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Clove based cropping systems on the east coast of Madagascar: how history leaves its mark on the landscape

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Abstract Clove farming developed on the east coast of Madagascar a little over a century ago. The species is largely cultivated and farmed by communities of smallholders. This study aims to characterize clove based cropping systems. There are three types of coexisting clove systems: monoculture where clove is the sole crop with inter-rows covered by wild grasses, agricultural parklands where clove is associated with annual crops (rain fed rice, sugar cane, cassava) and finally complex agroforestry systems where clove is associated with other crops (vanilla), fruit trees (lychees, breadfruit, jackfruit) and pepper vines, as well as some forest trees. The study also shows that the majority of existing clove trees in the various cropping systems are over 50–60 years old. Our study aims to characterise the different clove based cropping systems with the intention of establishing a typology by measuring biometric criteria associated with clove trees, by determining the accompanying species and by characterising the horizontal and vertical structuration of plots. From these observations, we suggest some evolutionary hypotheses of clove systems in an attempt to resituate this typology in a historical dynamic implicating the agricultural history of the

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east coast of Madagascar and the evolution of the smallholders' strategies.

Keywords Agricultural history · Complex agroforestry system · Clove tree monoculture · Parklands · *Syzygium aromaticum* · Smallholder strategy · Madagascar

Introduction

Agroforestry can be fairly consensually defined as the deliberate cultivation of perennial woody plants in ecological or economic interaction with seasonal of livestock crops, simultaneously or in time sequence (Nair 1985; Sinclair 1999; Torquebiau 2000). Agroforestry systems (AFS) preserve a high level of biodiversity, which promotes productivity, diversification of production (cash crops, food crops, green fodder, mulch, medicine, firewood, timber,…) thus promoting food security, resilience and economic insurance (Thrupp 2000; Rahman et al. 2017). But beyond the production function, agroforestry produces many eco-systemic services (soil fertility, water cycle, carbon sequestration) that are particularly important in a context of climate change (Mbow et al. 2014; Palacios Bucheli and Bokelmann 2017). As a result, the structure and use of agroforests is determined by a set of determinants such as ecological context, farmer's strategy, economic context, and also political context that may vary in space and time.

Today, in the east coast of Madagascar, the landscape is heavily marked by clove farming. But a summary analysis of the landscape shows that it is a diverse composite, a continuum of more or less complex AFS in which the clove tree is implicated (Michels et al. 2011). Clove trees are sometimes present in the almost mono-specific plantations right up to the relatively complex compounds where they accompany herbaceous and ligneous wild or cultivated species.

In the current context where several international funders (World Bank, European Union) intend to support Malagasy clove chains through sustainable development, it is helpful to better understand the strategies of the clove producers, as well as the structure and evolution of their systems of production.

Our study aims to characterise the different clove based cropping systems with the intention of establishing a typology by measuring biometric criteria associated with clove trees, by determining the accompanying species and by characterising the horizontal and vertical structuration of plots.

The second objective is to place the cropping systems in a historical dynamic. Based on the fact that clove trees are long-living—able to live for upwards of 80 years, and as much as a century (Ledreux 1932b; Leroy 1946)—and considering the short history of the clove tree in Madagascar (Danthu et al. 2014; Cocoual and Danthu 2018), it can be estimated that the cloves living today have probably conserved traces of the evolution of means of cultivation and the smallholders' strategies since the beginning of the development of this crop in Madagascar.

The following hypotheses were studied: (1) various cropping systems coexist to accommodate cloves; (2) the current typology of these clove AFSs is a product of the region's agricultural history, combined with the strategies of the successive occupants of the land.

Context

The clove in Madagascar

The clove tree (*Syzygium aromaticum* (L.) Merrill & Perry), from the Myrtaceae family, which originated in the Maluku Islands, was introduced to Madagascar around two centuries ago; firstly to Sainte-Marie Island then to the east coast of Madagascar (Boiteau 1936; Decary 1937; Dussel 1962) (Fig. 1).

Before 1900, the clove was cultivated only on Sainte Marie Island (Prudhomme 1901). The development of its culture on the "Great Island" began at the beginning of the twentieth century. Its value is derived from two products: the clove, the culinary spice and the ingredient of *kreteks* (Indonesian cigarette) (Parle and Khanna 2011; Arnez 2009) and the essential oil rich in eugenol (Razafimamonjison et al. 2014, 2016), basic ingredient of a variety of applications in the food industry, perfumery, medicine and aromatherapy (Lampman et al. 1977; Leela and Sapna 2008; Kamatou et al. 2012).

Despite its vulnerability to cyclones (Ledreux 1928, 1932b), frequently occurring on the east coast of Madagascar (Donque 1975), and various pests

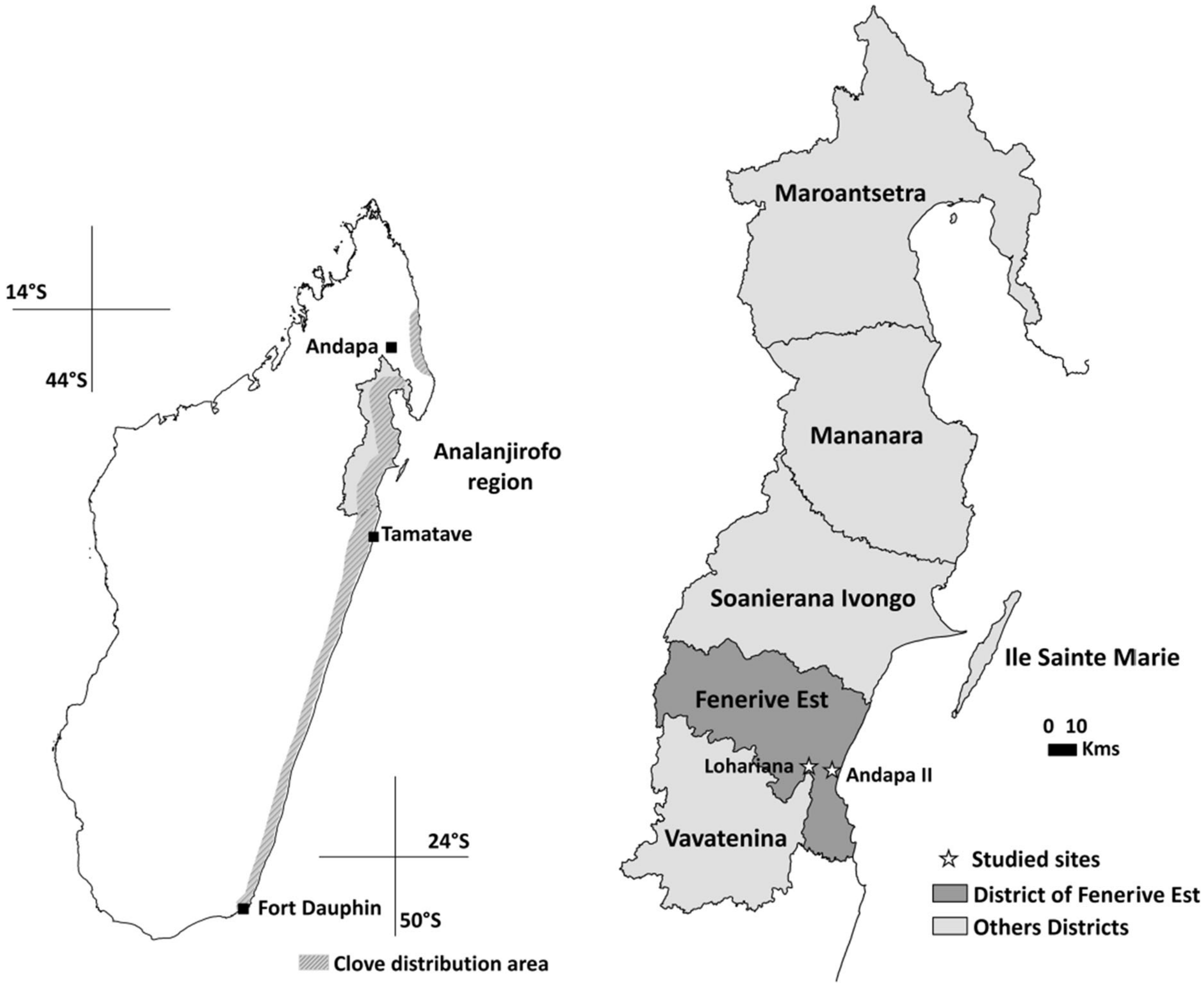

Fig. 1 Localisation of the clove growing zone in Madagascar (from Maistre 1955, 1964; Dufournet 1968; Danthu et al. 2014) and the two study sites: the *fokontany* of Lohariana and Andapa II

(mainly fungal diseases) (Heim and Bouriquet 1939; Bouriquet 1946), in particular the clove tree miner, *andretra* (lepidoptera *Chrysotypus mabilianum* Viette) (Frappa 1954; Dubois and Ranaivosoa 1966), cultivation of the clove trees developed gradually from the beginning of the twentieth century (Ledreux 1928, 1932b; François 1936; Leroy 1946). This development began as large colonial controlled plantations, as well as small plots belonging to native farmers (Isnard 1951; Cocoual and Danthu 2018).

Clove trees are currently grown and farmed all along the east coast of Madagascar from Fort-Dauphin in the South to Sambava in the North (Dufournet 1968), but are concentrated in the Analanjirofo region, particularly in the areas of low altitude of the districts of Vavatenina, Fenerive-Est, Soanierana Ivongo, Mananara-Nord, Maroantsetra (Fig. 1) (Danthu et al. 2014). Madagascar is the second largest world producer of cloves after Indonesia and the largest exporter of cloves and clove essential oil. These products are currently the top Malagasy agricultural exports, with vanilla and lychees (Danthu et al. 2014; Gouzien et al. 2016).

In the Analanjirofo region, the main crops are rice, sweet potato, cassava, vanilla, coffee, sugar cane, lychees and peppercorns, as well as cloves (Dandoy 1973; Jahiel et al. 2014). Rice growing occupies the lowlands and *tavy* (slash and burn) is commonly practiced on the higher ground in hilly areas (Rqibate et al. 2014).

The first agronomic practices

We based our reconstitution on the earliest technical and scientific documents from the colonial period: Ledreux (1928, 1932b), François (1936), Boiteau (1936), Leroy (1946), Isnard (1951), Maistre (1955), which provide documentary evidence of a real interest by the French colonial powers in the development of cloves in Madagascar (Cocoual and Danthu 2018). They revealed that initially two main farming models coexisted in the zone. The first model was clove-based and of low density (200/250 trees ha^{-1}), with the trees mainly planted in rows, making up plantations often owned by settlers (Fig. 2). The second model, comprising of smaller plantations owned by native peasants, presented more varied and more densely planted cropping systems (Fig. 3). Isnard (1951) has estimated that these latter plantations represented around two-thirds of the surface area of the zone's clove tree stock.

The agricultural technicians at the time, in fact, recommended low densities for planting clove trees in plantations: 300 even 100 trees/ha. These recommendations were adhered to in the settlers' plantations, but according to Maistre (1955, 1964), the native small holders planted at much higher densities of around 500 and up to 600 trees/ha, probably in anticipation of large numbers of young tree losses resulting from passing cyclones and/or devastation by pests such as

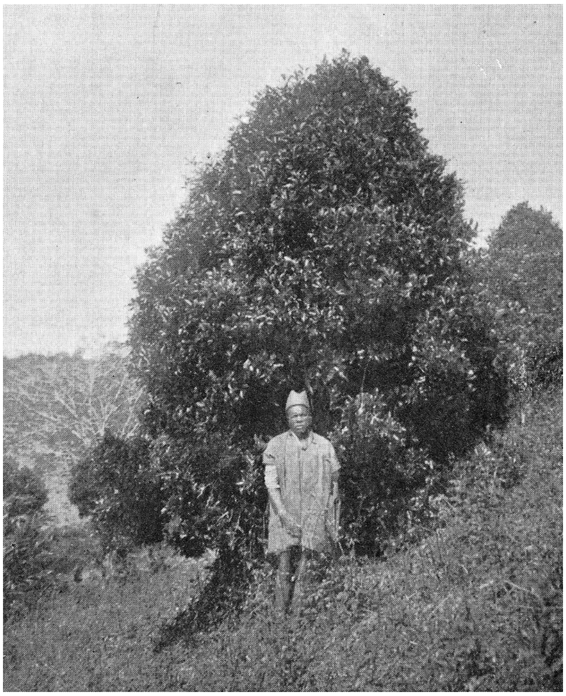

Fig. 3 A young (5 years old) clove tree near Fénérive-Est, east coast of Madagascar (Ledreux 1932a)

Fig. 2 Clove plantation in the 1950s on the Madagascar coastline (Maistre 1964)

andretra, in a context of low maintenance of plantations. The author reported, indeed, that the clove trees were often neglected, with only an annual clearing around the foot of the trees, as the clove were considered more as produce for picking (Tourneur 1947; Maistre 1955).

Clove trees were also dispersed throughout the *savoka* (local regrowth of vegetation which develops after slash and burn as secondary forest), sometimes to the extent of occupying all the available ground, to the detriment of food crops (Tourneur 1947).

The end of colonial rule brought in the demise of the big plantations, especially on the east coast which had been largely decolonised (Koerner 1969; Cocoual and Danthu 2018). These estates, which were often divided into smaller parcels, continued to be farmed by a plethora of more or less legal beneficiaries, with a more or less invested interest, who exploited the clove trees without concern for the plant's conservation. Clove tree densities gradually diminished as the trees aged and the consequences of climate, biological constraints and repeated pruning bore their effects. This brought about the dynamics described by Penot et al. (2016), where such evolution culminating in the disappearance of clove from the landscape has been observed in Sainte Marie Island, the cradle of clove culture in Madagascar.

Materials and methods

Survey apparatus

The study was made on 42 AFS including clove plots in the districts of Fenerive-Est (or Fénérive-Est, south part of the Analanjorofo region): *fokontany* of Lohariana (rural district of Ambatoharanana) (plots L1–L19) and Andapa II (rural district of Ambodimanga II) (plots A1–A23) (Fig. 1). These plots were chosen on the basis of a "reasonable choice" aiming to represent the whole range of ecological contexts where clove trees are grown.

In each plot, a sub-plot of 900 m^2 (30 m × 30 m) was marked out, as homogeneous and representative of the plot as possible. Measurements were carried out within this sub-plot. We gathered information on tree density and age of the clove trees in each sub-plot and on the flora composition and spatial arrangement associated to clove trees.

Three sets of variables were collected and developed: (1) one set relating to the clove trees, (2) a second set relating to the species of vegetables cultivated in association with clove trees (herbaceous; rice, sugar cane, vanilla, or ligneous; fruit trees for personal consumption or sale; breadfruit, lychee, jackfruit, mango, coffee…), and (3) a third set relating to wild native species that the farmers have conserved, preserved, even encouraged in their cropping systems for various uses, principally herbaceous, which might have value as forage and ligneous forest species suitable for fire wood, or other purposes (Table 1).

Floral composition of plots

The botanical characterisation was performed using the Braun-Blanquet (1965) recording method per plot of 30 m × 30 m, subdivided into nine mini-plots of 10 m × 10 m with botanical inventories (herbaceous, bushes, shrubs, trees…) and identity of the plant (common name and scientific name). These were derived from herbarium samples and comparison with the reference specimens in the TAN (Parc Botanique et Zoologique de Tsimbazaza) and TEF (Département des Recherches Forestières et Piscicoles of FOFIFA, Centre National de Recherche Appliquée au Développement Rural), national herbaria of Madagascar in Antananarivo, or by consulting the database of the Missouri Botanical Garden (TROPICOS 2016).

The characterisation of the vertical structure of the planting system was performed according to the method described by Nusbaumer et al. (2005). It consists in moving a 8 m long graduated pole within the vegetation, along a 30 m transect in the middle of the plot following two orthogonal axes. A reading was taken at a point every metre: the heights of the points of contact between the vegetation and the pole as well as the name of the species concerned were noted. Beyond 8 m, the height of the points of contact was estimated visually.

The following scale was used to estimate the rate of herbaceous cover (cultivated and wild): 0 when the surface of the plot was clear, 1 point when the cover was estimated at 20% and 5 if the entire surface was covered in herbaceous vegetation.

Table 1 Variables measured or calculated to characterise the different plots

Variable	Unit	Abbreviation	Contributions of variables on the axes (%)	
			Axe 1	Axe 2
Variables associated with clove trees				
Number of clove trees (density)	*Number of trees* ha^{-1}	*NCT*	*21.58*	*8.99*
Diameter à breath high of clove trees	cm	DBHCT		
Cumulative basal area of clove trees	m^2 ha^{-1}	BACT		
Area occupied by the crowns of clove trees	m^2 ha^{-1}	AOCCT		
Variables associated with cultivated herbaceous species combined with clove trees				
Number of cultivated herbaceous species	Number of species ha^{-1}	NSCH		
Coverage rate of cultivated herbs	*%*	*CCH*	*37.36*	*0.82*
Number of cultivated ligneous species	Number of species ha^{-1}	NSCL		
Number of individuals of cultivated ligneous	*Number of trees* ha^{-1}	*NICL*	*0.60*	*39.38*
Cumulative basal area of cultivated trees	m^2 ha^{-1}	BACL		
Area occupied by the crowns of cultivated ligneous	m^2 ha^{-1}	AOCCL		
Variables associated with combined wild species				
Number of wild herbaceous species	Number of species ha^{-1}	NSWH		
Coverage rate of wild herbs	*%*	*CWH*	*38.87*	*0.48*
Number of wild ligneous species	Number of species ha^{-1}	NSWL		
Number of individuals of wild ligneous	*Number of trees* ha^{-1}	*NIWL*	*1.59*	*50.33*
Cumulative basal area of wild trees	m^2 ha^{-1}	BAWL		
Area occupied by the crowns of wild ligneous	m^2 ha^{-1}	AOCWL		

The five independent variables retained are in italics; for these variables, their absolute contribution on axes 1 and 2 are given

Table 2 Estimation of the age of clove trees on the word of the owners questioned for the study and by ring counting on trunks sampled at breast height (measurements taken from four perpendicular radii)

Average diameters of trunks (cm)	Age estimated from word of owners (years)	Age estimated from ring counting (years)
20.5 ± 0.7	42/45	48.3 ± 1.6
23.5 ± 0.5	± 50	55.3 ± 1.4
27.2 ± 1.0	± 60	65.7 ± 2.4
31.8 ± 0.9	60/70	74.8 ± 2.2

Determination of the age of the clove trees

The age of the clove trees was assessed by questioning the owners on the history of their plot. The validity of this information was checked by counting the number of rings on four recently fallen or felled clove trees from which slices of trunk were sampled, dried then polished on one side with sanding discs of different grains (50, 100, 120, 220, 320 and 400). The rings were counted from four perpendicular radii and the mean age established (Worbes 1995, 2002; Detienne et al. 1998). Table 2 shows a good correspondence with the age stated by the local farmer, corroborating this source of information.

Although based on a very small number of samples, we considered that the information collected was sufficiently reliable to assess the age of the trees. Therefore, a complete tree-age analysis based on a larger sampling, taking into account the position of the tree in the landscape, would be interesting to complete that point.

Statistical treatment and data analysis

Two principal components analyses (PCA) were performed using the XLSTAT 2015 programme to determine the distribution of the 42 plots. The first PCA (Fig. 4) was carried out to eliminate the redundant variables focusing on the circle of correlation taking into account the value of the angle α formed by two vectors and the length of the vector of each variable. The variables are redundant if $\alpha < 90°$ and the longer the vector the greater the variable. This elimination was performed within the three sets of variables: those related to the clove trees, those related to the associated cultivated species and those related to the associated wild species. The second PCA was performed to study the influence of the five variables retained (NCT, CCH, NICL, CWH, NIWL) on the distribution of the plots (Table 1; Fig. 5).

In the tables the means are given ± the standard deviation.

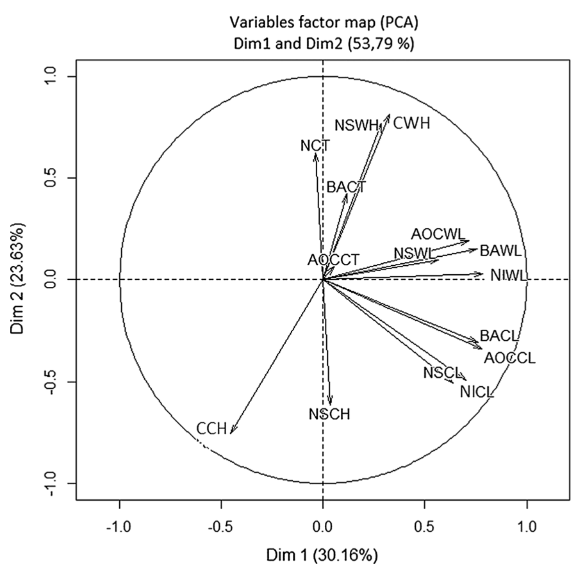

Fig. 4 Circle of correlation showing the value of the angle α formed by the vectors and the length of these vectors for the fifteen variables measured in the plots (see Table 1)

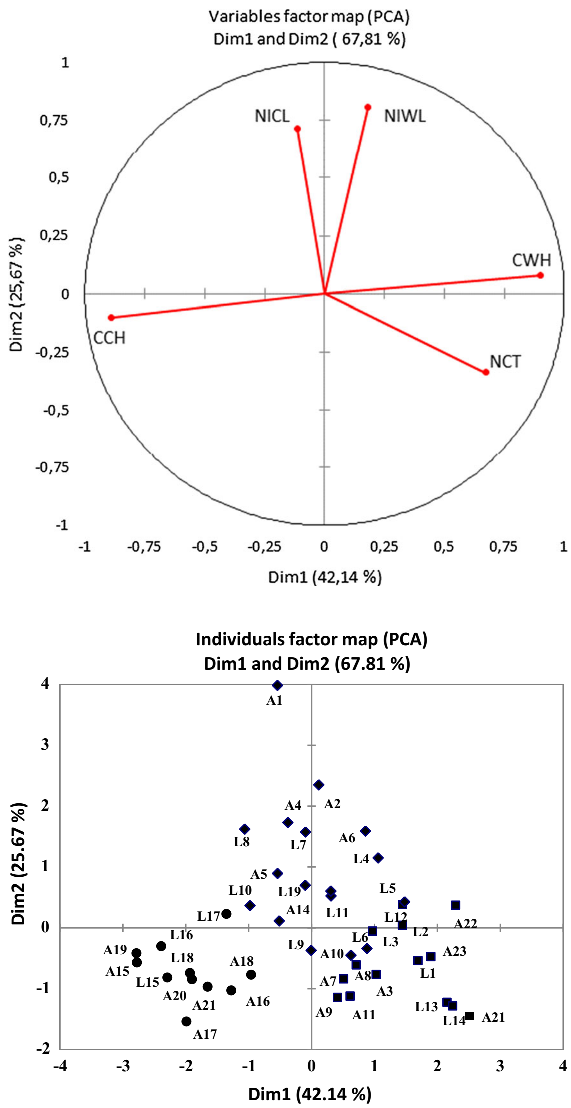

Fig. 5 Distribution of 42 plots of clove trees identified in the *fokotany* of Lohariana (L1–L19) and Andapa II (A1–A23) (east coast of Madagascar) on the factorial map F1/F2, according to the five variables measured or calculated selected (NCT, CCH, NICL, CWH, NIWL, see Table 1). Three groups of plots are highlighted: G1 (square), G2 (circle) and G3 (diamond) corresponding respectively to the monoculture, parkland and complex AFS plots

Results

Typology of the different clove cropping systems

The PCA factorial plan (Fig. 5) shows that the axes 1 and 2 explain 67.81% of the total variability (42.14% for Axis 1 and 25.67% for Axis 2). The NCT (density of the clove tree plots), CCH (coverage rate of cultivated herbaceous vegetation) and CWH (coverage rate of wild herbaceous vegetation) variables contribute to a great extent on axis 1 (21.58, 37.36 and 38.87%, respectively) whilst NICL (density of cultivated ligneous plants) and NIWL (density in wild ligneous species) contribute to axis 2 for 39.38 and 50.33%, respectively.

The points representing the 42 plots are distributed into three groups.

Group 1 (G1) is characterised by a large number of clove trees (NCT) and a high coverage rate of wild herbaceous plants (CWH) (Fig. 5). These plots have a density of clove trees estimated at 239 plants per hectare representing a basal area of 14.8 m^2 ha^{-1} (BACT) and crowns that occupy around a third of the plot's surface (AOCCT, Table 3), the height of which rarely exceeds six metres (Figs. 6a, b, 7). This group of plots is also characterised by the presence of many species of wild herbaceous plants (NSWH) belonging to the *Poaceae* and *Asteraceae* families (Table 4), with a ground coverage rate exceeding 85% (CWH), a few scattered *Ravenala madagascariensis* and no cultivated herbaceous species (NSCH). The coverage rate of the intermediary strata is low (2 to 4 m) consisting mainly of clove trees and small numbers of trees and bushes, occasionally in greater numbers (NIWL), which are often spontaneous: guava, cattley guavas, *Harungana madagascariensis*, coffee (Fig. 7).

Group 2 (G2) consists of plots characterised by the presence of cultivated herbaceous species (CCH, Fig. 5) with a relatively low density of clove trees. These plots contain significantly fewer clove trees than those in Group 1 (average density of 158 ha^{-1} compared with 239 ha^{-1}) but for a cumulative surface of crowns equivalent to around 3000 m^2 ha^{-1} (NCT, AOCCT, Table 3, Fig. 6d). The average number of associated cultivated species is 1.6 (NSCH), with a coverage rate of 60–90% (CCH, Table 3). These are often tall herbaceous species (cassava, corn, sugar cane or banana…) and rain fed rice (Table 4, Fig. 8). Other accompanying ligneous species were observed but these were not usually much taller than the clove trees (Fig. 6c), and were usually fruit trees: coffee trees, jackfruits, litchis, soursops, and a few rambutans. There were also a few rare young clove trees aged around 10 years and newly planted plots.

Group 3 (G3) is characterised by a large number of accompanying cultivated (NICL) and wild (NIWL) ligneous species (Fig. 5): on average 10 species per ha [NSCL, NSWL, Table 3)]. The ligneous strata is dense, with a coverage rate of 40–60% (AOCCT, AOCCL, AOCWL, Table 3, Fig. 6e, f) and the clove trees make up around half the ligneous species present (NTC *vs.* NICL + NIWL) but are not the dominant species. The upper strata is taken up by forest species, particularly cultivated ones (fruit trees) up to around 6 m tall (Fig. 6e, f). The emergent ones are *Artocarpus heterophyllus, Litchi chinensis* and a few rare ligneous forest species with a coverage rate of 25–30% (Fig. 9). The strata ranging from 4 to 8 m is characterised by fruit trees such as *Citrus reticulata* and *Annona muricata*, *Annona reticulata*, *Annona squamosa* with a coverage rate of around 50%. The intermediate stratum (2–4 m) is made of ligneous forest species such as young *Harungana madagascariensis*, a pioneer species, and a few sparse juvenile species characteristic of the Malagasy coastal forests such as *Intsia bijuga* (Table 4). These forest species represent only a few plants for a basal area of less than 1 m^2 ha^{-1} (BAWL). *Jatropha thouarsii*, as well as coffee and banana trees also occupy this stratum, with a coverage rate of around 50% (Fig. 6f). Finally, the lower strata (< 2 m) is characterised by wild herbaceous plants such as *Stenotaphrum dimidiatum*, *Cynodon* sp., *Ageratum conizoïdes*, *Clidemia hirta*, as well as vanilla and a few pepper lianas, which use the trees as climbing supports.

Age of clove trees

The clove trees generally have a diameter at breast height (DBH) between 20 and 35 cm (DBHCT, Table 3). Relative to the estimations in Table 2 (as stated by owners on a limited number of trees and ring counting), this diameter corresponds to an approximate age of the trees at between 50 and 75 years.).

Discussion

Three distinct types of clove based cropping systems

The quantitative and qualitative information compiled has enabled the identification of three cropping systems of increasing complexity.

Table 3 Synthesis of the main ecological characteristics of the three groups of clove plots identified on Madagascar's east coast by PCA (see Fig. 3 and Table 1) and attachment to a reference cropping system

	Groups of plots by PCA		
	G1 L1, L2, L3, L12, L13, L14, A11, A3, A7, A8, A9, A21, A22, A23	G2 L15, L16, L17, L18, A12, A15, A16, A17 A18, A19, A20	G3 L4, L5, L6, L7, L8, L9, L10, L11, L19, A1, A2, A4, A5, A6, A10, A13, A14
Characteristics associated with clove trees			
Number clove trees/ha (NCT)	239 ± 28	158 ± 41	182 ± 62
Average DBH of clove trees (cm) (DBHCT)	27.3 ± 5.5	26.7 ± 7.8	21.9 ± 4.0
Basal area of clove trees (m^2 ha^{-1}) (BACT)	14.8 ± 7.7	10.8 ± 5.3	11.4 ± 9.7
Area occupied by crowns of clove trees (m^2 ha^{-1}) (AOCCT)	2966 ± 770	2979 ± 239	3028 ± 721
Characteristics associated with combined cultivated species			
Number of species of cultivated herbaceous/ha (NSCH)	0	1.6 ± 0.7	1.8 ± 1.0
Coverage of cultivated herbaceous (%) (CCH)	0	75 ± 13	21 ± 17
Number of cultivated ligneous species/ha (NSCL)	1.1 ± 1	1.7 ± 0.6	7.1 ± 5
Number of cultivated ligneous individuals/ha (NICL)	14.0 ± 11	35.3 ± 22.5	178.5 ± 47.3
Basal area of cultivated ligneous (m^2 ha^{-1}) (BACL)	1.0 ± 0.4	0.6 ± 0.3	5.9 ± 1.1
Area occupied by crowns of cultivated ligneous(m^2 ha^{-1}) (AOCCL)	189 ± 92	235 ± 100	1167 ± 547
Characteristics associated with combined wild species			
Number of wild herbaceous species/ha (NSWH)	9.0 ± 5.0	0.5 ± 0.7	5.1 ± 3.8
Coverage with wild herbaceous (%) (CWH)	85 ± 13	11 ± 5	57 ± 17
Number of wild ligneous species/ha (NSWL)	2.0 ± 1.1	1.4 ± 0.5	2.8 ± 1.2
Number of wild ligneous individuals/ha (NIWL)	27.1 ± 15.1	5.0 ± 3.9	49.3 ± 15.4
Basal area of wild ligneous (m^2 ha^{-1}) (BAWL)	0.3 ± 0.2	< 0.1	0.4 ± 0.3
Area occupied by crowns of wild ligneous (m^2 ha^{-1}) (AOCWL)	19 ± 15	2 ± 2	23 ± 21
Reference cropping system			
	Monoculture	Woodland	Complex agroforestry system

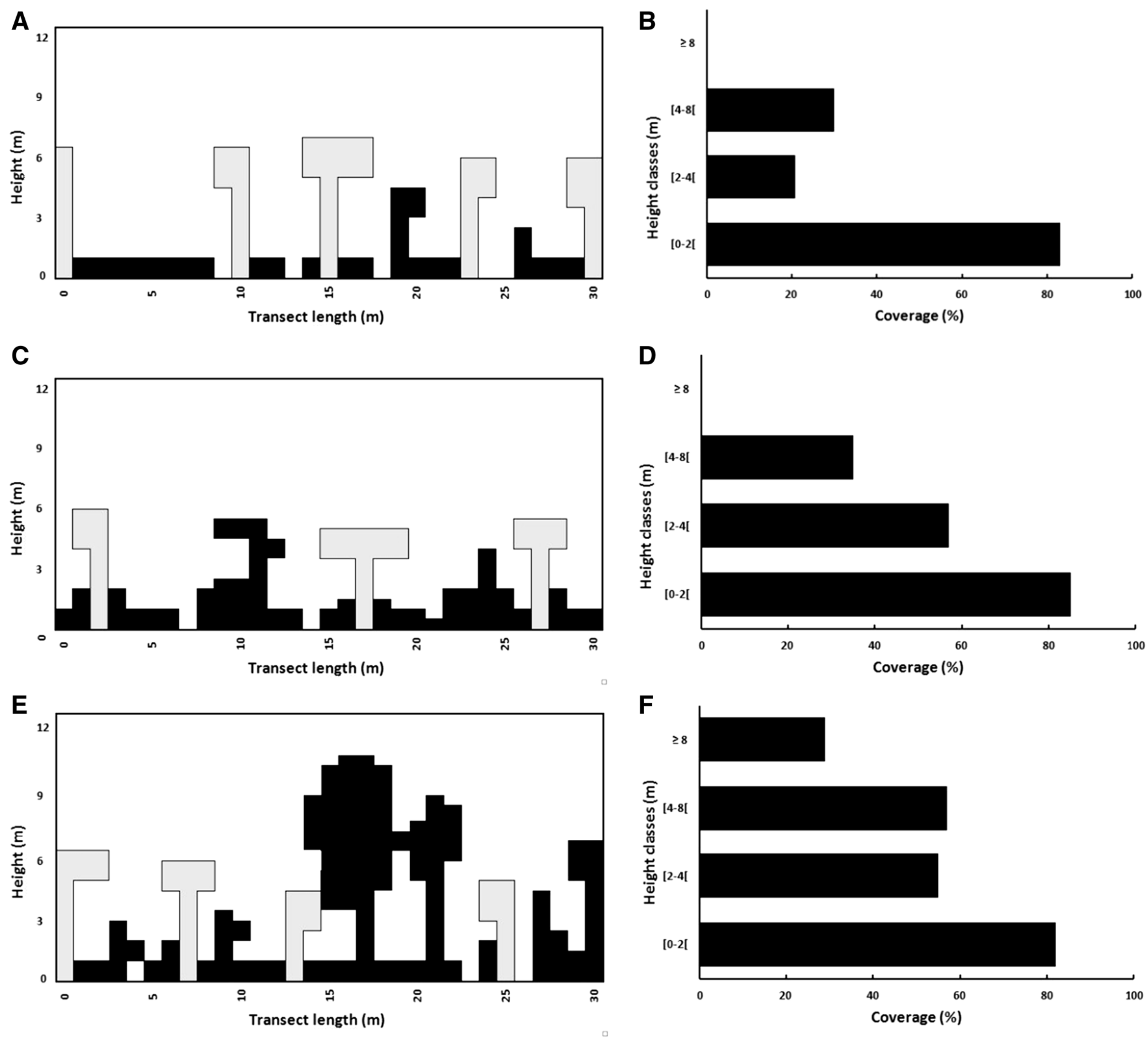

Fig. 6 Structural profiles and coverage diagrams of clove plantation systems on the east coast of Madagascar: monoculture (**a**, **b**), parklands (**c**, **d**), complex agroforestry system (**e**, **f**). The grey shaded areas represent the clove trees, the black shaded areas, the other species

The simplest system (G1), a monoculture of clove trees farmed without any accompanying cultivated species is mainly productive: production of clove and/or clove essential oil derived from the distillation of leaves and branches collected from pruning. These parcels of land are sometimes used for grazing zebu cattle (free-ranging or tethered) as indicated by Petit (1967), which is in fact "under-tree grazing" according to the definition of Torquebiau et al. (2002), but generally this system assimilates more with the system described by Nair (1985) as "agro-sylvo-pastoral systems with a commercial production function" or "Plantation tree crops" by Sinclair (1999). Michels et al. (2011) consider these parcels of clove trees characterised by the absence of weeding as a "monoculture orchard with minimized work".

The second cropping system identified associating cloves trees, trees and cultivated species (G2), corresponds to "parkland" of Torquebiau (2000) and Torquebiau et al. (2002). According to Michels et al. (2011), this system is a "simple AFS". Whereas Nair (1985) describes it as "agro-silviculture the purpose of which is to provide commercial production combined with subsistence production". But contrary to other

Fig. 7 Clove plot in monoculture (Fenerive-Est district)

parkland systems such as those of *Faidherbia albida*, *Vitellaria paradoxa* (shea) or *Parkia biglobosa* (locust bean) in Sahelian Africa (Vandenbelt 1990; Bernard et al. 1995; Wala et al. 2005), the main ligneous species (clove, in this instance) has been introduced and is non-native.

The third cropping system is more complex. The clove trees are associated with herbaceous and ligneous species, often cultivated, and less frequently forest species (G3). It corresponds to the definition of forest-gardens given by Torquebiau (2000). According to Nair (1985), it is an "agro-sylvicultural productive system the purpose of which is to provide a combined commercial and subsistence production", whereas for Michels et al. (2011), it is a complex AFS. The majority of species found there are fruiting. Forest species, represented by individuals often small sized juveniles, are generally characteristic of recent secondary formations or disturbed habitats, such as *Harungana madagascariensis*, *Albizia* sp. and *Desmodium* sp., whilst only the few *Intsia bijuga* observed in these parcels are indicative of undisturbed coastal forests (Table 3) (Thiel 1975; Du Puy et al. 2002; TROPICOS 2016). The low forest component differentiates this system from the "garden-forests" defined by Wiersum (2004).

Old stocks of clove trees

The surveyed plantations were probably established, for the most part, between the colonial period from 1940s to 1960s or 1970s, even though some recent plantations are observed. This can be generalised to the majority of the zone's clove trees. After this date, and despite the actions of major programmes to support the clove tree plantations (Maillot 2014; Leydet 2015), relatively few new plantations seem to have been undertaken and observed in the field.

Historical perspective of the evolution of clove based cropping systems

Today, clove trees, mostly planted during the colonial period and up to the 1970s, are present in three different AFS: monoculture, tree parks and complex agroforestry systems, with a wide variation in density. These three cropping system patterns are therefore an evolution of the systems put in place in the first half of

Table 4 Synthesis of plants most often accompanying clove trees in different clove based cropping systems on Madagascar's east coast

Species most frequently associated with clove trees	Cropping system		
	Monoculture	Woodland	Complex agroforestry system
Cultivated herbaceous		*Manihot esculenta* (Euphorbiaceae)	*Vanilla planifolia* (Orchidaceae)
		Oryza sativa (Poaceae)	*Musa paradisa* (Musaceae)
		Saccharum officinalis (Poaceae)	
		Zea mays (Poaceae)	
Wild herbaceous	*Stenotaphrum dimidiatum* (Poaceae)	*Clidemia hirta* (Melastomataceae)	*Stenotaphrum dimidiatum* (Poaceae)
	Cynodon sp. (Poaceae)	*Tristema verusanum* (Melastomataceae)	*Cynodon* sp. (Poaceae)
	Ageratum conyzoïdes (Asteraceae)	*Ageratum conyzoïdes* (Asteraceae)	*Ageratum conyzoïdes* (Asteraceae)
	Bidens piloza (Asteraceae)	*Ravenala madagascariensis* (Strelitziaceae)	*Clidemia hirta* (Melastomataceae)
	Ravenala madagascariensis (Strelitziaceae)		*Emilia citrina* (Asteraceae)
Cultivated ligneous	*Coffea arabica* (Rubiaceae)	*Coffea arabica* (Rubiaceae)	*Annona muricata* (Annonaceae)
		Artocarpus heterophyllus (Moraceae)	*Annona reticulata*(Annonaceae)
		Artocarpus altilis (Moraceae)	*Annona squamosa* (Annonaceae)
		Litchi chinensis (Sapindaceae)	*Coffea arabica* (Rubiaceae)
		Nephelium lappaceum (Sapindaceae)	*Artocarpus heterophyllus* (Moraceae)
			Artocarpus altilis (Moraceae)
			Litchi chinensis (Sapindaceae)
			Nephelium lappaceum (Sapindacea)
			Citrus reticulata (Rutaceae)
			Citrus spp. (Rutaceae)
Spontaneous and forest ligneous	*Harungana madagascariensis* (Clusiaceae)	*Harungana madagascariensis* (Clusiaceae)	*Harungana madagascariensis* (Clusiaceae)
	Psidium catleyanum (Myrtaceae)		*Intsia bijuga* (Fabaceae)
	Psidium guajava (Myrtaceae)		*Desmodium* sp. (Fabaceae)
	Syzygium malaccense (Myrtaceae)		*Albizia chinensis* (Fabaceae)

the twentieth century (Danthu et al. 2014; Cocoual and Danthu 2018).

Presently, the plots managed in monoculture have a clove density of around 250 plants/ha corresponding incidentally to that recommended previously by the agricultural technicians of the colonial era (Ledreux 1928, 1932b; François 1936; Boiteau 1936; Leroy 1946) aimed at the colonial plantations. These plots, as

Fig. 8 Woodland where clove trees are associated with cultivation of rain fed rice (Ambodimanga II)

Fig. 9 Complex agroforestry system associating cloves with fruiting trees (breadfruit, lychee, *Citrus*) (south-east of Tamatave)

observed in our previous 2010/2016 surveys in Sainte Marie areas (Penot et al. 2016), originate either from the minimally-degraded, old colonial plantations or from the native farmers plots, initially densely planted, which have thinned out over time without the owner having taken any action to restock or replace the missing plants. These plots are almost exclusively valorised by products derived from the clove trees (essence and cloves).

At the present time, the parks with low density plantings of clove trees (around 150 plants/ha) are probably from former dense plantations established during the colonial period, which have suffered a strong clove tree density erosion. Current farmers have therefore developed a strategy of diversification and value both the original crop, the clove, as well as the accompanying annual and perennial crops, essentially food stuffs, using more or less long fallow periods in extensive pasture.

Complex AFS sheltering clove are never described in the former publications. They are not explicitly referred by Ledreux (1928), François (1936), Isnard (1951) or Maistre (1964). These authors understood the clove tree only in pure and aligned plantations. They did not consider small local planters' plots, even if they represented, according to Isnard (1951), approximatively two-thirds of surfaces planted in clove trees. The origin of these current complex AFS is probably mixed plantations (agroforests, home gardens, forest-gardens) established by these first Malagasy farmers, systems considered by colonial technicians to be of no value. They may also have derived from the same origin as the parklands: a former plantation with a declining clove tree density that the farmer will have complemented with fruit trees.

Our study, completing the works of Michels et al. (2011), Danthu et al. (2014) and Cocoual and Danthu (2018), proposes a final typology of clove based cropping systems in Fenerive-Est District. We identify and describe three systems: monoculture, parkland and complex SAF. We situate this typology using a historical perspective, combining the directives of the colonial powers with the perceptions and strategies of the local farmers.

This knowledge sheds some light on current issues concerning cloves in Madagascar including the urgency to renew current ageing plantations as stated by Leydet (2015), trade-offs between the production of cloves and essential oil [clearly demonstrated by Fourcin et al. (2015)] and competition between cash crops and food crops aimed at safeguarding food security (Mariel et al. 2016).

Combined with the works of Cocoual and Danthu (2018), Penot et al. (2016, 2017), Gestin (2016) on Sainte Marie, Fenerive-Est, Mananara, our work also highlights that the issues relating to cloves in Madagascar vary according to time and space and must be approached with consideration to the diversity of the local contexts, each of which presents their own specific past and present features. Clove has definitely left its mark on the landscape.

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