fruit trees % | 53,6 | 68,0 | 64,2 | 27,8 | 52,6 | 67,5 |
| Clove trees | Mean clove tree density trees ha-1 | 212,5 | 159,5 | 127,0 | 161,1 | 179,1 | 263,7 |
| | Share of clove trees with DBH<15 cm % | 47,8 | 86,3 | 35,4 | 94,6 | 21,3 | 28,7 |
| | Share of clove trees with 15 ≤DBH≤20 cm % | 11,5 | 11,9 | 8,6 | 2,5 | 8,2 | 10 |
| | Share of clove trees with 20<DBH<29 cm % | 26,9 | 1,9 | 43,2 | 2,9 | 43,2 | 37,1 |
| | Share of clove trees with DB ≥29 cm % | 13,8 | 0 | 12,8 | 0 | 27,4 | 24,1 |
| In lower stratum | cropping system based rice, cassava, pasture fallow | | | ++ | | ++ | |
| | vanilla lianas | ++ | | ++ | | | |
| | pineapple plants | | | | + | | |
| | banana stems | | + | +++ | | | |
| | sugar cane | | | ++ | | | |
| | bamboo plants (*Nastus capitatus*) | | + | | | ++ | |

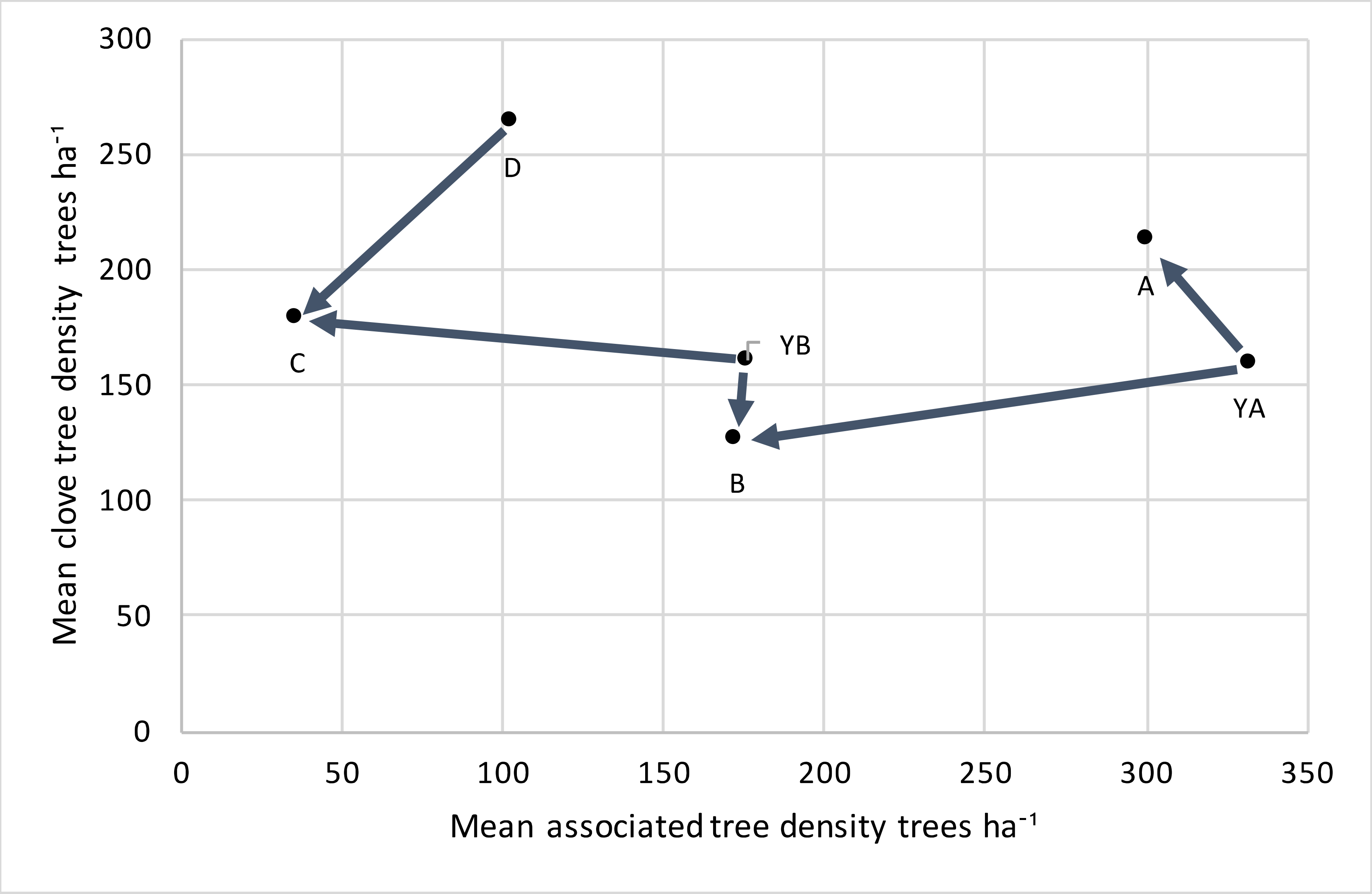
A : clove agroforestry system ; YA : young clove agroforestry system ; B : diversified clove parkland ;
YB : young diversified clove parkland ; C : simple clove parkland ; D : clove plantation.
+, ++, +++ : degree of presence ; DBH : trunk diameter at breast height

Share of clove trees with several trunk = 33,3 % (30 plots)



Number of trees
0
10
20
30
40
50
60
70
80
Coffea canephora
Mangifera indica
Grevillea banksii
Bombacopsis glabra
Artocarpus heterophyllus
Cocos nucifera
Harungana madagascariensis
Intsia bijuga
Citrus reticulata
Albizia chinensis
Cinnamomum verum
Ficus tiliifolia
Streblus dimepate
Nephelium lappaceum
Litchi chinensis
Albizia lebbeck
Ind (ranomainty)
Artocarpus altilis
Psidium cattleianum
Ravenala madagascariensis
Dracaena reflexa
Eucalyptus robusta
Persea americana
YA
A
YB
B
C
D


(a)
baT
dT
SI
mbaC
pCba
pCag
Dim 1 (52.97%)
Dim 2 (26.48%)
(b)
System A
System B
System D
System C
Dim 1 (52.97%)
Dim 2 (26.48%)



Mean clove tree density trees ha-1
Mean associated tree density trees ha-1
300
250
200
150
100
50
0
0
50
100
150
200
250
300
350
D
C
YB
B
A
YA