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Influence of slash-and-burn farming practices on fallow succession and land degradation in the rainforest region of Madagascar

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Abstract

Slash-and-burn agriculture (*tavy*) is the major cause of upland degradation and deforestation in eastern Madagascar. Upland degradation studies are largely based on floristic loss and have ignored the link to agriculture, the main activity on the uplands. The objectives were to analyze jointly with the Betsimisaraka farmers how slash-and-burn practices influence fallow species succession, and how current fallow/cropping regimes influence agricultural productivity and upland degradation dynamics. The study was conducted in the Vohidrazana/Beforona area, located at the margins of the Ankeniheny-Zahamena rainforest corridor. Semi-structured interviews were conducted in 9 villages resulting in 96 individual and 22 group interviews. These were complemented by 212 historical field plot inventories on 32 farms. The researchers' and farmers' knowledge systems were treated equally and complemented each other in the joint analysis. Over the last 30 years, fallow periods decreased from 8–15 years to 3–5 years. Hence, fallow vegetation is changing within 5–7 fallow/cropping cycles after deforestation from tree (*Trema orientalis*) to shrub (*Psiadia altissima*, *Rubus moluccanus*, *Lantana camara*) to herbaceous fallows (*Imperata cylindrica* and ferns) and grasslands (*Aristida* sp.), when land falls out of crop production. This sequence is 5–12 times faster than previously reported. The frequent use of fire is replacing native species with exotic, aggressive ones and favors grasses over woody species, creating treeless landscapes that are of minimal productive and ecological value. Unlike most discussions during the past 20–30 years that refer to fallow duration *per se* as a measure to soil recovery, our results show that fallow periods need to increase in length with each additional fallow/cropping cycle after deforestation in order to restore the soils to a similar level of productivity. Already with the third cycle after deforestation, vegetation starts to degrade quickly in parallel with agricultural productivity decline. The Betsimisaraka's fallow knowledge is very rich. Fallows are characterized by species life form, species composition, vegetation appearance, cycles after deforestation, and agricultural potential. Distinct fallow types are easily identifiable in the field and inform on the critical threshold, below which soils are lost to farming. Clear management guidelines go along with each fallow type. We recommend upland agricultural intensification and diversification based on improved soil fertility through optimized organic and inorganic inputs and fire-less land management that encourages the re-establishment of nutrient stocks. If young farmers perceive a real opportunity in agricultural intensification, the migration towards the forest borders to pursue *tavy* might be halted.

Keywords: *Tavy*; Betsimisaraka; Vegetation succession; Agricultural productivity; Biodiversity; Upland rice

1. Introduction

Slash and burn agriculture or *tavy* is the traditional and predominant land use practice of eastern Madagascar.

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Primary forest or secondary vegetation is cut, burned, and upland rice is cultivated for one season, followed by a root crop such as manioc or sweet potato. After the harvest, land is left to fallow. Detailed description of the *tavy* system can be found in Kiener (1963), Vicariot (1970), Terre-Tany/BEMA (1997, 1998) and Styger (2004). As elsewhere in the world, *tavy* is sustainable under conditions of low population density and abundant land, yet as early as 150 years ago and continuing today *tavy* was recognized as the principal cause of deforestation and subsequent upland degradation (Humbert, 1927; Kiener, 1963; Oxby and Boerboom, 1985; Gade, 1996; Marcus, 2001). During the last half-century, *tavy* induced deforestation and resultant loss of biodiversity has accelerated. Between 1950 and 1985, half of the then remaining eastern rainforest – 7,600,000 ha, or 68% of the original forest – was reduced to 3,800,000 ha or 34% of the original (Green and Sussman, 1990). Today, deforestation continues apace even though the forest remnants are among the most critical of the 25 global biodiversity hotspots (Myers et al., 2000).

Intensive *tavy* practice not only leads to forest and biodiversity loss, it severely degrades local and regional ecosystems. Frequent fires accompanying shortened fallow periods favors nutrient loss from *tavy* systems, which impacts on their productivity (Pfund et al., 1997). Fire also kills native, regenerating tree species and allows exotic, invasive shrubby and herbaceous species to colonize the open surfaces (Humbert, 1927; Koechlin, 1972; Lowry et al., 1997). Over time, recurrent cutting and fire cycles have produced landscapes with little secondary forest regrowth dominated by species-impoverished successional grasslands. These are subject to erosion and are abandoned for agriculture. The transition from rainforest to grassland through stages of fallows, often referred to as *Savoka*, has been described by a number of authors. Their analysis largely concentrated on botanical descriptions of vegetation group succession (Humbert, 1927; Lowry et al., 1997; FAO, 2000), or, in a step further, related succession to soil properties (Dandoy, 1973; Razafintsalama, 1996; Pfund, 2000).

In neither case have these studies linked vegetation changes directly to farming practices, *tavy* cycles, and agricultural productivity. Yet, given the fact that the rainforests are primarily deforested for cropping purposes and that farmers are the primary agents influencing vegetation change, understanding the linkage is a critical first step in developing and implementing sustainable agricultural practices and seeking the betterment of rural peoples' lives.

The objectives of this study were to analyze together with the local Betsimisaraka farmers how slash-and-burn practices influence fallow species change and succession, and how current fallow/cropping regimes influence agricultural productivity and upland degradation dynamics. From this information we (1) summarize the implications of current *tavy* practices on the future of agriculture, the landscape, and the farming communities and (2) recommend management interventions to minimize biotic and land degradation, and to support the development of a more sustainable, productive and profitable upland farming system.

2. Methodology

2.1. Study area

The Vohidrazana/Beforona study area is located at the margins of the Ankeniheny-Zahamena rainforest corridor, one of the largest remaining contiguous rainforests in the mid-eastern region of Madagascar. Most of the country's remaining rainforests are located along this mountainous range that stretches from North to South Madagascar parallel to the East Coast. The rainforest is classified as evergreen humid forest at low altitude (0–800 m) and mid altitude (800–1800 m) (Humbert, 1955; Faramalala, 1995; Du Puy and Moat, 1996). The altitudinal range of the study area is between 500 and 1200 m a.s.l. Annual rainfall is between 2550 mm (at 550 m a.s.l.) and 3450 mm (at 750 m a.s.l.) with annual mean temperatures of 21.5 and 20.4 °C, respectively. The soils are Inceptisols and Ultisols (US Soil Taxonomy) with moderate to high acidity (pH 3.5–5.0) and aluminum saturation between 60% and 90%. Nutrient contents, especially phosphorus, are extremely low in surface and subsoils, (Johnson, 1992; Brand and Rakotondranaly, 1997). The study area, typical of the eastern region, is characterized by the traditional slash-and-burn agriculture (*tavy*) of the Betsimisaraka people and by forest cover loss and soil degradation. Nine villages were selected located between 0 and 10 km from the forest boundary on the eastern and western side of the forest corridor (Table 1).

2.2. Deforestation and land use dynamics

Whereas next to the forest fallows are characterized by tree and endemic shrub species, the vegetation changes with increasing distance to the forest. At 10–15 km, exotic shrubs are dominating fallows, which eventually transforms into grass fallows beyond 15 km, as described by Brand (1997).

Table 1
Selected villages, agricultural zones and GPS coordinates

Villages	Agricultural zone	GPS coordinates	
		South	East
West side of corridor			
Ampahitra	Forest	19°04′29″	48°14′01″
Ambohimanarivo	Fallow	18°48′26″	48°15′21″
Berano	Forest	18°50′55″	48°19′50″
East side of corrido*r*			
Ambodilazana	Forest	18°59′47″	48°32′94″
Ambavaniasy	Forest	18°56′49″	48°30′38″
Marolafa	Fallow	18°57′52″	48°35′14″
Ambatomalama	Fallow	18°58′26″	48°35′50″
Ambinanisahavolo	Fallow	18°58′12″	48°35′41″
Ambatoharanana	Fallow	–	–

This sequence of vegetation has its origin in the land use and deforestation history. Deforestation started out at the coast with the first colonization of people about 2000 years ago. Over the centuries people moved from the coast to the interior of the country, pushing the forest limits steadily back while raising in altitude. Deforestation in the Beforona region, which is located about 65 km from the coast, started 150 ago, whereas the Vohidrazana area, another 10 km westwards, was first settled in the 1930s (Brand and Zurbuchen, 1997).

Close to the forest border, the vegetation is a mosaic of forest patches, fallow land and agricultural fields. Farmers tend to spread out within the territory for their *tavy* practices and install temporary homestead for the season next to their rice fields. In this zone, the presence of forests is dominating the landscape. In this paper we refer to this zone as *forest zone*. Only a few kilometers from the forest border, natural forest has completely disappeared from the landscape. People deforest last forest patches in order to gain the maximum amount of agricultural land. In Beforona the last forest has been cut in the late 1980s/early 1990s. The vegetation is characterized by shrubby fallows and grass fallows. This zone is referred to as *fallow zone* in this paper.

2.3. Agricultural system

For the Betsimisaraka, *tavy* rice cultivation is the first farming objective. *Tavy* has been the agricultural system inherited from the ancestors and is culturally deeply rooted. The *tavy* field is not just a rice field *per se*, as often referred to in the literature, but is a mixed cropping system with a multitude of crops planted in large spacing within the rice crop. Except for tall corn plants, other crops are almost invisible from the outside. They include cucumber (cash crop during hunger period), melons, sesame, a variety of beans, such as common beans (*Phaseolus lunatus*), cow peas (*Vigna unguiculata*), rice beans (*Vigna umbellate*). In addition, a number of weeds are harvested as leafy vegetable. In the *forest zone*, agriculture depends on *tavy*, manioc and sweet potato fields and banana plots (cash crop). There is little agricultural diversification, no lowland rice production and only a few fruit tree species are grown such as *Annona* sp. and *Eriobotyra* sp. Forest product extraction is an important additional activity that complements the shortcoming of food crop and cash crop production. In the *fallow zone* of Beforona, we find a more diversified agricultural system which includes next to *tavy* agroforestry plots that harbor a variety of fruit trees (*Citrus* sp., litchi, avocado, papaya, *Annona* sp., Jack fruit, *Nephelium* sp., *Eugenia* sp.), banana and coffee plants. Additionally, ginger has become an important upland cash crop in the past decade and farmers install irrigated lowland rice field in the narrow valley bottoms.

With continuing degradation of the uplands, especially young farmers tend to migrate closer to the forest border to convert forestland into agricultural fields. Although deforestation is illegal, the lack of law enforcement translates in free access of forest resources. Population densities are higher closer to the forest border than in further distance to the forests where uplands are more depleted. In proximity to the forest boundaries, population growth rates of the Malagasy population approaches 3% per annum (Barck and Moor, 1998). With deforestation direction going westwards, farmers are currently quickly advancing into the mountainous Vohidrazana zone, and confronted with a cooler climate at higher altitude (900 m a.s.l.) which is less favorable for agriculture compared to the lower lying Beforona region (500 m a.s.l.). Interestingly, the cropping practices and varieties used in higher elevation do not much differ from the lower lying areas. A land cover analysis of the different land use systems in the Beforona-Vohidrazana region shows that 60% of the land is covered by fallows and 12% by *tavy* fields. Ginger and cassava fields make up 2.5% and 0.5% of the surface. Thus fallow and upland crops cover 75% of the land surface. Agroforestry plots and lowland rice fields occupy only 7% and 3%, respectively. The rest of 15% is composed of 12% of rainforest corridor, 2% of reforestation and 1% of rainforest patches within the agricultural landscape (Brand and Randriamboavonjy, 1997).

2.4. Component studies

Field research extended over 25 months from June 1999 to June 2001. The field research team consisted of the first and second author, and in each of the nine villages of a farmer native to the village. The methodology was based on semi-structured in-depth interviews with open, qualitative (i.e. not fixed) responses. A total of 96 individual and 22 group interviews were conducted using standard methodological guidelines (Patton, 1990). Field research was subdivided in two component studies.

2.4.1. Upland cropping system characterization

To identify upland cropping system strategies, upland management practices and the associated dynamics of soil degradation, 44 individual and 13 group interviews were conducted. For the individual interviews, informants were either identified as key-informants by local leaders or selected opportunistically by field researchers. Key-informants were invited to participate in focus group discussions.

2.4.2. Farmer fallow characterization

In this component 52 individual and 9 group interviews were conducted. Informants were selected and interviewed using the same methods as described above. The inquiry focused on fallow characterization, fallow species succession, fallow growth, and agricultural productivity in relation to fallow/crop cycles after deforestation. Additionally, 212 farm plot inventories were undertaken on 32 farms describing plot management since deforestation, and discussing issues of soil fertility management and land use dynamics.

2.5. Interview process

Considerable suspicion and mistrust regarding outsiders characterized the initial interaction with the farmers as they feared negative repercussions because of their *tavy* practices. There were regional cases of imprisonment of farmers who engaged in deforestation for *tavy* which is illegal by law. Thus, interviewers placed much emphasis on gaining trust by presenting themselves as being transparent, showing respect, being aware of the connotations of the vocabulary used, being impartial and non-judgmental, and not insisting on answers to every question. Informants could choose the time and location of the interviews. The interviews were based on an interview guide that provided focus while remaining flexible enough to accommodate in-depth responses. Interviews were conducted in French and Malagasy. To assure the reliability of the translation and recorded information, all field notes were inspected and discussed by the bi-lingual research team prior to finalization, and errors in translation were corrected. Contributions of the farmer collaborators were essential. They were able to communicate with the farmer informants in the Betsimisaraka dialect, which provided the researchers with important insights into local culture and farming practices. In order to acknowledge informant's involvement, participant farmers were invited after completion of interviews to the authors' agricultural experimental sites, where innovations and new ideas were discussed and knowledge shared. This process was very satisfactory for everyone involved.

2.6. Quality of information and data analysis

Data reliability was maximized by 2 years of field research conducted by the research team that became accustomed to the local customs and traditions. Interview information was compared and triangulated with inventory of plot histories and field observations, and was used to identify, confirm, or refute emerging patterns during the fieldwork. Repeated encounters with selected informants allowed researchers to verify, confirm, or reformulate certain pieces of information. Fallow characterizations are site specific, but we are certain that the described findings can be confidently applied to the larger Vohidrazana/Beforona area.

Data analysis and interpretation was the primary responsibility of the principal investigator and began with the transcription of field notes and the plotting out of farm plot histories. This was followed by a process of indexing all interviews according to contents and topics. The information was then regrouped and systematically examined for emerging patterns. The patterns were checked for consistency across the interviews and plot inventories. Topics with consistent information were developed and are presented as results. Analytical guidelines were obtained by Patton (1990).

3. Results

3.1. Soil fertility restoration under the current tavy system

In the *tavy* system, soil fertility restoration depends solely on the natural fallow. The ability of fallow vegetation to restore soil fertility within the given fallowing time is therefore of critical importance in assuring crop productivity. In the Vohidrazana/Beforona area, the fallow periods have been decreasing since the 1970s. In the *fallow zone*, the fallowing period was 8–15 years in the 1970s, decreased to 6–10 years in the 1980s and eventually reached 3–4 years at present. On the agricultural land in the *forest zone* fallow periods have also decreased since the 1970s and are currently 3–8 years in length with an average of 5 years. It is noteworthy that the traditional cropping practices stayed the same and remained independent of the length of fallow periods. Our findings show that the time needed to restore soil fertility increases with each fallow cycle following deforestation. In order to produce a good rice crop, which for local standards is ca. 1.5 t/ha, a fallow period should be at least 3 years for the first two cycles (C1, C2), 5 years for C3, 8 years for C4, 12 years for C5, and 20 years for C6 (Fig. 1). If a fallow period is maintained at 5 years for all the cycles, yields remain satisfactory until the third cycle, but beyond that point soil fertility is mined and yields decrease rapidly (see also Fig. 4). These findings stem initially from farmers' information and from plot histories, where fallow composition and growth characteristics could be observed in relation to age of fallows and number of cycles. The results could be confirmed through a regression analysis that looked into biomass nutrient accumulation from 1 to 10 years of fallow age for the different cycles. Most interestingly, the findings from the nutrient analysis coincide with farmers' information (Styger, 2004). Although farmers are aware of optimal waiting periods, they are hardly able to respect them in the

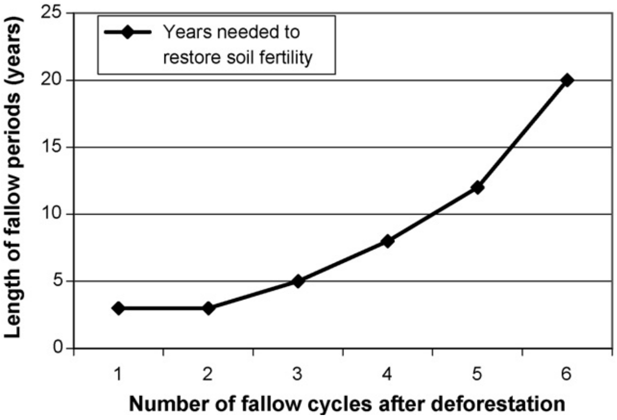


Fig. 1. Recommended fallow period for the production of 1.5 t/ha of upland rice from the first to the sixth fallow cycle after deforestation (under the current fallow management regime; according to farmers' information, triangulated with plot histories and later confirmed through nutrient stock analysis of fallows in different ages and cycles in Styger, 2004).

later cycles and crop the fields prematurely after 3–5 years (see also under Section 3.7).

3.2. Major fallow species in the study region

One of the most striking features in the eastern region of Madagascar is the existence of mono-specific stands of fallow vegetation. In the Vohidrazana/Beforona area, fallows are often dominated by a single species of tree, shrub, or herb or appear in mixtures of a few major species listed in Table 2. It additionally informs on the species origin and vernacular name, its natural propagation methods and dispersal mechanisms.

3.3. Fallow species succession as a function of cropping/fallowing cycles following deforestation

In this section, the successional change of fallow vegetation is described at the plot level as driven by the current agricultural practices. Based on the field inventories and in-depth discussions, a clear relationship between fallow species occurrence and land use history and intensity could be established. The results focus on the current fallow periods of 3–5 years and are presented in an overview in Fig. 2 and further discussed below.

The first fallow after deforestation is most often dominated by the trees *Trema orientalis* and *Harungana madagascariensis*. They are sometimes associated with the shrub *Solanum mauritianum* which has a rapid initial growth, forms quickly a low canopy, but dies back after 6–12 months giving way to *Trema.* In the absence of *Trema* and *Harungana*, the endemic shrub *Psiadia altissima*, dominates the first cycle as seen in the Ambavaniasy area. *Trema*, *Harungana* and *Psiadia* establish rapidly from seeds after a forest has been cleared. *Already in the second fallow cycle after deforestation*, a major shift in species composition occurs. Tree species are replaced by the endemic shrub species *P. altissima.* The trees occur only in low numbers and diminish with each additional fallow cycle following deforestation. From the third cycle onward, *Psiadia* either remains the principal shrub species or is outcompeted by the two exotic and invasive species *Rubus moluccanus* or *Lantana camara. Aframomum angustifolium*, a perennial herbaceous species, is another important fallow species but covers less ground. Associated species that hardly form single stands are *Clidemia hirta* and *Tristemma virusanum*.

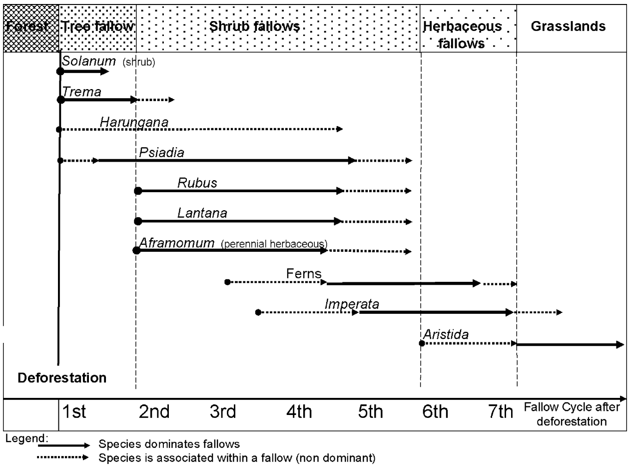


Fig. 2. Fallow species succession as a function of cropping/fallow cycle and time since primary forest.

Among the pioneer species *P. altissima* is the most adaptive and plastic. It appears from the first cycle to the last woody cycle on degraded land—albeit with a less vigorous appearance. The two exotics *R. moluccanus* and *L. camara* have similar growth habits and ecological requirements. They grow on medium fertile soil of the region, have a shrubby and viny habit, and form a dense, thick, spiny stand that is not penetrable without a machete. After canopy closure at 2.5–4 m in height, the stand no longer increases in height, and it becomes very difficult to distinguish a 5-year from a 20-year fallow. *Rubus* is the most aggressive among

Table 2
Major fallow species in the Ankeniheny-Zahamena forest corridor zone, along the Beforona–Moramanga axis

Species	Family	Origin	Dispersal	Propagation	Vernacular name
Trema orientalis (L.) Blume	Ulmaceae	PT, IN	B	S	Vakoka
Harungana madagascariensis Lam. ex Poir.	Clusiaceae	IN (A, M)	B	S	Harongana
Solanum mauritianum Scop	Solanaceae	EX	B	S	Bakobako
Psiadia altissima (DC.) Drake	Asteraceae	EN	W	S	Dingadingana
Rubus moluccanus L.	Rosaceae	EX	B	S, V	Takoaka
Lantana camara L.	Verbenaceae	EX	B	S, V	Radriaka
Aframomum angustifolium (Sonn.) K. Schum.	Zingiberaceae	IN (A, M)	B	S	Longoza
Clidemia hirta (L.) D. Don	Melastomataceae	EX	B	S	Sompatra
Tristemma virusanum Juss.	Melastomataceae	EN	B	S	Voatrotroka
Pteridium aquilinum (L.) Kuhn	Dennstaedtiaceae	PT	W	Rh, SP	Rangotra be
Sticherus flagellaris (Bory ex Willd.) Ching	Gleicheniaceae	PT	W	Rh, SP	Rangotohatra
Imperata cylindrica (L.) Raeusch.	Poaceae	PT	W	Rh, S	Tenina
Aristida similis Steud.	Poaceae	IN	W	S	Kofafa, Bozaka
Hyparrhenia rufa (Nees) Stapf	Poaceae	PT	W	S	Kofafa, Bozaka

Origin: EN, endemic; IN, indigenous; EX, exotic; PT, pantropical; A, Africa; M, Madagascar. Dispersal: B, bird; W, wind. Propagation: S, seed; V, vegetative; SP, spores; Rh, rhizomes.

the shrubby species, and out-competes and suppresses *Lantana, Aframomum*, or *Psiadia* if they appear in the same plot. This is also the case for regenerating indigenous tree species, in which case *Rubus* impedes the development of a potential secondary forest.

In the third and fourth cycle, the two fern species, *Pteridium aquilinum* and *Sticherus flagellaris*, and the pantropical grass *Imperata cylindrica* start to appear in low density. Farmers refer to *Imperata* and ferns as 'sisters' as they often appear simultaneously on a plot. They thrive on fire and are favored over more susceptible species with each burning cycle—a fact widely acknowledged for *Imperata,* as for instance reported from West Africa (Chikoye et al., 2000) and Indonesia (Grist and Menz, 2000; Hartemink, 2001). These species become dominant *beyond the fifth cycle*. Land management, relief, soil fertility status and seed sources determine how quickly ferns and *Imperata* become the principal species. The ferns usually appear earlier in the succession than *Imperata*. In many cases, *Imperata* gradually replaces ferns within a sequence. In the last succession phase, grasslands replace ferns and *Imperata*. Contrary to what is found in tropical Asia (Garrity et al., 1996; Grist and Menz, 1997), *I. cylindrica* in eastern Madagascar is not a persistent fire-climax species and does not represent the last stage in succession. *Beyond the 6th cycle* and after repeated burning it is replaced by a few grass species composed of *Aristida similes*, *Aristida* sp., *Hyparrhenia rufa*, *Paspalum conjugatum*, *Panicum brevifolium*, and *Pennisetum* sp., among others (Dandoy, 1973; Pfund, 2000).

3.4. Betsimisaraka fallow characterization

The Betsimisaraka use a rich terminology to characterize fallows. Each fallow type integrates a range of attributes and characteristics, including species life form, species composition and associations, cycle reference, vegetation growth rate, appearance, fallow height, age, and agricultural potential. The specific combination of these factors makes up a unique fallow type. Each factor by itself, on the other hand, provides too few characteristics to portray a fallow fully. In addition, farmers have management guidelines that go along with each fallow type. The interrelationships among fallow types were characterized together with

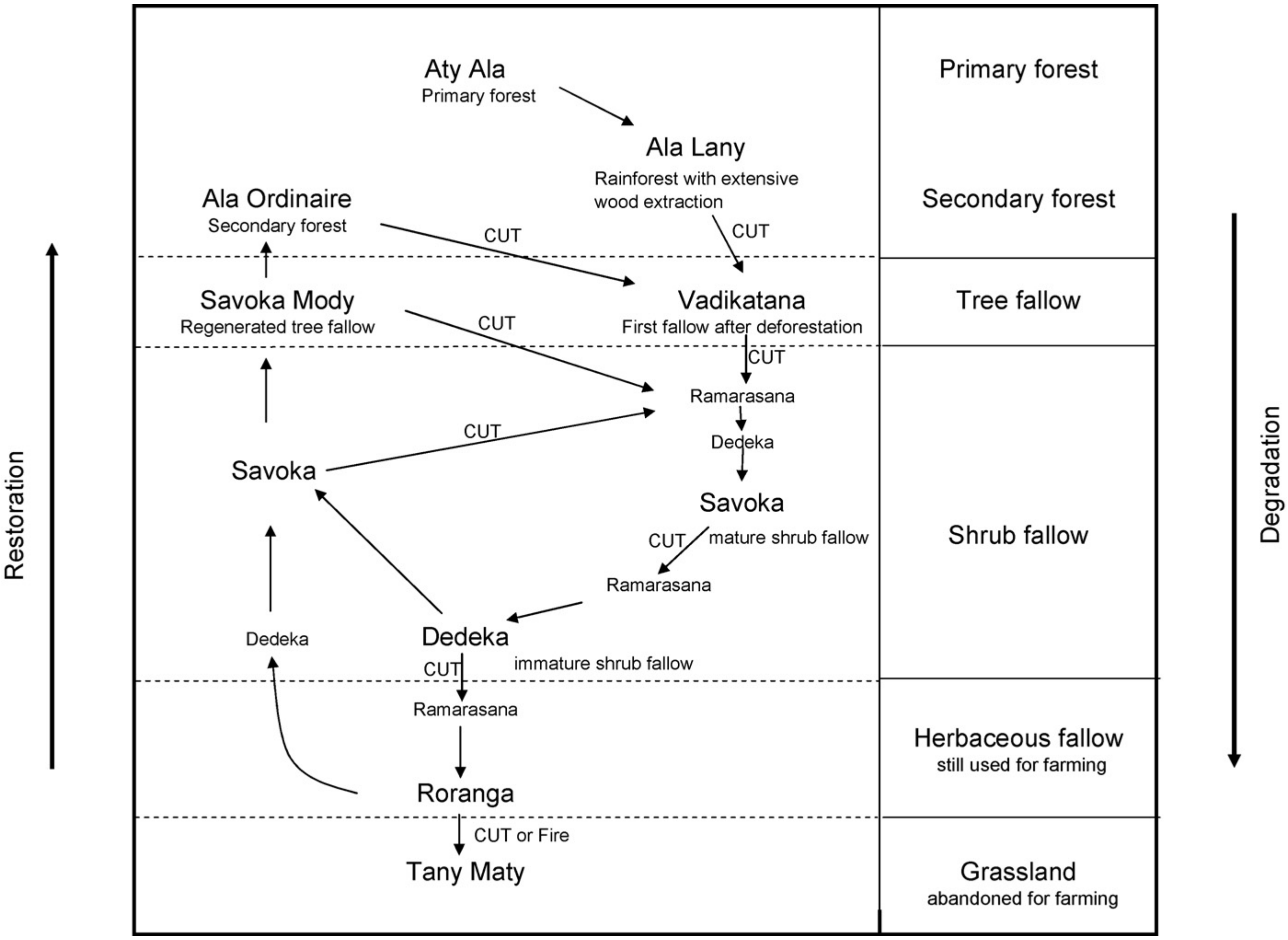


Fig. 3. Betsimisaraka fallow characterization in the Vohidrazana/Beforona region indicating the degradation, restoration and sustainable production pathways as a result of fallow use for upland rice cultivation. (The fallow terminology and the detailed development of the pathways are explained in details in the text.)

farmers and a schema developed, which is presented in Fig. 3 and further discussed below. There are three major pathways within the succession of fallows (a) the sustainable pathway, (b) the pathway of restoration, and (c) the pathway of degradation.

3.4.1. Sustainable pathway

3.4.1.1. Vadikatana. Independent of management, the first fallow after deforestation (either primary forest or *Ala Be*, or secondary forest or *Ala Ordinaire*) and following the first rice crop is called *Vadikatana*. It is a tree fallow dominated by *Trema* and *Harungana.* It is the most desired fallow as it produces the best rice yield (see also Fig. 4 and explanation in Section 3.6).

3.4.1.2. Ramarasana–Dedeka–Savoka. In the second and following cycles, the fallow transits in its development from *Ramarasana* to *Dedeka* to *Savoka*.

Ramarasana is the initial fallow stage that starts from the moment when the rice panicles are manually harvested one by one, until the left-behind standing rice straw is overgrown by the fallow and not visible anymore. This can take between 6 months and 2 years depending on location and soils. Herbaceous weeds that have developed since the last weeding initially characterize the species composition. The woody fallow species composition is influenced by the species from the previous fallow and the neighboring plots, and by the fire and cultivation regime. Traditionally, the cropping of a *Ramarasana* is neither desirable nor recommended, as the soil fertility is not yet restored and the herbaceous plants are too aggressive as weeds. After the disappearance of the rice straw, the fallow turns into a *Dedeka*.

A *Dedeka* is a shrubby fallow that is small in height (1–1.5 m), featuring yellowish or light green leaves indicating nutrient deficiencies. The wood growth is poor and stem diameters are thin compared with the species average. Woody species progressively replace the herbaceous species present in the *Ramarasana* stage. Most important species are *Psiadia*, *Rubus* and *Lantana*. Farmers stress that the *Dedeka* is the most sensitive stage in fallow development. If slashed, burned or cropped, the woody species are at risk of being killed off and the next fallow could become an herbaceous fallow or *Roranga*, thus drift into the degradation pathway. In order to remain within the sustainable pathway and to maintain upland productivity, it is necessary to wait until a *Dedeka* develops into a *Savoka*. But as soil degradation advances, and with each additional cropping/fallowing cycle, the *Dedeka* stage takes longer and can easily reach more then 10 years (see also Section 3.1).

A *Savoka* is also a shrubby fallow but taller in height (2–4 m), and the color of the leaves is darker green compared to *Dedeka*. The shrubby species are essentially the same as in the *Dedeka*, although more herbaceous species are outshaded. The fallow has a 'thick,' dense aspect. The woody biomass is well developed with larger stem diameters than those encountered in the *Dedeka*. A well-developed *Savoka* is also referred to as being 'mature' (*Savoka Matoy*), indicating that the fallow is ready to be cultivated again. Within the Betsimisaraka fallow terminology, *Savoka* represents a very specific category. It should not be confounded with the term often used in the literature (Faramalala, 1988; Lowry et al., 1997; FAO, 2000) where *Savoka* is used as the common term for fallow, which corresponds to *Jinja* in the Betsimisaraka classification. Farmers' rules for maintaining soil productivity is to cultivate only fallows that have at least reached the *Savoka* stage and to crop it for only 1 year before leaving it to fallow again.

3.4.2. Pathway of restoration

If a *Savoka* is left to regenerate further, it develops into a tree fallow (*Savoka Mody*'s) and eventually into a secondary forest (*Ala Ordinaire*). Both vegetation forms have become extremely rare in the study area, as pressure on land has increased. A *Savoka Mody* is characterized by the presence of forest species such as *Croton* sp., *Macaranga* sp., *Dombeya* sp., *Ficus* sp., *Dicheatanthera* sp., *Myrica* sp. and *Albizia gummifera* (Direction des Eaux et Forêts, 1996; Styger et al., 1999; Pfund, 2000). Their wood is of mediocre and light quality. The tree height exceeds 4–5 m and the stands are at least 10–20 years old. Precious wood species, if present, are in the seedling stage. For fallow quality, a *Savoka Mody* can be compared to a Vadikatana, representing the best fallow for rice production. *Ala Ordinaire* or secondary forest is at least 50–60 years old and is characterized by stem diameters that allow the extraction of timber boards from soft wood species. During that time additional hardwood species establish in the under-story.

3.4.3. Pathway of degradation

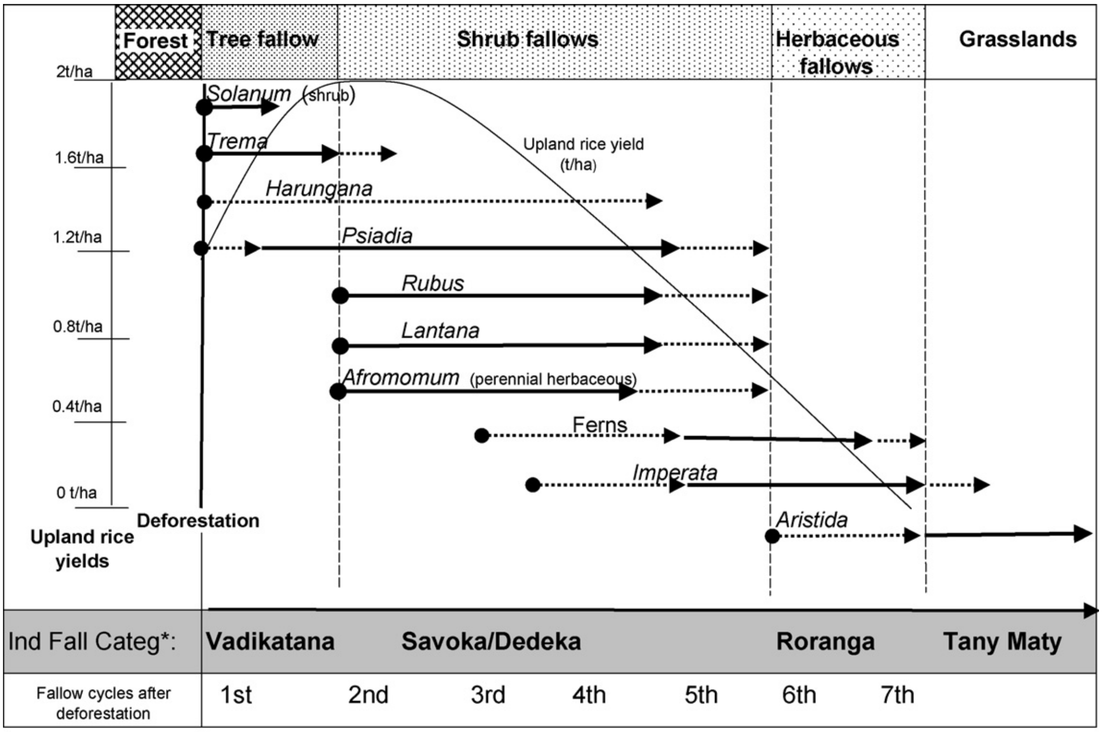
As described above, the degradation pathway is initiated if a *Dedeka* is cultivated or burned, and develops into a *Roranga*, a herbaceous fallow formed by *Imperata* and fern species. Upland rice production is ceased, and soils may be used for root crops or pineapple. According to farmers, the key element in restoring agricultural productivity is the presence of woody species in the fallows. If a *Roranga* is burned once or several times, *Imperata* and ferns disappear and the vegetation transforms into impoverished grasslands with species such as *Aristida* sp. and *Hyperrhenia* sp., among others. These grasses grow in tuffs, leaving much of the soil surface bare, which provokes sheet erosion with each rain event. These grasslands, referred to as *Tany Maty* (dead land) or *Tany Masina* (sour land), are abandoned for cropping and are characterized by depleted organic matter pools and hardened red soils. Farmers manage these landscapes for cattle grazing with annual fires creating an irreversible vegetation form without woody species regeneration. Only the young regrowth is palatable, and the productivity is extremely low.

3.5. Regeneration of woody species on degraded land

Herbaceous fallows in the *Roranga* stage are limited in their ability to accumulate biomass and restore soil fertility (Styger, 2004). Thus, woody species growth is essential to regain land for agriculture. According to farmers, the first woody species in a pure *Imperata* stand reappears after 5–7 years. After a minimum of 15–20 years a woody species canopy that is able to out-shade *Imperata* can be expected. In a fern fallow, the reestablishment of woody species can easily take 20 years and another 10 years until woody species provide a canopy. These estimates are among the more optimistic scenarios and depend on complete absence of fire. One of the reasons for these long time spans in the fern fallows is the formation of a thick and dense root mat on the soil surface. During the hot rainy season, the superficial root mat absorbs the sun's heat and the soil underneath the fern roots dries out and hardens. These factors create a very hostile environment for establishment and growth of any other plant species. Farmers' have limited ability to restore a *Roranga* fallow. They may resort to hand tilling the land, which is an uncommon practice in the region, or to planting bananas that eventually out-shade the herbaceous ground cover. This is only applicable on a small scale and leave farmers defenseless against the rapidly spreading of herbaceous fallows that cover the hillsides.

3.6. Integration of findings on the Betsimisaraka fallow characterization, species succession, and upland rice productivity

The findings on species succession and on the Betsimisaraka's fallow knowledge are integrated in Fig. 4. Farmers' upland rice yield estimates are added, which were confirmed through rice harvest in an agricultural experiment (Styger, 2004). Rice yields attain only 1.5 t/ha in the first cropping cycle after deforestation and are highest in the second cycle with a maximum of 2–2.5 t/ha. This may be due to several reasons. After the initial burn of the slashed forest trees, not all of the woody biomass burns entirely and thus still covers large parts of the soil surface, which results in lower planting density of rice. In addition, the forest soils in the region are characterized by a thick organic O-horizon (up to 20 cm), composed of roots and litter, before the mineral soil or A-horizon is reached. After the first burn, this layer is not reduced uniformly, creating heterogeneous conditions for the crop roots to grow in. In the second cropping cycle, the O-horizon is mostly decomposed and the soil resembles agricultural soil with a thin litter layer. The plant roots grow within a more uniform mineral A-horizon that is rich in organic matter. After the second cropping cycle and with each further cycle, yields decrease rapidly. When the *Roranga* stage is reached, a rice crop of 500 kg/ha could theoretically be expected, but an unrealistic time allocation



* Ind Fall Categ: Indigenous Fallow Categories

Fig. 4. Fallow species succession as a function of cropping/fallow cycle and time since primary forest, and in relation to Betsimisaraka fallow characterization and upland rice yields (t/ha).

for *Imperata* or fern rhizome control, which can easily translate into five weedings per crop, is not anymore economical for farmers.

3.7. Landscape implications of past and current upland use and management

A further integration of the above findings is now taken to the landscape level. The dynamics of past and current upland use and management have shaped the landscape. As already described above, the change of vegetation from tree to shrub and to grass fallows can be observed by moving away from the forest border towards the *fallow zones*. The chronological transformation of the landscape is described in what follows.

When colonizing a forested valley, farmers begin cutting forests in the lower parts of the valley, and with each year move slowly uphill. The upper parts of hillsides are protected longer, especially if the land is still plentiful, as it requires greater effort to cut higher locations. With low population densities, fallows are either reused when in a *Savoka* stage or develop back into *Savoka Mody*'s or secondary forests (*Ala Ordinaire*).

With increasing population pressure, fallow periods become shorter and farmers rotate among their lower hillside fields more frequently, achieving satisfactory yields only for a few cycles. With the subsequent decline in rice productivity and the desire to secure more land, farmers move further uphill, cut more forests and cultivate the hilltops. The lower lying plots benefit from eroding hilltop soil, and continue to be productive. It is now possible for the farmers to rotate between the plots from the upper and lower hillsides for a few additional cropping cycles, until the lower fields become overused again. At the same time, hilltops degrade more quickly due to their shallower soils that have been additionally subject to erosion since deforestation.

Imperata and ferns establish first on the hilltops and spread downhill with each additional cycle. This situation can be observed today in the Beforona area. The land starts falling out of production and farmers concentrate anew on cropping lower hillside fields that are already in the *Dedeka* stage. When the lower hillsides are burned for the *tavy* field preparation, the fire escapes easily uphill and it is almost impossible to protect the upper hillslope from fire. With this dynamic, the entire hillside can turn into a *Roranga* fallow and fall suddenly out of production. If fires continue to be present, the land is easily converted into the *Tany Maty* stage. These findings contradict Brand and Pfund (1998) who describe that fallows at the foot of the hills stabilize at an intermediate stage or mixed or degraded fallows, when herbaceous fallows occupy the upper slopes.

The dynamics of these degradation processes are hereafter described for two concrete cases, the village of Ambavaniasy (*forest zone*), and the village of Ambinanisahavolo, Beforona (*fallow zone*). In Ambavaniasy, fallows are still in the early cycles and hilltops are often still forested. Soils remain relatively fertile and have a production-buffer capacity. Farmers can easily find fertile land to crop, can deforest a new plot, or borrow land from neighbors. With increasing distance to the forest border, in Ambinanisahavolo, where the last rainforest remnants had disappeared 10–20 years ago, the fallow cycle numbers are already advanced across the village territory and *Dedeka* has become the dominant fallow. As seen in Fig. 1, the fallow periods should theoretically become longer with advancing cycles, but in reality they are shortened as result. With fallows starting to turn into *Roranga* and therefore fall out of production, pressure on the remaining fallows increases. Farmers do not have the time to wait for a fallow to fully recover, and a rapid vicious circle is unleashed.

Degradation accelerates quickly once it has crossed the threshold from buffered (first to third cycle) to mining conditions (beyond the fourth cycle, if fallow periods are not substantially increased). Farmers above the threshold (in the *forest zone*) seem not to worry about the ongoing dynamic as long as the majority of their soils exhibit buffering ability. Also, under traditional land tenure, land sharing is a common practice with the effect that fallow and cropping lengths and practices become fairly uniform across the village territory (Styger, 2004). In this way, approaching and crossing the critical threshold may happen without much awareness at first, but then conditions start to change rapidly across the landscape, and farmers have no efficient large-scale strategies to counteract the rapid soil mining processes. According to farmers' estimates in Ambinanisahavolo, half of the village territory, especially the hilltops, has fallen out of production for rice over the past 10 years. Farmers also foresee that 10 years from now all the village hillside land will be degraded to an extent that it will be lost for rice production. This shows the speed of landscape degradation in the region. While farmers in Beforona had the opinion that farming some 20–30 years ago was excellent with good upland production (Oxby and Boerboom, 1985; Styger, 2004), they now fear losing all their upland soils within 10 years.

4. Discussion

4.1. Time required for restoring soil fertility

With the currently short fallow periods of 3–5 years, a rice yield of 1.5–2 t/ha can only be achieved up to the third cycle. Beyond that – and with each additional cycle – the fallow periods would need to increase to assure a similar level of productivity. The capacity of a 5-year fallow period to rehabilitate soil fertility varies considerably depending on the cycle of cropping. Thus, the length of the fallow period *per se* does not support statements or assumptions about agricultural productivity recovery if it is not placed in relation to the cycle number following deforestation. If the cycle numbers are not known, a fallow period should be related to the degree of soil and vegetation degradation within a given ecological zone. This association is often missed in the literature, and length of fallow periods is often used as sole parameter to estimate the restoration of soil fertility (Van Reuler and Janssen, 1993; Silva-Forsberg and Fearnside, 1997; Brand and Pfund, 1998; Kato et al., 1999). In addition to soil fertility restoration, cycle numbers following deforestation should also be integrated in discussions on species composition of fallows, and vegetation recovery and growth. Fallow growth directly translates into biomass production and nutrient stock accumulation and thereby to the restoration of agricultural productivity (Nye and Greenland, 1960). Analysis of biomass and nutrient stocks of the here identified fallow categories in relation to cycles following deforestation, constituted a next step in research of the land degradation dynamics (Styger, 2004).

4.2. Speed of vegetation succession and upland degradation

The current fallow use frequencies indicate a transition from rainforest to herbaceous fallow vegetation within 20–40 years, which is 5–12 times faster then previously reported. An estimation of land degradation was advanced by Chauvet (1972), who predicted that forests turn into grassland within maximum 10–15 cycles with an average fallow period of 10 years. Thus, the time span for the transition from forest to secondary grasslands would have taken between 110 and 160 years. These estimates may have been valid in the 1970s when fallow periods were between 8 and 15 years, but since then the situation has changed drastically. In a more recent approximation, Brand and Pfund (1998) indicate for the study area a time span between 200 and 250 years for land to arrive at the arrested grassland vegetation. These estimates do not take into account the changes in fallow lengths over the past 30 years that resulted in a very rapid acceleration of the succession dynamics. They can no longer be considered valid under the current land management regimes.

4.3. Betsimisaraka fallow characterization as practical diagnostic tool

The Betsimisaraka fallow characterization represents a powerful and practical diagnostic tool that allows observers to estimate the numbers of cycles after deforestation, determine the agricultural production potential of an area, and inform on the precautions to be taken in performing management interventions—all by looking at fallow vegetation. This is especially facilitated by the fact that fallows are often dominated by a single or a few species. The connection of vegetation analysis, agricultural potential and management implications has been missing so far in the literature. The gathering and analysis of the locally available knowledge provided very important insights in that respect, which are directly applicable for the design and development of improved upland management techniques. To obtain the same knowledge would have taken many years of experimentation. The gained insights from this study result from in-depth consultation and exchange between the two knowledge systems of the researchers and the local population. Put at the same level, both systems contributed equally to the understanding and description of the dynamics of the ongoing land degradation processes.

4.4. Species occurrence and succession in natural fallows

The foregoing findings derive from field observations and farmers' information. There are currently no ecological studies available for the eastern region that identify the ecological and biological factors driving the observed species succession (establishment, growth, competitiveness, etc.) in relation to current land use practices such as slashing, burning and cropping. There is also no information available on dependencies or synergies between soil microbes and either the major fallow species or the rainforest species of eastern Madagascar.[1] Ecological studies are not only missing for the rainforest region but are scarce for entire Madagascar and are mostly limited to field observations. Gade (1996), for instance, reports from the highlands that three straight years of setting fire to the same woodlot removed all ligneous growth. Bloesch (1999) who studied fire use in drier western Madagascar, concluded that 3–4 fires within a period of ca. 15 years may transform a formerly intact dry forest into savanna. Fallow species occurrence and succession is site specific, which we confirmed through our own observations. Further south of the Island, for instance, in the Fianarantsoa area, bamboo species and the exotic guava species (*Psidium cattleianum*, Myrtaceae) form single species stands, whereas in the Beforona region, the two species only occur in low densities within the landscape.

Homogenous stands of fallow species can also be observed elsewhere in the tropics. The genus *Trema*, for instance, includes many fast growing, short-lived pioneer species common in early successional vegetation in tropical humid zones (Vazquez-Yanes, 1998) as reported, for instance, from Ghana (Swaine and Hall, 1983), North-East Borneo Island (Ohtsuka, 1999), China (Cao et al., 1997), or Eastern Paraguay (Kammesheidt, 1998). The disappearance of *Trema* after the first fallow cycle in Madagascar indicates a high susceptibility towards slashing and burning, and most likely a rapid depletion of soil seed banks. In other parts of the world, comparatively improved resilience of early successional species has been reported. In Thailand, for instance, farmers are able to maintain a productive system of upland rice production by depending on the regrowth of the pioneer species *Macaranga*

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[1] The first species description of endo-mycorrhizal fungi, initiated by the main author, indicated a decrease in mycorrhizal species diversity with increasing fallow degradation (Styger et al, unpublished).

denticulata (Euphorbiaceae) within 7 year fallow/cropping cycles (Yimjam et al., 2003).

In many locations of the tropics, exotic, naturalized and invasive shrubs, such as *Rubus* and *Lantana*, have replaced the indigenous vegetation. A prime example is *Chromolaena odorata* (Asteraceae), which once was introduced into Asia and Africa and spread aggressively across the continents, although it does not appear in Madagascar. In many parts of the world it is considered to be a noxious weed. However, in South Asia, farmers learned to manage *Chromolaena* as 'improved' fallows over their natural vegetation (Roder et al., 2004). Another species from the Asteraceae family, with similar properties is *Tithonia diversifolia*, which is common throughout eastern Africa. *I. cylindrica* is one of the most widespread and aggressive grasses in Asia and Africa, and with some spread also in Latin America, although for unclear reasons, it has proved to be less aggressive there. Unlike in Madagascar, *Imperata* vegetation represents the last stage of succession in Asia (Styger and Fernandes, 2006).

4.5. Fire as a main driver of degradation

With the presence of periodic fires, reversion of landscape degradation is essentially impossible. The more degraded the land, the more difficult it is to reclaim. Our field observations and farmer knowledge suggest that the threshold is reached between the third and fourth cycle after deforestation when herbaceous species are starting to dominate the fallows. Dry, herbaceous vegetation catches fire more easily than woody vegetation. Fire control becomes more difficult. Wildfires often escape and damage neighboring plots. We encountered many examples in the field, where accidentally burned young *Savoka* turned into *Roranga*, thereby eliminating a productive plot of land for agriculture without getting any benefits of production. With the increasing scarcity of available cropland and the shortening of fallow periods, burning frequencies increase across the landscape. Fire-loving herbaceous plants are perpetuated and the natural regeneration of woody plants is impeded all the more until the woody species disappear from the landscape. In respect to biodiversity conservation, indigenous woody flora still present in *Savoka Mody*, *Vadikatana*, and even under *Savoka* has vanished and no longer regenerates.

5. Conclusions and recommendations

The findings of this paper indicate that the *tavy* system with its currently short fallow periods is collapsing. The discussion around *tavy* has been heated for as long as 150 years, and is today more urgent then ever. *Tavy* represents the main cause of deforestation and threat to endemic biodiversity loss in Madagascar. On the other hand, the detrimental role of the current *tavy* practices on the agricultural productivity is receiving much less attention. Among conservation and development organizations, the notion of slashing and burning fallows is often an acceptable form of farming as long as farmers keep out of the forests. However, the larger picture obtained through this study indicates that with the rapid degradation of the fallow systems, farmers will keep up the pressure on the primary forests due to lack of available and suitable alternatives.

From the farmers' point of view in the study zone, the interaction with governmental services, development and conservation organizations has mostly been unsympathetic. Outsiders often show their disapproval of the *tavy* practices openly and urge farmers to stop *tavy* and substitute it, for instance, with lowland rice fields or agroforestry fruit tree gardens. These interactions fail to support farmers in addressing their priorities and real needs. In addition, extension service has been absent for many decades already in the study zone. Thus, faced with poverty and lack of alternatives and information, farmers hold on to their traditional practices in order to produce enough food to survive. Despite the large amounts of funds spent on environmental protection programs to conserve the natural forests of Madagascar, the authors foresee that *tavy* will prevail and forests and biodiversity will continue to disappear, unless feasible, affordable and sustainable upland farming techniques are developed that depart from the local farming practices and priorities.

To develop alternatives with the Betsimisaraka represents a challenge as farmers are much rooted in the traditional practices, and have not been exposed to many new technologies and ideas. The careful development of alternative agricultural practices should especially be done in collaboration with young farmers. If the young obtain a real interest in agricultural intensification, they may not feel the need anymore to leave their native villages and migrate to the forest border to undertake *tavy*. From the technical perspective, the restoration of soil fertility should build on the biological potential of the system, by optimizing nutrient cycling (e.g. through residue and weed recycling, mulching) and by producing and recycling of high quality organic matter (e.g. through improved fallows and cover crops). These interventions are aimed to increase the levels of soil organic matter, which is critical for the nutrient holding capacity of the soil. The recent development of the agro-ecological practices and techniques by FOFIFA (national research institution) with support from CIRAD are welcome, but needs to go beyond the research stage and demonstration plots and adapt the techniques in an interactive way with farmers in their fields over a period of several years. The use of targeted fertilizers (for instance to address the prevalent phosphorus deficiencies) should be explored, especially for 'jump-starting' the depleted soil systems.

The development of fire-less land management is incontrovertible and represents a key entry-point where the vicious circle of degradation can be turned around. With intensification measures at the plot level and with a fire-less regime, large sections in the landscape could have anew the opportunity to naturally regenerate. This would allow for the creation of a mosaic landscape and for diversified agricultural and forestry systems. In addition, management interventions in different landscape niches can provide ecological services such as erosion control and water source protection through the reforestation of hilltops, and the restoration of native biodiversity within the production landscapes, among others. And ultimately, there is a need to address land tenure security. Although traditional land tenure rules are very inclusive, allowing members of society access to land and thus providing some social security, the lack of land tenure security at the individual level impedes the readiness for farmers to invest in their land. Here again, close stakeholder consultation needs to be undertaken and ideally locally adapted land tenure models should be developed, in order to protect the social as well as the individual interests.

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