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## Local Knowledge of the Interactions between Agrobiodiversity and Soil: A Fertile Substrate for Adapting to Changes in the Soil in Madagascar?

Juliette Mariel<sup>1,2\*</sup>, Vincent Freycon<sup>3,4</sup>, Josoa Randriamalala<sup>5</sup>, Verohanitra Rafidison<sup>6</sup>, and Vanesse Labeyrie<sup>1,2</sup>

**Abstract.** *In the tropics, the reduction in fallow periods in shifting rice cultivation and deforestation have led to soil degradation. How crop diversity is managed by farmers to adapt to this change remains poorly studied. Our study in Madagascar focuses on the management of 38 species in agroforestry, a practice that was gradually adopted by Betsimisaraka farmers to replace shifting rice cultivation. We describe how farmers perceived changes in the soil and how they adapted their farming practices to these changes, and analyze their knowledge of the interactions between the different plant species and the soil (soil-agrobiodiversity interactions) that underlie these adaptations. The farmers' perceptions of changes in the soil, their causes and consequences, were recorded in 19 individual interviews and three focus groups. Farmers' knowledge of soil-agrobiodiversity interactions was recorded in 84 individual surveys and one focus group. Farmers grouped soils in two main classes according to the topography and used four criteria to characterize them. The main change in the soil they observed was the decline in soil fertility due to deforestation. In response to these changes, farmers changed their crop species and management practices (e.g., spatial organization of crops, fertilization, species associations). These adaptations are based on shared knowledge of the soil requirements of crop species and their effect on fertility, despite the recent adoption of agroforestry. Our study highlights the dynamic and holistic dimension of farmers' knowledge of the soil and its interactions with different plant species.*

**Keywords:** *changes in the soil, farmers' knowledge, soil-plant interactions, agrobiodiversity management, Madagascar*

### Introduction

In many tropical countries, shifting cultivation has long been the main form of subsistence farming for people who live in and relate with the forest (Cairns 2007; Pollini 2014). Shifting cultivation is based on a three-phase cycle of slash-and-burn clearing, cultivation, and fallow (FAO 1984; Messerli 2003). With population growth, farmers are reducing fallow time because less land is available. This reduction leads to

soil degradation, i.e., the decreased capacity of soil to provide ecosystem goods and services (Adhikari and Hartemink 2016), including soil erosion and loss of soil fertility. Following Karlton et al. (2013), we define soil fertility as the state of a soil that combines inherent (mineral composition, texture) and changing (structure, organic matter content, phosphorus concentration) qualities that give the soil different functional capacities (e.g., supporting plant

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growth). Soil fertility is typically assessed either by crop yield or through indicators like organic matter content, indicator plants, and water holding capacity. Soil erosion and soil nutrient exploitation resulting from shifting cultivation impact agricultural productivity, thus raising concerns about the sustainability of this practice (ICRAF 1995; Mazoyer and Roudart 2017). Thus, in many places throughout the tropics, farmers are adapting their farming practices to the new constraints resulting from changes in the soil (Padonou et al. 2014; Saito et al. 2006).

Local knowledge plays a key role in the process of co-evolution between farmers' practices and soils by helping design sustainable management methods for agricultural soils (Altieri and Anderson 1986). Farmers' knowledge is location specific and culturally relative; i.e., associated with a system of references, values, and symbols specific to the population (Niemeijer and Mazzucato 2003). The ethnopedology literature highlights the importance of documenting farmers' knowledge of their soils to get a holistic understanding of the sustainability issues related to its management (Milne 1947; Sillitoe 2006). A large share of this literature focuses on the indicators used by farmers to assess soil fertility at a given time (Brinkmann et al. 2018; Dawoe et al. 2012; Karlton et al. 2013; Moges and Holden 2007; Padonou et al. 2014; Styger 2007). However, studies documenting local knowledge about changes in the soil and adaptation over time are lacking (Niemeijer and Mazzucato 2003). In a context of agricultural transition, in our case in Madagascar, where Betsimisaraka farmers recently shifted from slash-and-burn agriculture (*tavy*) to agroforestry systems (Arimalala et al. 2019; Mariel et al. 2021; Michel et al. 2021), it is important to document farmers' local knowledge of the changes in the soils to be able to support local and agrobiodiversity-based agricultural development. Such knowledge is instrumental in helping farmers build agroecosystems that are resilient to global changes and adapted

to local conditions (Altieri 2002; Jackson et al. 2010).

A second gap in the ethnopedology literature concerns local knowledge of the management of plant biodiversity in relation to changes in soils. Indeed, agrobiodiversity, which includes both cultivated plants that are introduced into the agroecosystem by farmers (Altieri 2002) and spontaneous plants that naturally colonize the agroecosystem (Vandermeer and Perfecto 1995), is a key resource to adapt to environmental heterogeneity and changes, including changes in soils (Niemeijer and Mazzucato 2003). Previous studies documented farmers' practices for the management of the different plant species in relation to soil in space (Junqueira 2015) and over time (Mbow et al. 2008; Padonou et al. 2014). Other authors focused on local knowledge of plant species as indicators of soil fertility (Dawoe et al. 2012; Grossman 2003). However, few studies have documented farmers' knowledge concerning the use and management of agrobiodiversity (i.e., the diversity of plant species as a whole) to cope with changes in soil fertility.

Our study focuses on the knowledge of soil-plant interactions held by Betsimisaraka farmers of the northeast coast of Madagascar. Since the middle of the twentieth century, farmers in this area have been engaged in a transition from shifting agriculture (*tavy*) to agroforestry, in which soil and changes in the soil play a key role. The first objective of our study was to document the observations of local farmers concerning changes in soil in the hills (*tanety*), their causes and consequences, and how farmers modified their *tanety* cultivation practices to cope with these changes. Assuming that species diversification associated with agroforestry practices is the main way for farmers to adapt to these changes in the soil, our second objective was to describe farmers' knowledge of the interactions between soil and agrobiodiversity. To better understand changes in cultivation practices, especially the way farmers manage plant species in

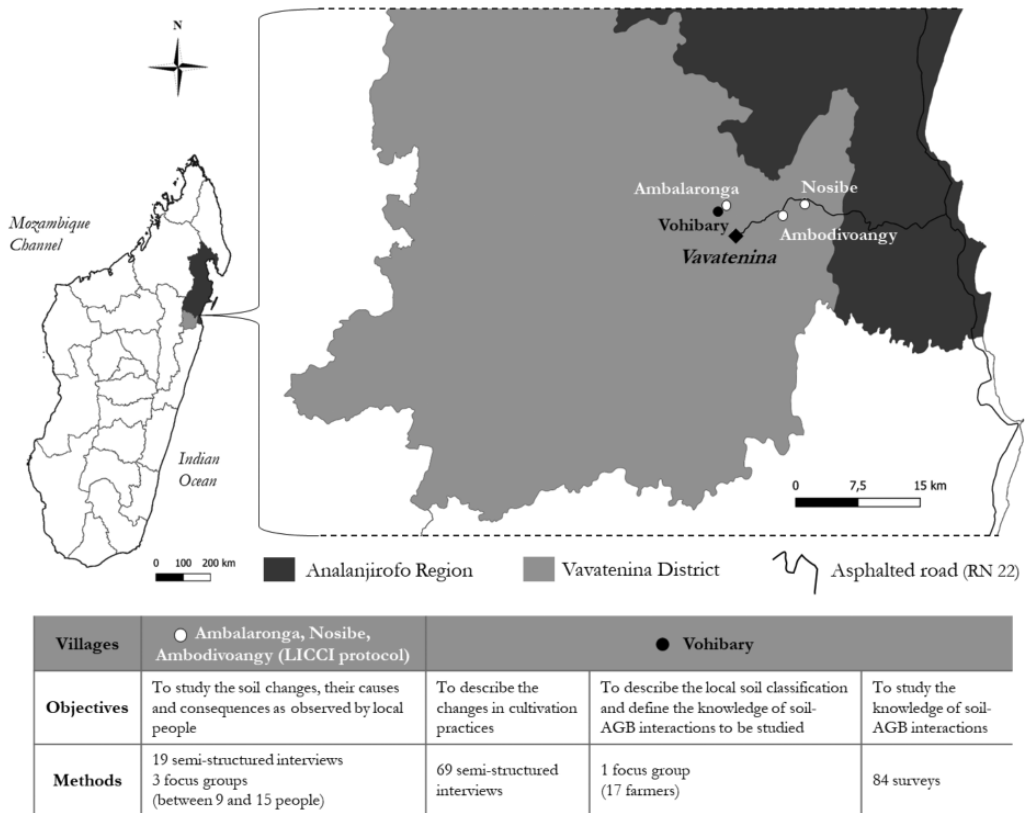
their agroforests according to their interactions with the soil and its variability in space and over time, we documented the local farmers’ classification of soils, and the way farmers think the different plant species affect soil fertility, and, in return, are affected by it.

Material and Methods

Study Site

The study was conducted in the four Betsimisaraka villages of Ambalaronga, Nosibe, Ambodivoangy, and Vohibary, located in the rural district of Vavatenina, in the Analanjirofo region on the northeast coast of Madagascar (Figure 1). The Vavatenina area is characterized by a humid tropical climate, annual average rainfall 3600 mm, annual average temperature 24 °C (Jury

2003). The cool winter rainy season lasts from June to September and the hot summer rainy season from October to May. Regular cyclones affect the area between December and March. The Vavatenina landscapes are characterized by *tanety* (convex hills), separated by narrow valleys in which the lowlands are used to cultivate irrigated rice, which is the main staple food of the Malagasy people. The *tanety* are characterized by summits whose altitude increases from 200 and 500 masl from east to west, and steep slopes that can reach 50°, thus exposing the *tanety* to a high risk of erosion. The *tanety* soils are mostly ferralsols or acrisols (IUSS Working Group WRB 2014) and their depth varies depending on the topography and the intensity of erosion (Dandoy 1973). The lowland soils are gleysols and the soil at the bottom of the slopes has humic properties.



**Figure 1.** Presentation of the study area and the different methods applied in the villages surveyed. AGB: AGroBiodiversity; LICCI: Local Indicators of Climate Change Impacts Research Program.

These soil and climatic conditions favor the development of rich agrobiodiversity. The *tanety* may be cultivated either with a single species, such as clove trees (*Syzygium aromaticum*) or cassava (*Manihot esculenta*), or *tsabo*, a local term used to describe land cultivated with several associated species, including edible species. The species in a *tsabo* may be woody plants, such as clove trees, coffee trees (*Coffea canephora*), fruit and timber trees, herbaceous plants, such as banana (*Musa* sp.), sugarcane (*Saccharum officinarum*), pineapple (*Ananas comosus*), and tubers (e.g., yam, *Dioscorea* sp.), or lianas, such as vanilla (*Vanilla planifolia*). The *tsabo* may also include herbaceous and woody fallow species and several species of bamboo (Bambusoideae). The size of each *tsabo* ranges from 0.1 ha to 1 ha (Mariel et al. 2021). Thus, the specific composition and structure of the *tsabo* are very variable and are at the origin of more or less diversified agroforestry systems of varying complexity. Most of the products from *tsabo* are self-consumed by households. Some (e.g., bananas, yams, avocados [*Persea americana*], and various leafy vegetables [*Spilanthes oleracea*]) are sold at the Vavatenina market and sometimes in the Fenerive market, located 60 km away. Only the products of clove trees (cloves and essential oil), vanilla, and lychees (*Litchi chinensis*) are exported, after being transported to the port of Tamatave, about 100 km away.

### Ethics Approval

The study was conducted respecting the Code of Ethics of the International Society of Ethnobiology (ISE 2018). A research permit was issued by the General Secretary of the Malagasy governmental institution Directorate General for the Environment and Forestry before the study began (N°299/19/MEDD/SG/DGEF/DGRNE). Before any interviews were conducted in the village, a meeting was held with the village leader and the inhabitants to fully inform them of the purpose of the study and how it would be conducted. The methodology, the type of data collected, and its future use were

explained to farmers so they understood what participating in the surveys would involve and the expected benefits of the study. The farmers participated voluntarily, were free from coercion, and had the right to withdraw at any time. Before taking part in the interviews, the farmers gave their prior informed verbal consent.

### Interviews and Focus Group

All the interviews and focus groups were carried out by at least one researcher and our local interpreter. We always worked with the same interpreter so the questions and answers were always translated in the same way, thus ensuring the consistency of the information collected. Before the beginning of the interviews and the focus groups, a preliminary stage of clarification and understanding of the surveys was carried out with the interpreter.

### *Changes in the Soil: Causes and Consequences*

We applied the protocol developed by the LICCI research program (Local Indicators of Climate Change Impacts<sup>1</sup>) in November 2019 following two steps (see table in Figure 1). First, we conducted 19 semi-structured interviews in the three villages of Ambalaronga, Nosibe, and Ambo-divoangy to record changes in the soil observed by local people. By describing the changes to the local soil, along with the farmers' soil classifications, we followed the approach of Niemeijer and Mazzucato (2003), who emphasized the importance of not considering farmers knowledge as static, but also how knowledge changed over time. Next, we coded the changes in the soil and their drivers into indicators in the four classes proposed by Reyes-García et al. (2021): climatic, physical, biological, and socio-economic systems. Second, we held three focus groups (one per village, each with between nine and 15 participants) in order to collectively define whether the observations from the semi-structured interviews were consensual. At the end of the three focus groups, we retained only the observations



that had reached a consensus and that cited the soil, either as an indicator of change in the physical environment or as a factor of change. To access different knowledge and perception profiles in both the interviews and focus groups, we chose people of different ages and gender and whose livelihood activities were linked to the use of environmental resources.

### *Changes in Cultivation Practices in Response to Changes in the Soil*

Between October and November 2019, we conducted 69 semi-structured interviews in the village of Vohibary to explore which cultivation practices had changed over the past three generations. The questions we asked were: 1) Could you explain what has changed between the current cultivation practices of *tanety* and those of elders; and 2) Why and how do you think these changes took place? We only analyzed responses in which the changes in cultivation practices the farmers described were caused by a change in the soil. We classified the responses according to the type of practice (i.e., cultivation technique, fertilization, changes in equipment, and in work time) and the type of modification (i.e., adaptation of an existing practice, abandonment or adoption of a new one).

### *Local Knowledge of Soil and Soil-Agrobiodiversity Interactions*

In April 2019, we organized a focus group with 17 farmers of different age categories located in Vohibary. The first step was to find out how they classified and described *tanety* soils. The questions we asked were: 1) How many soil classes do you differentiate on *tanety* and according to the topography; 2) What do you call them; and 3) Can you describe them? The second step of the focus group was to explore local knowledge concerning the interactions between the different plant species and the soil (hereafter referred to as “soil-agrobiodiversity interactions”), specifically whether farmers adapted their plant species management practices to the differ-

ent classes of soil they defined. To this end, the farmers were asked to show the location of the different soil classes according to the topography in a *tsabo* drawn on the ground, and then to link the different plant species with the soil class on which the species grew best. The different plant species were represented by cards that could be moved around. The farmers’ explanations of the spatial distribution of plant species in the *tsabo* in relation to the soil classes and the topography helped identify groups of species based on their ability to adapt to the spatial heterogeneity of soils and on their effect on soil fertility.

To further explore these two aspects of the soil-agrobiodiversity interactions (i.e., the soil requirements and the effect of the plant species on soil fertility), 84 individual surveys were conducted with farmers (23 women and 61 men) from different households in Vohibary (about 65% of total households) (see the table in Figure 1). Two questions (A and B), formulated in a way with which local farmers were familiar, were posed concerning each of the 38 species that were characteristic of local agrobiodiversity and played an important role in the *tsabo* (Mariel et al. 2021). Question A asked whether the species *mifidy tany* (“chooses its soil,” i.e., whether it requires particular soil conditions) or whether, on the contrary, the species *tsy mifidy tany* (“does not choose its soil,” i.e., it can adapt to all soil conditions). Question B asked whether the species *mandalonaka tany* (“makes the soil fertile”), *mampatoy tany* (“makes the soil infertile”), or *tsy miova* (“is soil neutral”).

## **Results**

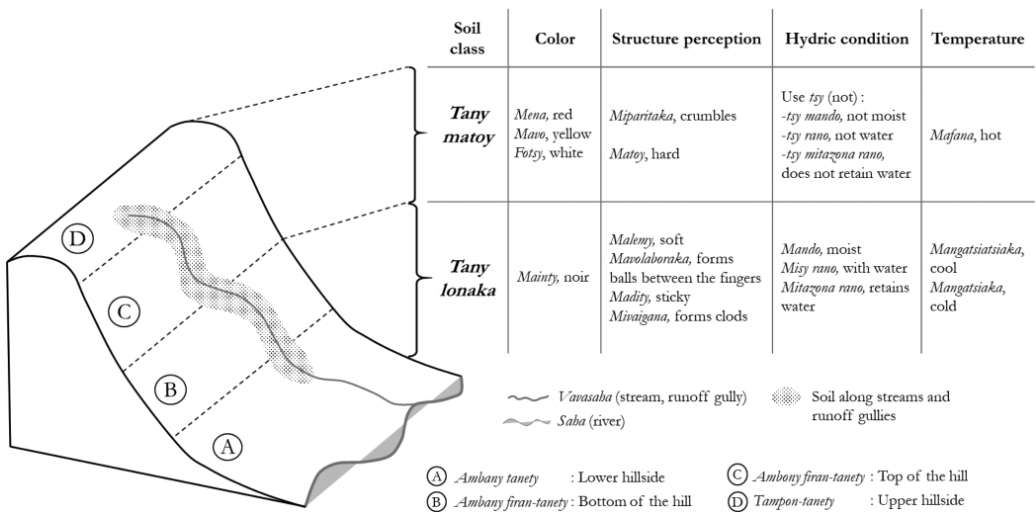
### **Local Soil Classification**

Farmers in Vohibary differentiated two main classes of soil in relation to the topography of the *tanety*: the *tany lonaka* (fertile soil), associated with the lower part of the hill (Figure 2A, B) and *vavasaha* (runoff gullies), and the *tany matoy* (literally “at the end of its life”), associated with the

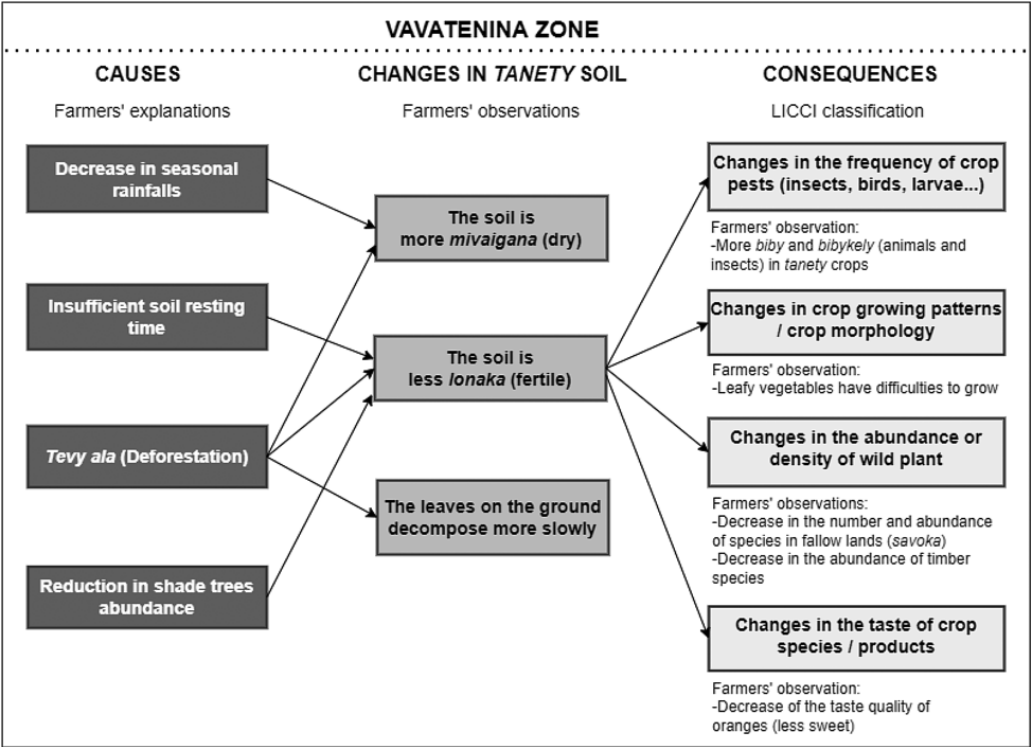
upper part of the hill (Figure 2C, D). The word *mamokatra* (contraction of *mamoa* [fruiting] and *vokatra* [harvesting/production]) has been used to describe highly fertile soils that enhance plant growth and yield. The same word is also used to refer to a woman who has many children. To further describe these two soil classes, farmers used four criteria: color, structure, hydric condition, and temperature (Figure 2). According to the farmers, some spontaneous species develop more easily than others on the two classes of soil. On a *tany lonaka*, the species are herbaceous plants (*Stenotaphrum dimidiatum*, *Clidemia hirta*) and the invasive vine *takohaka* (*Rubus alceifolius*). On a *tany matoy*, the species are mainly *tenina* (*Imperata cylindrica*), *ovotra* (*Ravenala madagascariensis*), and different ferns (e.g., *Pteris* sp.) that quickly colonize the area. Farmers further distinguished the two classes by explaining that the soil on the lower part of *tanety* and near streams was more *fasika* (i.e., sandy). The word *ambaratonga* (literally “ladder”) was sometimes used by the farmers we interviewed to specify that the soil was not uniform in depth. This metaphor could be related to the notion of soil profiles and horizons used by soil scientists.

Changes in the Soil: Causes and Consequences

People from Vavatenina area unanimously reported observing three changes in the soil: reduced fertility, increased compactness, and the slower decomposition of leaves left on the surface of the soil (Figure 3). Overall, the changes affecting *tanety* soils made it less fertile, drier, harder, and hotter. People reported that the main cause of these changes was *tevy ala* (deforestation). Overexploitation of the land due to a shorter fallow period and the lack of shade trees were cited as drivers of reduced fertility. The decrease in seasonal rainfall was mentioned as a cause of soil drying. Local people reported that reduced soil fertility was the change in soil that most impacted their livelihood, mainly because it affected crops. They mentioned in particular that reduced soil fertility: 1) increased crop pests and diseases; 2) had negative impacts on crop growth; and 3) had negative impacts on the taste of fruits and tubers (Figure 3). The fourth consequence reported by farmers concerned the non-cultivated vegetation of *tanety* (i.e., the fallow land and the stands of woody trees), specifically, a negative impact on their species richness and the abundance of the different species.



**Figure 2.** Local classification of *tanety* soils described by farmers from Vohibary in focus group (N = 17). The table details the types of criteria used to differentiate the two soil classes.



**Figure 3.** Presentation of *tanety* soil changes, their causes and consequences that were described by people of the Vavatenina zone (from Ambalaronga, Nosibe, and Ambodivoangy villages) and confirmed during focus groups conducted in the three villages. The protocols applied were developed by the LICCI research program<sup>1</sup>.

**Changes in Cultivation Practices**

To cope with soil degradation, the farmers in Vohibary identified seven types of changes in cultivation practices (Table 1). The adoption or adaptation of species associations and the use of organic matter inputs were the main changes made to cope with the reduction in fertility, in soil water content, and with the increase in soil compactness. For example, the use of *tain'ny aomby* (zebu [*Bos* sp.] manure) and *zezika* (composted plant material, primarily intended for fertilizing vegetable gardens) was applied to plantations in *tsabo* (Table 1; Figure 4). Another example was the cultivation of silky oak (*Grevillea robusta*) in association with clove trees. The farmers explained that silky oak had the ability to fertilize the soil and keep it moist. In addition, increasing their work time and using different tools (a pickaxe) were other ways

of adapting to changes in the soil. Overall, the farmers now had to spend more time in their *tsabo* to care for their plants and trees. Planting techniques were also adapted to cope with the reduction in fertility; for example, by digging deeper holes and filling them with *zezika* for the transplant of young clove trees. Two other planting techniques were adopted: the establishment of small individual clove tree nurseries, to replace “broadcast” seed planting, and the planting of yams in rice bags filled with a mixture of soil and sand, to allow the tubers to grow more easily.

**Local Knowledge of Soil-Agrobiodiversity Interactions**

Farmers in Vohibary defined their *tsabo* according to the two soil classes: *tany lonaka* (fertile soil) at the bottom and the *tany matoy* (infertile soil) at the top (Figure 5). The discus-



**Table 1.** Changes in cultivation practices initiated by farmers from Vohibary in response to soil changes, based on the type of change (adoption, adaptation, abandonment) and the type of practice.

| Type of change               | Types of practices   |
|------------------------------|--|
| Adaptation                   | <b>Changes in planting tools</b>   |
|                              | - Use of more powerful tools to dig the soil (as <i>angady</i> : pickaxe)  |
|                              | <b>Changes in working time</b>   |
| Adoption<br>or<br>Adaptation | - Increasing in working time spent caring for <i>tsabo</i> plantations and maintaining crops   |
|                              | - Increasing in the frequency of weeding   |
|                              | <b>Practices of species associations</b>   |
| Adoption<br>or<br>Adaptation | - Planting silky oak ( <i>Grevillea robusta</i> ) to increase soil moisture  |
|                              | - Planting silky oak to fertilize the soil   |
|                              | - Planting vanilla at the foot of banana   |
| Adoption<br>or<br>Adaptation | - Planting shade trees (silky oak, <i>Albizia stipulata</i> . and <i>lebbeck</i> )   |
|                              | <b>Techniques of organic matter input</b>  |
|                              | - Use of <i>tain'ny aomby</i> (zebu manure)  |
| Adoption<br>or<br>Adaptation | - Collecting leaves, grasses and young branches of <i>Litsea glutinosa</i> at the feet of banana and clove trees                             |
|                              | - Use of <i>zezika</i> (mixture of zebu manure, dry leaves, vegetable waste, and household garbage)  |
|                              | <b>Techniques of planting</b>  |
| Adoption<br>or<br>Adaptation | - Making deeper holes when transplanting clove trees   |
|                              | - Filling the holes with <i>zezika</i> for the transplantation of clove trees  |
|                              | - Use of jute bag filled with sand to plant yam tubers   |
| Adoption<br>or<br>Adaptation | - Designing small individual clove tree nurseries  |
|                              | - Making shelters in branches and leaves of traveller's palm ( <i>Ravenala madagascariensis</i> ) to protect young clove plants from the sun |
|                              | - Covering surface roots with leaves   |
| Abandonment                  | <b>Cultivation practice</b>  |
|                              | - Rice shifting cultivation  |
|                              | <b>Crop species</b>  |
| Abandonment                  | - Coffee tree, taro  |

sion with farmers during the focus groups enabled the identification of five groups of species based on their spatial distribution in the *tsabo* and their interactions with the two soil classes. The first group consisted of raffia (*Raphia farinifera*) and bamboo

(*Bambusa* sp.), planted at the bottom of the *tsabo* because of their need for very wet soil, as well as at the edge of the *tsabo* because their roots *mampatoy tany* ("make the soil infertile"), according to the farmers; for this reason, these species should not be planted

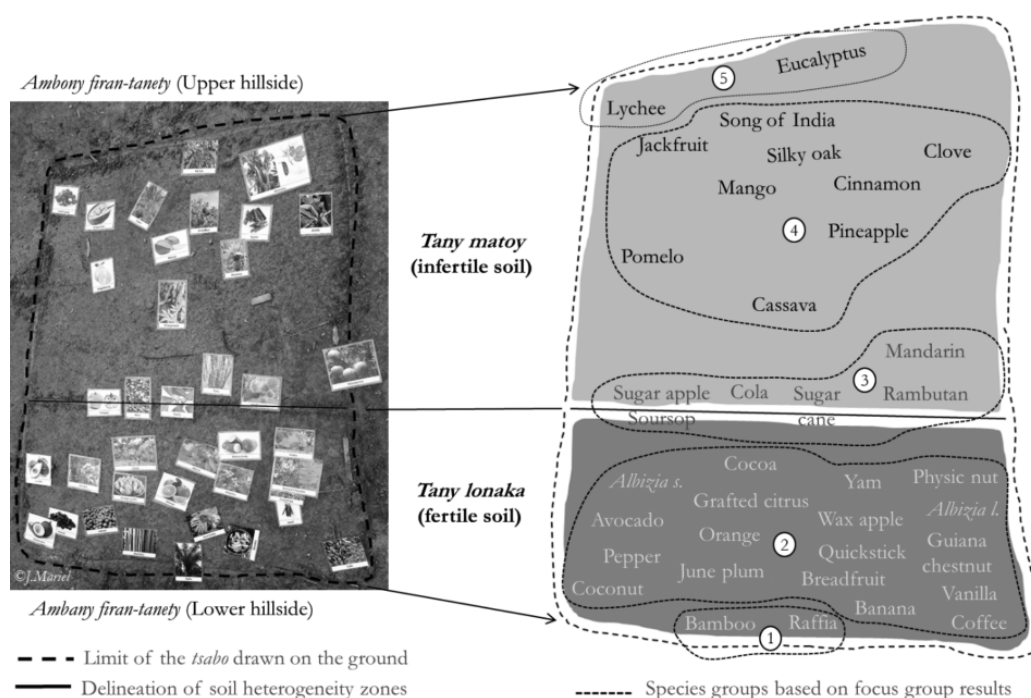


**Figure 4.** Photographs taken by J. Mariel during several visits to *tsabo* owned by farmers from Vohibary. These photographs illustrate different soil fertilization techniques through the addition of organic matter. A) Collecting leaves, grasses, and young branches of *Litsea glutinosa* at the feet of banana and clove trees; B) Collecting peelings and rotten fruits at the feet of vanilla; C) Composting the banana stems with household and vegetable waste, zebu and pig manure and chicken droppings; D) Cutting a dead banana stem into small pieces and piling them up at the feet of vanilla.

near other species. The second group consisted of 17 species, mainly fruit species associated with coffee (*Coffea canephora*) and vanilla (*Vanilla planifolia*), and shade trees such as *Albizia stipulata* and *Albizia lebbbeck*. The farmers explained that these species needed to be planted in a fertile soil to enable good growth, good quantity, and quality yields. The third group was characterized by five species (four fruit trees and sugarcane) distributed at the boundary between the two soil classes. Farmers said that these species could grow on infertile soil but that they became productive later than when planted in fertile soil. The fourth group included nine species described by farmers as being able to grow on a *tany matoy*. These species were mostly trees, especially clove, but also included non-woody species, such as cassava and pineapple (*Ananas comosus*). The fifth group included eucalyptus

(*Eucalyptus* sp.) and lychee (*Litchi chinensis*), two species adapted to a *tany matoy*; however, farmers explained that because these species “make the soil infertile,” they had to be planted on the edge of the *tsabo*.

The analysis of the proportion of responses regarding whether or not each species *mifidy tany* (“chooses its soil”) showed that the level of agreement among the 84 farmers surveyed varied with the species. Among the 38 species discussed, the soil requirements (question A) were clear for four species that “choose their soil” (banana, yam, coffee, raffia) and 10 species that “do not choose” (e.g., clove, eucalyptus, lychee), for which more than 75% of farmers gave the same answer (Figure 6A). There was less agreement (between 75% and 60% of responses) between farmers concerning the soil requirements of nine species that “choose their soil” (e.g., vanilla, pepper

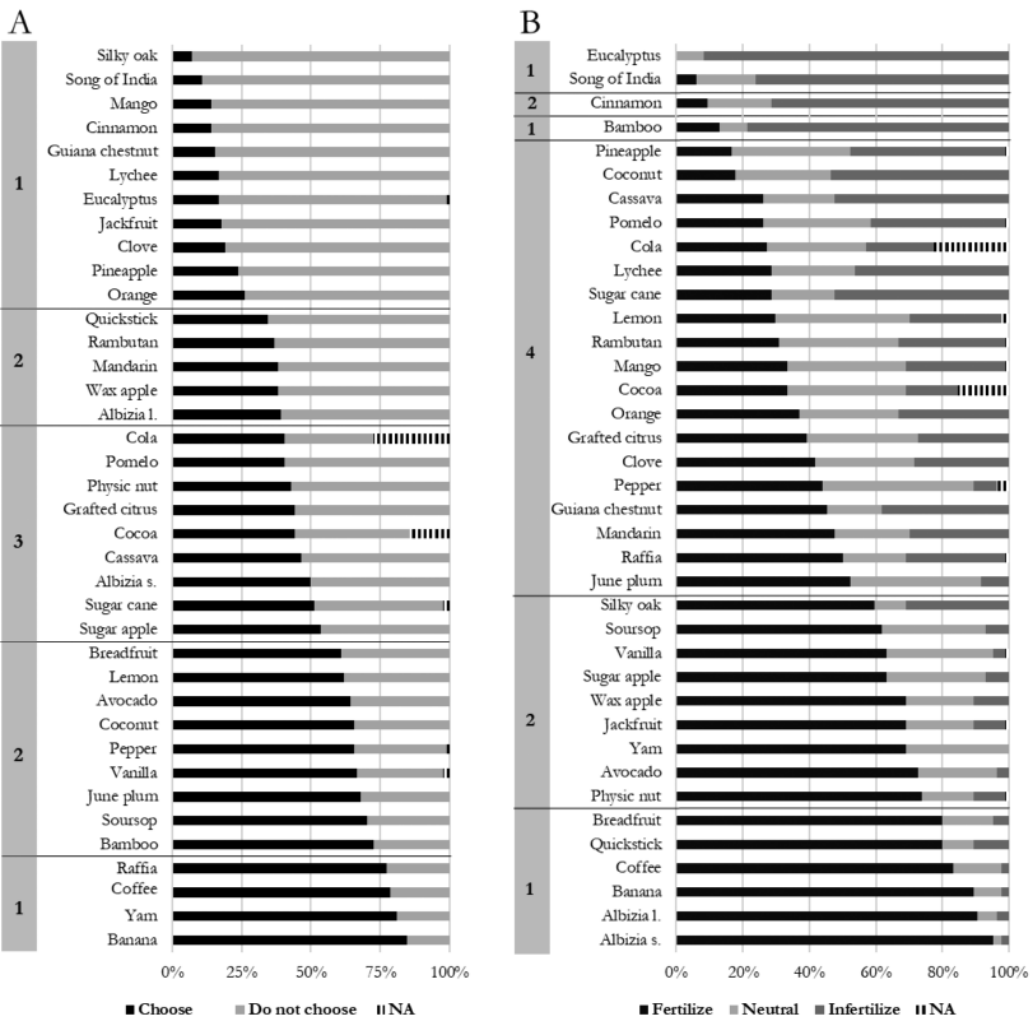


**Figure 5.** Result of the exercise carried out in focus group with farmers from Vohibary (N = 17), for which they were asked to distribute 38 plant species (cards) in a *tsabo* drawn on the ground, according to species adaptation to the different soil defined by the farmers' classification and related to the topography.

[*Piperum nigrum*], large bamboo) and six species that “do not choose” (mainly fruit trees). For the remaining nine species (e.g., two citrus species, *Albizia stipulata*, cassava, and sugar cane), there was no clear-cut response, as nearly half reported that these species “choose their soil” and the other half the opposite. We noted that farmers more frequently said “I don’t know” in response to question A concerning cola (*Cola acuminata*) and cacao (*Theobroma cacao*) than for the other species. Concerning question B, the effect of plants on soil fertility was clear (at least 75% of responses) for six species that *mandalonaka tany* (“fertilize the soil”), including the two *Albizia* species, quickstick (*Gliricidia sepium*), and banana, and three species that *mampatoy tany* (“make the soil infertile”), such as large bamboo, song of India (*Dracaena reflexa*), and eucalyptus (Figure 6B). For question B, the level of agreement was less clear (between 75% and 60%

of responses) for nine species that fertilize the soil (e.g., several fruit trees, yam, vanilla, and grevillea) and one species that “makes the soil infertile” (cinnamon [*Cinnamomum verum*]). The farmers explained that “it is often because of the roots that a plant makes the soil infertile” and gave the example of eucalyptus, which had *matoy vahitra* (“hard roots”). These *matoy vahitra* were characterized by a strong capacity to absorb soil water and to spread far and fast in the soil. The leaves were also mentioned because, when they were thick and leathery, they did not decompose well. Regarding the “neutral” effect on fertility, only pepper had a proportion of responses above 45%, and 14 other species had a proportion between 30% and 45%. Like with question A, cacao and cola accounted for the highest proportion of “I don’t know” answers.

Our comparison of the results of the knowledge study on soil-agrobiodiversity



Group 1: proportion of responses above 75%  
Group 2: proportion of responses between 60% and 75%  
Group 3: proportion of responses between 40% and 60%, and relatively high proportion of non-responses,  
Group 4: proportion of responses between 30% and 45%

**Figure 6.** Proportion of responses given by farmers from Vohibary (N = 84) for each species (N = 38) and according to the knowledge of soil-agrobiodiversity interactions: (A) the edaphic requirement of species; i.e., the species *mifidy tany* ("chooses its soil") or *tsy mifidy tany* ("does not choose"); (B) the effect of species on soil fertility; i.e., the species *mandalonaka tany* ("makes the soil fertile"), *mampatoy tany* ("makes the soil infertile"), or *tsy miova* ("does not change the soil").

interactions revealed that knowledge of the soil requirements of species was more shared by farmers than knowledge related to the effect of species on fertility, with 30 species (N = 38) for which more than 60% of respondents agreed on the answer for the former, as opposed to 19 species for the

latter. For some species, a comparison with the way farmers spatially distributed agrobiodiversity according to the soils of *tsabo* (Figure 5) revealed a clear link between spatial position, soil requirements, and their effect on fertility. Among the 21 species planted in the lower part of *tsabo* (Figure 5:

Group 1, 2), 13 species “choose their soil” and 12 “make the soil fertile” (proportion of responses more than 60%). Among the 11 species located at the top of the *tsabo* (Figure 5: Group 3, 4), nine species “do not choose their soil” and three “make the soil infertile” (proportion of responses more than 60%).

## Discussion

### Farmers’ Knowledge and Observations Provide a Holistic Perspective of the Soil and of Changes to the Soil

Our study provides insights into farmers’ observations of changes in soils and their drivers, which has been the subject of limited research in ethnopedology. In the Vavatenina area, people reported that the soil of *tanety* has become less fertile since the disappearance of the forest. The forest was still present in 1966, but the extent of the forest was very unequal in the Vavatenina landscape and, in Vohibary, only some remnants of primary forest remained (Dandoy 1973). These observations are in agreement with various scientific reports in Madagascar on soil degradation, including strong erosion and a decline in fertility (Brand and Pfund 1998; Gay-des-Combes et al. 2017), mainly resulting from the reduction in the fallow period for *tavy* rice production (Messerli 2003; Styger et al. 2007). Our interviewees did not explicitly mention *tavy* as the main cause for the loss of fertility and mostly cited deforestation. Farmers in Vohibary also used the expression *haign’andro be* (literally “sunburn”) to explain that, in the absence of trees, the soil surface receives too much sun, which dries out the land and makes it more difficult to cultivate. The farmers’ classification of soils reflects their perception of its degradation. They related the soil fertility criterion to the topography using the criterion of color (Figure 2). This classification logic is close to the concept of “catena” (Borden et al. 2020; Milne 1947), illustrating the process

of erosion made visible by changes in the color of the soil. In studies conducted in Madagascar (Brinkmann et al. 2018; Saito et al. 2006; Styger et al. 2007), the link between the soil classes distinguished by farmers and their distribution in the landscape in relation to topography is poorly described.

The focus group conducted with farmers in Vohibary showed that they differentiated *tanety* soils by using criteria related to soil physical qualities (compactness, moisture, and temperature). These criteria are commonly reported in other ethnopedological studies (Huynh et al. 2021; Karltrun et al. 2013; Moges and Holden 2007; Padonou et al. 2014), but, in our context, they also referred to the environment in which the soil is located, including the topography, but also the level of shade and the plant species present through the effects of their leaves, roots, or architecture on soil moisture, temperature, and compactness. This indicates that the farmers’ perception of soil fertility is holistic and is not only limited to soil texture and color. In that sense, they have extended the concept of soil fertility to the fertility of the whole agro-ecosystem and adapted it to the changes they observed. In a study of Betsileo farmers in the highlands of Madagascar undertaken to document their knowledge of soils, Blanc-Pamard (1986) reported that *tanety* soils were described by only a few criteria, while paddy fields in the lowlands were differentiated in many classes associated with several combined criteria (e.g., color, moisture, texture to the touch, odor). In our study, Betsimisaraka farmers described *tanety* soils with precision, suggesting that *tanety* agriculture is more important to them than other forms of agriculture. One possible explanation is that, in the past, Betsimisaraka farmers were more reliant on *tavy* than the populations of the highland, who mainly relied on paddy rice. In addition, Betsimisaraka farmers have probably also increased their knowledge of *tanety* soils since the expansion of clove



cultivation (Danthu et al. 2014). Indeed, Niemeijer and Mazzucato (2003:409) argued that “when new crops are cultivated, different soil characteristics may become the most important discriminating factors between soil types.”

### **Farmers Apply Local Technical Adaptations to Cope with Degraded Soil**

Our study also documented changes the farmers made in their practices to adapt to soil degradation. Faced with degraded *tanety* soils, farmers in Vohibary apply a variety of fertilization, planting, tillage, and crop cultivation techniques that have also been observed in other tropical regions affected by soil degradation (Mbow et al. 2008; Padonou et al. 2014). To adapt to drier and harder-to-work soils, they used more robust tools, and they also reported spending more time working in *tsabo* (Table 1; Figure 4). The use of manure and composted materials are frequent examples of short-term adaptive practices, but their sustainability is questionable because they depend on livestock that require grazing areas, while land pressure is high on arable land. In our case, these practices were probably adopted after the 1970s, as Dandoy (1973) did not mention the use of zebu manure. He highlighted the low importance of livestock while Blanc-Pamard and Ruf (1992) mentioned this practice in relation with coffee cultivation in another part of the Analanjirofo region. The latter authors pointed out that this practice has become widespread with the return of young people from urban migration, for whom the only available land at an affordable price was degraded land. Thus, to “recolonize” these poor soils, holes were dug and filled with manure before planting coffee, similar to the *zai* technique used in the Sudano-Sahelian region to restore the fertility of arable land (Roose et al. 1993). We hypothesize that the same type of phenomenon occurred in Vohibary and, more broadly, in the Vavatenina area,

which was formerly a coffee-growing region. We also observed the use of two techniques for the cultivation of clove trees that were previously associated with coffee (Blanc-Pamard and Ruf 1992): the establishment of clove tree nurseries using compost or manure and the transplanting of young clove plants, also by digging holes and filling them with organic matter. Thus, farmers transposed the technical knowledge they acquired for coffee cultivation, but also for taro (*Colocasia* sp.) (Rakoto Ramiarantsoa and Lemoigne 2014), to clove trees, which gradually replaced coffee from the 1970s along the northeast coast (Danthu et al. 2014). Documenting these local coping practices, combined with farmers’ description of soils, could help develop technical recommendations for more sustainable local soil management based on farmers’ knowledge (Barrios and Trejo 2003; Huynh et al. 2021; Krasilnikov and Tabor 2003).

### **Farmers’ Knowledge of Soil-Plant Interactions Addresses Declining Soil Fertility through Agroforestry**

The main contribution of our study to the ethnopedology literature is to show that, in five decades, farmers developed new knowledge and practices based on the use of crop diversity to adapt to the changes in the soil resulting from their practice of shifting rice cultivation (*tavy*). Indeed, 50 years ago, farmers predominantly practiced *tavy* farming and frequently looked for new fertile soil by moving away from the village to still-forested areas: “the only remaining humus-bearing land is located on the tops of the highest hills that limit the *terroir*” (Dandoy 1973:16). Nowadays, we observed a variety of practices not only aimed at maintaining soil fertility but also at adapting to infertile soil; these practices are based on plant species diversification and on a detailed knowledge of their adaptation to the different types of soils, as well as on the impact of each species on soil fertility.

Species, such as silky oak and banana, are now planted for their positive effects on the soil and indirectly on other associated species, in particular, clove (Mariel et al. 2021), but also vanilla. The two *Albizia* species (*A. lebbbeck* and *A. stipulata*) that served as shade trees in coffee plantations (Blanc-Pamard and Ruf 1992) continue to be planted, not for the coffee trees but to maintain soil moisture and soil temperature that both contribute to soil fertility. Diversification and replacement of one species or variety by another are recurrent practices in response to soil degradation. However, the choice of a species or variety is often based on its ability to survive in the new soil conditions (Mbow et al. 2008; Padonou et al. 2014). In our case, our study of farmers' knowledge and practices shows that perennial species are also cultivated for their ability to regenerate soil fertility (Table 1; Figure 6), i.e., they represent a long-term adaptation strategy.

Documenting local knowledge of soil-agrobiodiversity interactions provides a better understanding of the role of soil in the spatial distribution of the species implemented by the farmers, which appears to result from their own choices, combining their knowledge of soil classification (linking fertility and topography) with their knowledge of soil-agrobiodiversity interactions (soil requirements of species and their effects on fertility). Dandoy (1973) and Blanc-Pamard (1986) reported similar observations, but at the landscape scale: "the apparent disorder of the rural landscape hides an adaptation of crops to each type of soil" (Dandoy 1973:26). Therefore, farmers seek to cultivate species with low soil requirements on infertile soil and know that other species need a fertile soil. Among the species that require a fertile soil, the farmers explained that many of them maintain fertility. These species include coffee and its two shade trees (*Albizia* sp.), as well as banana and many other fruit trees. Our observation concerning the distribution of coffee and banana according to the topography

and soil conditions of *tsabo*, mostly at the bottom of the slope and on the richer soils, is in line with the observations made by Blanc-Pamard and Ruf (1992). These authors reported that, in parallel with the monoculture coffee plantation promoted during the French colonial era, farmers developed diversified coffee plantations with various edible crop species (Blanc-Pamard and Ruf 1992). Dandoy (1973) also reported the association of coffee with fruit trees in home gardens whose soil was enriched by inputs of household waste.

Our study also sheds light on certain changes in cultivation practices induced by changes in the soil. In particular, the practice of associating species, such as silky oak with clove and banana with vanilla, is explained by the fact that more than 60% of farmers surveyed know that these two species "make the soil fertile" and, therefore, they can improve the growth and productivity of crops associated with them. The reason many fruit trees "make the soil fertile" is related to their unharvested fruits that fall to the ground. When the fruits collect at the feet of vanilla or clove trees and mix with dry leaves, they supply organic matter by decomposing.

This knowledge of soil-plant interactions forms a "fertile substrate for designing new technologies that respect both the environment and local practices" (Jankowski 2014) and calls for reflection on modes of fertility regeneration and restoration of degraded landscapes that are adapted to the agroforestry transition in the Vavatenina area. These practices could be based on the use of species that both fertilize the soil and have lower soil requirements, making it possible to plant them on degraded land as *mena* and *matoy* soil on *tanety*. This is notably the case for *Albizia stipulata* and *Gliricidia sepium*, two species of the Fabaceae family that help enrich the soil (Sharma et al. 1995; Szott and Kass 1993). Jackfruit (*Artocarpus heterophyllus*) and silky oak could also be planted in association with clove trees, especially since one tree is a

source of food and the other a source of wood (Mariel et al. 2021). Conversely, introducing cinnamon and eucalyptus in *tsabo* requires taking their negative effect on fertility into account to be sure their presence will not lead to deterioration of the soil and harm the surrounding crop species. Many researchers recognize that sustainable agroforestry practices are the product of local knowledge (Altieri 2004; Thapa et al. 1995), but more efforts are needed to co-construct agricultural development with local actors based on farmers' knowledge, articulated with scientific knowledge appropriate to the local context (Jacobi et al. 2017; Rist and Dahdouh-Guebas 2006).

### Conclusion

Our study shows that Betsimisaraka farmers observe changes in soils, which they mainly attribute to their own impact on the forest cover, and that these farmers continuously update their knowledge and management practices in response to such changes in the soil. Our results also reveal that farmers have a holistic view of the fertility that is not limited to soil characteristics, but includes the whole agroecosystem. Finally, by describing how farmers relate plant diversity to soil fertility and use this knowledge to adapt to changes in the soil, our study contributes to a topic that has been the subject of limited research in the field of ethnopedology. This study underlines the importance of including local knowledge of soil and its interactions with agrobiodiversity for the sustainable soil management in agricultural development projects.

### Notes

<sup>1</sup> <https://licci.eu/research-tools/>.

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