FIRE-LESS ALTERNATIVES TO SLASH-AND-BURN AGRICULTURE (*TAVY)* IN THE RAINFOREST REGION OF MADAGASCAR

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FIRE-LESS ALTERNATIVES TO SLASH-AND-BURN AGRICULTURE (*TAVY*) IN THE RAINFOREST REGION OF MADAGASCAR

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Slash-and-burn agriculture, or *tavy*, is the predominant farming system in eastern Madagascar and the major cause, in combination with increasing population and scarcity of fertile land, of deforestation and upland degradation. Current land use trends suggest increasing rainforest loss and between five to ten times faster upland degradation then previously believed. Despite degradation and declining yields, farmers' remain committed to *tavy*. Incredibly, no technical alternatives or functional extension services are locally available.

The objectives of this research were to study upland use strategies and degradation dynamics and develop fire-less alternatives to intensify and improve agricultural production. A multidisciplinary approach was used, combining qualitative inquiry, indigenous knowledge study, biophysical soil and fallow characterization, and agricultural experimentation.

Upland degradation was described through fallow species succession in relation to post-deforestation cycles. Indigenous fallow categories were identified that integrate species composition, vegetation aspect, and agricultural productivity; provide management guidelines and identify the 'point of no return' after which soils are lost to agriculture. Quantification of biomass and nutrient stocks along a degradation gradient showed that tree fallows (*Trema orientalis*) obtained highest nutrient stocks after 5 years. For short fallows, the shrubs *Rubus moluccanus* and *Psiadia altissima* were most productive.

Very low nutrient accumulation occurred with *Imperata cylindrica*. As expected, soil nutrient stocks decreased with increasing degradation.

Tavy was compared with three techniques: mulching alone (M0) and with the addition of 40 and 80 kg/ha applications of phosphorus using locally available guano-phosphate (M40, M80 respectively), on a rotation of upland rice, beans, ginger, and *Crotalaria grahamiana* fallow on the four above-mentioned fallows. Traditional or *tavy* practices yielded 1.2 t of rice, 0.2 t of beans and 4.3 t of ginger per ha. Although *tavy* showed slightly higher productivity for the first rice crop, M80 outperformed *tavy* with respect to beans, ginger, and *Crotalaria* by 324%, 195%, and 366%. M40 was less productive than M80 but was significantly better than M0 and *tavy*. M0's yields were better than *tavy* only for ginger. *Crotalaria's* nutrient stocks at one year were 6 to 20 times greater than those of natural fallow. M80 can be recommended, with guano applied once during an intensified rotation followed by a leguminous fallow. The additional investment in M40 or M80 was 185 or 370$/ha/rotation, however, after only one rotation, the M40 and M80 treatments produced $700 and $1350 in additional returns relative to *tavy*. If the current government policy is to protect remaining forest, farmers will need to intensify agriculture and eliminate fire from the landscape. The fire-less approach presented is one possible pathway.

BIOGRAPHICAL SKETCH

Erika Styger from Zurich, Switzerland, had dreamed since childhood of going to Africa. This dream came true for the first time when she was able work for several months in an agricultural training center in Zimbabwe during her studies in agronomy at the Swiss Federal Institute of Technology in Zurich (ETHZ). She earned the degree of Master of Science in Agronomy at the Institute of Crop Science, with fieldwork at the Biological Control Program, IITA, Cotonou, Benin, in 1989. She was then seconded by the Swiss Agency for Development and Cooperation to work as an associate scientist with the Agroforestry Research Project ICRAF/ISAR in the Rwandan highlands. There she obtained very thorough training, learning how to conduct research that maintains international standards while taking local realities and needs into account. Sadly, she had to abandon the first Ph. D. project because of the Rwandan genocide that disrupted the country in early 1994. From 1994-1995, she took on a job with the Swiss development agency Intercooperation as project director for the Agricultural Development Project SAF-CO in Morondava, Madagascar, concentrating her efforts on developing agricultural and agroforestry activities together with the farming community with an action-research approach . In 1995/1996 she headed an ethnobotanical study on indigenous fruit trees in Madagascar for Intercooperation, Switzerland. After six years of field research, she resumed her pursuit of a Ph.D. and was accepted by Cornell University to work under Prof. E. C. M. Fernandes in the Department of Crop and Soil Sciences. This time, the Ph.D. project succeeded. She plans to make best use of her gained knowledge and experience and continue working to improve farming conditions for African farmers.

I would like to dedicate this dissertation to the great teachers
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Chapter 1

Introduction

Slash-and-burn agriculture or *tavy* is the traditional and predominant land use in eastern Madagascar. The fertilizing and pH-buffering effects of the ashes of the burned primary or secondary vegetation allow farmers to produce as staple foods upland rice, manioc, and sweet potatoes on the nutrient-depleted and acid Inceptisols and Ultisols (Johnson, 1992). *Tavy* is a very old practice and is deeply rooted within the culture and religion of the Betsimisaraka, the dominant ethnic group in eastern Madagascar. By practicing *tavy*, people are able to connect to their ancestors, which are their direct link to God or *Zahanary*. Thus it is a sacred practice to the Betsimisaraka (Vicariot, 1970). The strong connection is also illustrated by the saying "A Betsimisaraka without a *tavy* field is not a Betsimisaraka."

While the *tavy* system was for many centuries a sustainable form of land use, it has been identified over the past 150 years as the major cause of deforestation and of upland degradation generated by frequent fire use and cropping. Since the beginning of the twentieth century, many authors have advocated the urgent need to develop alternatives to *tavy* and fire use (Humbert, 1927; Kiener, 1963; Oxby and Boerboom, 1985; Gade, 1996; Marcus, 2001). The excessive and ongoing deforestation activities threaten Madagascar's biodiversity. Half of the eastern rainforest was destroyed within only 35 years, reducing it from 7,600,000 ha in 1950 (68% of the original surface) to 3,800,000 ha in 1985 (34%) (Green and Sussman, 1990). Madagascar is among the three most critical of the 25 biodiversity hotspots in the world as identified for conservation priorities. The flora and fauna show an exceptionally high level of endemism at species, genera, and family level but at the same time experience exceptional loss of habitat, as the remaining areas are critically small (Myers et al., 2000). According to the latest estimates, Madagascar's primary vegetation is below 10% of its original extent, although there is no recent reliable map available. (Lowry II et al., 1997; Myers et al., 2000)

The *tavy* practice is also the major cause of upland degradation. Frequent fire use favors nutrient losses from the system, impacting the system's productivity (Pfund et al., 1997). It also kills native regenerating tree species and allows exotic, invasive shrubby and herbaceous species to colonize the open surfaces (Humbert, 1927; Koechlin, 1972; Lowry II et al., 1997). This has produced over time a landscape with hardly any secondary forest regrowth. The landscapes are mostly treeless and characterized by species-impoverished secondary grasslands, subject to erosion and abandoned for agriculture. Grasslands occupy 63-72% of Madagascar's land surface, according to various estimates. (Koechlin, 1972; Direction des Eaux et Forêts, 1996; Gade, 1996)

In addition to all these dynamics, consider also that Madagascar is one of the poorest countries in the world, with 3% annual population growth, and poverty that has worsened from affecting 40% of the population in 1970 to affecting ca 75% in 1997(World Bank, 1999). The gross national income was, in 2000, 250 US$/person compared with 480 US$/person for sub-Saharan Africa (World Bank, 2001).

The study area was located next to the Mantadia – Zahamena forest corridor, one of the largest contiguous remaining rainforests, on an east–west axis between Beforona and Moramanga. This area is characterized by traditional Betsimisaraka agriculture, which dominates the eastern region, and by the loss of forest cover and soil degradation. The area is also marked by the absence of governmental services. No law enforcement for forest protection is exercised nor is there any agricultural extension service made available that would allow people to develop alternatives to their destructive practices.

A major additional problem is that the traditional *tavy* system has to sustain a population with a regional annual growth rate of 3% (Barck and Moor, 1998). This rapid increase in population has caused the fallow periods to decrease sharply from 8-15 years in the 1970s to 3-5 years currently, inducing yield declines and land degradation. Declining yields from subsistence agriculture lead to food deficits, engulfing people further in the vicious circle of poverty. It has also induced a migration from the depleted zones to the forest zone, where soils are still fertile and deforestation guarantees new land access. In the forest zone (Ambavaniasy), the population density is around 40 people/km^2, whereas 20km further east in the degraded zone (Salampinga), the farming system supports only ca 20 people/km^2 (Barck and Moor, 1998).

Outsiders have encountered difficulties in dealing with *tavy*, having failed to prevent further forest destruction and upland degradation. *Tavy* has also long been stigmatized as a criminal act. Burning and deforestation was pronounced illegal in the 1850s and has been repressed most of the time since then (Dez, 1968). The Betsimisaraka hid their *tavy* activities and created a dual identity, which Althabe (1969) described in terms of a 'split society' in his analysis of the Betsimisaraka. Farmers feel threatened and are still suspicious of outsiders today, and thus it remains difficult to approach the issue of *tavy*.

The development and research projects and organizations that have been active in the region since the 70s have placed greatest emphasis on lowland rice and cash crop development, speculating that these changes would provide enough incentives for the farmers to abandon *tavy*, which has been identified as uneconomical. (Projet Terre-Tany / BEMA, 1998; Messerli, 2000; LDI, 2001). The improvement of the annual upland cropping or *tavy* system has been mostly ignored. But so far most projects have lacked conspicuous success, *tavy* prevails, and forests continue to disappear. Today the search for alternatives is becoming more and more critical (Marcus, 2001).

The *tavy* system occupies 75-90% of the hilly landscape characterized by steep terrain, where lowland rice occupies only 2.7%, the traditional agroforests or *tanimboly* 6.6%, and the reforested areas 1.5% (Brand and Randriamboavonjy, 1997). The state of the uplands is therefore of major ecological importance to the agro-ecosystem. It has to be recognized that if lowlands and cash crops are to become important components within the agricultural system they have to be supported by a healthy and sustainable upland system.

Sustainable and productive uplands can provide food crops, cash crops, and wood products and supply services to the overall system such as water protection and storage within the landscape, microclimate regulation, soil fertility restoration, and maintenance if combined with erosion control. Thus annual upland cropping improvement should be integrated in any attempt to improve the Betsimisaraka farming system. On the other hand, ignoring *tavy* contributes directly to the upland degradation process that brings along erosion, favors landslides, flooding, and siltation of lowlands. The agro-ecosystem is susceptible to extreme events such as cyclones that can have devastating impacts on infrastructure and agricultural production, especially in the fertile lowlands.

An ideal upland management system should embrace the opportunities for landscape management without fire, enhance the system's potential for agricultural intensification, conserve and restore biodiversity within the landscape, and finally alleviate poverty by allowing increased and sustained production of food and cash crops. The goal of this research was therefore first to identify current upland use strategies and upland degradation dynamics and, based on these findings, develop fire-less upland management practices that intensify, improve, and sustain agricultural production and—what is equally important—are likely to be adopted by small farmers.

In Chapter 2, land use change over time is explored and farmers' current upland management strategies are identified. Constraints perceived by farmers for keeping the uplands productive in the long-term are recognized as well as how farmers react to overcome the constraints. Chapters 3 and 4 are dedicated to studying the dynamics of upland degradation under current practices, identifying the consequences for long-term agricultural productivity. Whereas in Chapter 3 the focus lies on fallow characterization along a degradation sequence based on indigenous knowledge complemented by field observations, in Chapter 4, it is based on the quantification of fallow vegetation biomass and nutrient stocks and the study of exchangeable soil nutrients, which directly influences agricultural productivity. Chapter 5 will present the results on testing fire-free alternatives to *tavy* that build on traditional cropping practices, provide limiting key nutrients to the system, and strive for the optimization of nutrient cycling of available biological resources. Chapter 6 is dedicated to the major key findings and conclusions.

Chapter 2

Farming system dynamics in eastern Madagascar, and farmers' strategies for overcoming agricultural upland constraints

INTRODUCTION

Madagascar has been populated for around 2000 years primarily by people immigrating from Indonesia and East Africa (Deschamps 1972; Wright and Rakotoarisoa 1997). Until 1500 the settlers in the eastern region lived in small permanent settlements along valleys and developed a rather stable shifting cultivation system called *tavy*, which was characterized by long fallow periods. Farmers planted crops they brought from Indonesia such as rice, taro, bananas, and coconut palm. With the low population density, this land use remained in equilibrium, until outside influences altered settlement structures and land use practices. Arabs and Europeans arrived from the 16th to 18th centuries, looking for slaves and agricultural products. In the 19th century, the Merina kingdom ruled over large parts of the country and in 1895 the island was colonized by the French. Under these political influences, and in combination with an increasing population and with decreasing fallow periods, the *tavy* system evolved from a stable shifting cultivation system into an unsustainable system of slash-and-burn agriculture. (Solheim 1965; Deschamps 1972; Mahefa 1992; Wright and Rakotoarisoa 1997).

Tavy has long been identified as the major cause of the deforestation of one of the worlds' most species-rich rainforests (Myers, Mittermeier et al. 2000). The *tavy* system, in combination with short fallow periods, is also the underlying cause of soil and vegetation degradation in the eastern uplands (Brand and Pfund 1998). In parallel, the urgent need to develop alternatives to *tavy* and fire use has long been advocated (Humbert 1927; Kiener 1963; Oxby and Boerboom 1985; Marcus 2001). This is especially important because the *tavy* cropping system extends over 75-90% of the landscape surface (Brand and Randriamboavonjy 1997). For the Betsimisaraka, the dominant ethnic group of Eastern Madagascar, the *tavy* practice is a traditional way of life, and is thus deeply ingrained culturally; the Betsimisaraka people have resisted repression that was directed against the *tavy* system for the past 150 years (Dez 1968).

A number of development and research projects and organizations have been active in the Beforona region since colonial times. They have mostly targeted the development of lowland rice and cash crops, speculating that these changes would provide enough incentives for farmers to abandon *tavy* (Terre-Tany / BEMA 1998; Messerli 2000; LDI 2001). The improvement of the annual upland cropping or *tavy* system was mostly ignored. So far, however, most projects have lacked noteworthy success; *tavy* persists and forests continue to disappear. Today the search for alternatives is becoming more and more critical (Oxby and Boerboom 1985; Marcus 2001).

Given the agricultural, ecological, and cultural importance of the uplands, the annual upland cropping improvement should be integrated in any attempt to improve the Betsimisaraka farming system. The farming system's description through quantitative surveys are available and provide a good introduction to the farming system of the study area (Terre-Tany / BEMA 1997; Terre-Tany / BEMA 1998). There is still very little in-depth information, however, on how land use has evolved and changed over time, what upland use strategies farmers adopt currently, how farming practices influence long-term productivity and upland degradation, how farmers perceive their situation and problems, and, finally, what their strategies and options are for responding to these recurring problems.

In order to obtain an in-depth understanding of these questions and given the farmers' suspicions and hesitation to talk about *tavy* to outsiders, a qualitative research approach was chosen. This allows the study of selected issues in depth, in detail and with openness, and without the constraints of predetermined categories of analysis (Patton 1990).

Objectives

1) Recognize natural resource use and agricultural system change over time
2) Identify the major upland use strategies that farmers employ
3) Learn what farmers' major constraints are to maintain satisfactory long-term agricultural upland productivity
4) Learn how farmers respond to overcome these constraints

Hypotheses

1) The identification of farmers' upland management strategies and the study of farmers' response to overcome constraints that impede agricultural long-term productivity will reveal local strategies that maintain agricultural productivity and result in a baseline for new research.
2) Upland management strategies vary among farmers with different access to and soil fertility status of land.
3) The diversification of the agricultural system with lowland rice and cash crops are not adequate alternatives to traditional *tavy*.

METHODOLOGY

Field research extended over 25 months from June 1999 to June 2001 and was performed under a collaboration agreement between CIIFAD (Cornell International Institute of Food, Agriculture and Development) and LDI (Landscape Development Interventions), a development project executed by Chemonics International Inc. and funded by USAID. LDI was active in the larger region of Moramanga-Ambatondrazaka-Tamatave in eastern Madagascar.

1. Study area

The study area was located at the margins of the Mantadia-Zahamena rainforest corridor, one of the largest remaining contiguous rainforests in the mid-eastern region of Madagascar, located in a mountainous zone at an altitude range of 750-1200m. The study area extended between 18° 48' 26'' S (Ambohimanarivo) and 19° 04' 29" S (Ampahitra) and 48° 14' 01" E (Ampahitra) and 48° 35' 50" E (Ambatomalama) (Figure 1). The area is typical of the eastern region, characterized by the traditional slash-and-burn agriculture (*tavy*) of the Betsimisaraka. Furthermore, the area was marked by forest cover loss and soil degradation. Studies were initiated at the Farmer Center CDIA (Centre de Diffusion et d'Intensification Agricole), located in Marolafa, Beforona. Initial contacts and introduction to communities and farmers were facilitated through the help of LDI field staff, and by the local farmers working at the CDIA Farmer Center.

2. Village selection

Nine villages were selected on the eastern and western sides of the forest corridor. The villages were in either the forest zone or the fallow zone. The forest zone is here defined as the agricultural zone adjacent to the forest corridor where farmers still engage in deforestation in order to claim and cultivate land. In the fallow zone, all primary forests were cut in the past and farmers do not have access to new land. The fallow zone is located beyond 5 km from the forest boundary. The location of the villages is shown in Figure 1 and the GPS coordinates are reported in Table 1. Two villages were selected for the in-depth studies. These villages were located in the forest and fallow zones and good contacts with villagers in them were already established. These two villages were Ambavaniasy and Ambinanisahavolo. Some characteristics are presented in Table 2.

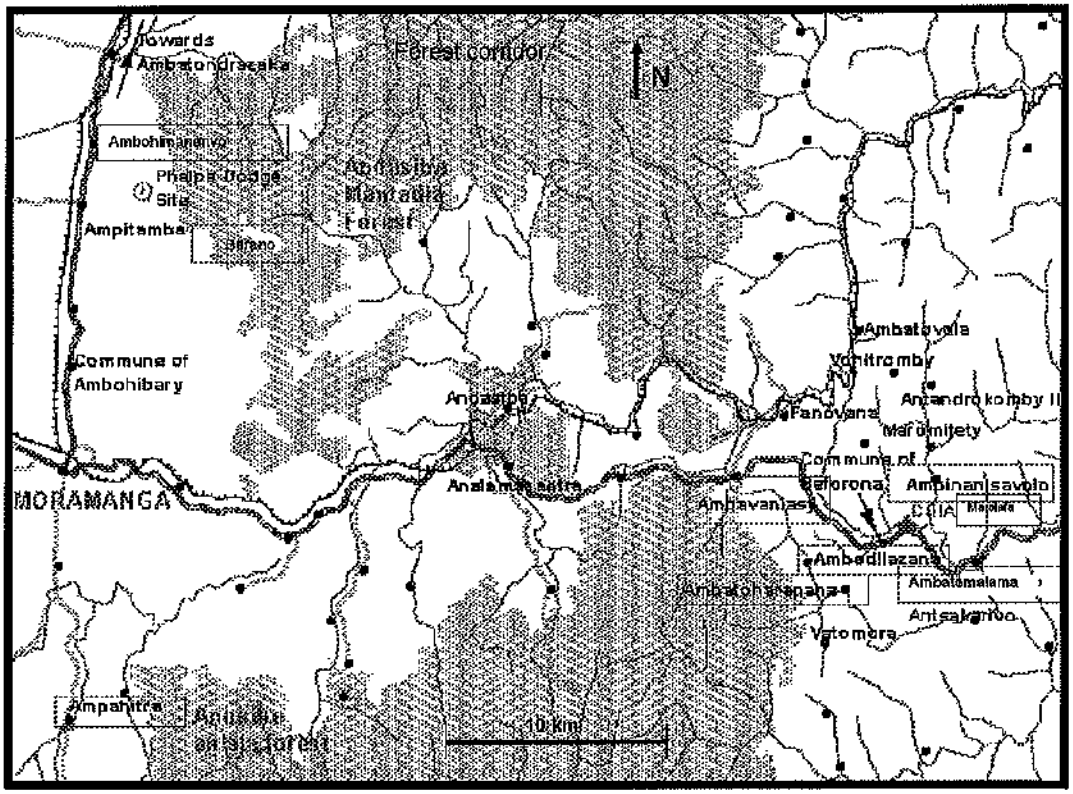


Figure 1: Study area with villages of intervention

Table 1: Selected villages, agricultural zone and GPS coordinates

Villages	Agricultural Zone	GPS Coordinates South	GPS Coordinates 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 corridor			
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	-	-

* Villages for in-depth study

Table 2: Characteristics of Ambavaniasy and Ambinanisahavolo

Characteristics/Village	**Ambavaniasy**	**Ambinanisahavolo**
Zone	Forest Zone	Fallow zone
Fokontany	Fanovana	4 villages: Ambinanisahavolo, Marolafa, Ambatomasina,
Commune	Ambalovola	Beforona
Fivondronona	Moramanga	Moramanga
Location	on RN2, at 142km from capital	3 km North of RN2, at 154km
Altitude (m a.s.l)	695m	550 m
Mean annual temperature (°C)	20.4 °C	21.5 °C
Mean annual rainfall (mm)	3431 mm	2563 mm
Population	340	320
People > 18 years	140	112
Lineages	-	5
Sembotrano (tombs)	-	2
Tangalamena (spiritual leader)	-	2
Distance to:		
Primary school 1st to 4th grade	5 km distance	in village
Primary school 5th to 6th grade	12 km distance	in village
Health care (Beforona)	13 km distance	5 km
Extension service	never	in 60s, coffee technician
Extension NGO	-	FAO (70s), SAF (early 90s), LDI (late 90s)
Research organizations	Terre-Tany (early 90s)	French colonial researchers (50s, 60s), Fofifa (70s, 80s), Terre-Tany (90s), Bema (90s), University of Antananarivo, Heidelberg, Cornell University(all 90s)

3. Research team

The research team was comprised of the principal investigator (myself), Mparany Harivelo Rakotondramasy, a researcher with a Master of Science degree and six years of field research experience, and two farmer-collaborators, Joela and Lezoma, who were native to the two villages selected for in-depth study. The farmer-collaborators were present at all the interviews in their own villages and participated actively in the interviewing process.

4. The four major studies: objectives, respondent sampling, and methodology used

Four different studies were conducted: 1) description of the farming system, 2) characterization of fallows, 3) history of the farming system, and 4) farmers' upland farming strategies. Qualitative methods were used and, in total, 96 individual and 22 group interviews were conducted over a 25-month period (group interviews were defined as those involving more than two interviewees). The list of interviews is presented in Appendix 1. Table 3 shows the timeline of the studies, as well as the number of interviews held for each of the studies.

Table 3: Timeline of four studies and number of interviews

Year	1999	2000	2001	
Month	6 8 10 12	2 4 6 8 10 12	2 4 6	Total Interviews
1 Farming system description	20 IN, 3 GR *	4 IN, 9 GR	12 IN	36 IN, 12 GR
2 Fallow characterization		20 IN, 6 GR	1 GR	20 IN, 7 GR
3 Farming system history	3 IND	3 IND 2 GR	1 GR	6 IN, 3 GR
4 Farmers' upland farming strategies		12 IND	22 IND	34 IN
Total Interviews				**96 IN, 22 GR**

* IN: Individual interview, GR: Group interview (>2 people)

4.1. Farming system description

The first study focused on the description of the farming system and its components, in particular on the cropping systems, and tree and forest use. Thirty-six individual and 12 group interviews were conducted in the nine villages. Most farmers were selected purposefully with an intensity sampling approach (Patton 1990). The farmers were selected according to their ability to provide rich and intense information of a particular farming system component. This sampling approach was pursued when farmers could be identified through village informants. On less common occasions, *ad hoc* and opportunistic farmer sampling was applied cases in which the research team contacted the farmers directly. The questionnaire guide is presented in Appendix 2.

In addition to interviews, a schematic map of the village territory was established in collaboration with farmers to obtain a territorial orientation. The map, which showed the village territory boundaries, the distribution of land by lineage, and various landmarks, proved invaluable in completing the in-depth studies. Also, a transect exercise through a representative section of the village territory was performed with three local village experts, following RRA methodology (Gueye and Schoonmaker Freudenberger 1991). The exercise focused on current land use, the cropping system, fallow cycles, fallow species, soil, relief, trees, livestock, land tenure, and landowners. Back at the village, the transect diagram was composed and then verified and completed with the assistance of local experts.

4.2. Fallow characterization

The methodology and results of this study are presented in Chapter 3.

4.3. Farming system history

Three group interviews were held with village elders in Ambavaniasy, Ambinanisahavolo, and Ampahitra. The objective was to identify principal changes in the farming system and in the state of local natural resources within the elders' lifespans, and to determine what the driving forces were for these changes. This was accomplished by reconstructing major historical events, gauging their impact on the community and land use, and then performing ranking exercises on natural resource development over time, including agricultural crops, forest resources, and fallow species. A questionnaire-guide is presented in Appendix 2. Native elders to the village were invited to participate. In Ambavaniasy, younger villagers participated as well, but elder women who were explicitly invited did not want to participate officially. Instead, they gathered outside of the door and participated to some extent from there. In Ampahitra and Ambinanisahavolo, participants were limited to elders, which allowed them to express their views at their leisure. The sessions were held according to RRA guidelines (Gueye and Schoonmaker Freudenberger 1991), and a moderator experienced in RRA methods joined the research team to guide the discussions. Discussions were tape recorded and later transcribed into Malagasy and then translated into French. The Malagasy transcript was returned to the villagers. In addition to these group sessions, six individual interviews were held with elders.

4.4. Farmers' upland farming strategies

This study was conducted in the villages selected for the in-depth study, Ambavaniasy in the forest zone and Ambinanisahavolo in the fallow zone. It consisted of two steps. First, upland farming constraints were identified through ten key-informant interviews. Second, selected farmers were interviewed about their specific strategies to farm the uplands and how they overcome the given constraints. In addition, farm plots and their histories were inventoried.

4.4.1. Identification of upland farming constraints through key-informant interviews

Key informants were selected by the criteria of being native to the village, having considerable farming experience—thus being 50 to 60 years old—and being good communicators. The interview focused on identifying the major strategies of upland management in the village, the land tenure situation, and the main constraints facing farmers in managing their land in order to maintain its long-term productivity. At the end of an interview, the list of constraints was recounted to each key informant and a ranking was applied according to the severity of the constraint and the possibility of influencing it through management.

4.4.2. Farmers' upland farming strategies through in-depth interviews

Selection of farmers for individual interviews was done purposefully and was based on a maximum variation sampling procedure (Patton 1990). This sampling strategy aims at identifying patterns and principal themes that cut across the variation that exists within the farming community. Thus the selected farmers responded to the extreme conditions of the two identified main constraints. Each constraint was divided into three sub-categories (identified by the key informants) and finally integrated in a matrix. The outcome is reported in Table 4. Farmers who corresponded to each particular profile were selected. In Ambavaniasy it was possible to distinguish three soil fertility categories, as good productivity still exists, whereas in Ambinanisahavolo, soil productivity loss across the entire village territory allowed us to distinguish only two categories. Soil fertility and productivity were categorized based on farmers' information about good, medium, and low productivity that represents, respectively, ca 2t/ha, 1.25 t/ha, and 0.5 t/ha of upland rice. Later use of the terms 'good,' 'medium,' and 'low' productivity will refer to these yields. The selected farmers were visited one to three times on their farms. At the first meeting the main strategies and constraints for sustainable upland production were discussed. It was followed by field visits where an

Table 4: Farmers selected for in-depth interviews in Ambavaniasy and Ambinanisahavolo

Upland surface	Soil fertility Upland rice productivity		
	2 t/ha Good	1.25 t/ha Medium	0.5 t/ha Low
Ambavaniasy			
> 25 ha	Radison	Lezoma	Lucille
10-25 ha	Pascal	Maro	Clarisse
< 10 ha	Justin	Andre	Rasamuel

Upland surface	Soil fertility Upland rice productivity	
	> 1.25 t/ha Medium-good	< 1.25 t/ha Low-Medium
Ambinanisahavolo		
> 25 ha	Ndriantsara	Gato
10-25 ha	Botovola	Rabe
< 10 ha	Florent	Lemaraina

inventory of farmer's fields was obtained and land use history for each plot was retraced as accurately as possible, focusing on cropping/fallow cycles and fallow vegetation change. A map of the fields was sketched during the field visits, integrating current and past land uses. At the same time, digital photographs of the fields were taken. The maps were later superimposed on the photographs, to document field arrangements and field use within the landscape. Methodological difficulties arose during the plot history review because farmers couldn't always remember precisely the details of fallow and cropping sequences or the dates of deforestation, especially if it had occurred 20 to 30 years in the past. In case farmers did not remember, focus was shifted to understanding the principals of upland use and management applied by the farmer. If a farmer remembered the plot history clearly, however, detailed notes were taken. As a result of these factors, it was not possible to establish a perfect historical mapping of all the farmers' fields, but a good in-depth understanding of the individual upland farming strategy was gained nevertheless. The same principal of either understanding the principal or taking detailed notes applied to another difficulty, namely reconstructing the cropping sequence within a rotation, because not all the crops occupy the same surface.

5. Interview process

Given farmers' suspicions regarding outsiders, considerable emphasis was put on being respectful, and being very careful in how interviews were conducted. This began with letting the farmer choose the location for the encounter, which was most often his or her house or field. Time was reserved for social interaction at the beginning of each interview, as participants became acquainted with the interviewers over small servings of food. The formal interview process started with an introduction by the farmer collaborator, explaining the objective of the visit as well as the research objectives. The interviews were based on a questionnaire guide that provided focus while remaining flexible enough to accommodate further in-depth questions. Questions were open-ended. They were posed by the principal investigator in French. The research assistant translated them into Malagasy for the farmer and translated the response back into French. The principal investigator was responsible for the notes, which were made as close in wording to the translation as possible. The farmer collaborator contributed to the communication process by explaining certain aspects in the Betsimisaraka dialect if necessary. Each interview was limited to one hour. At the end of all the interviews, farmers were invited to an experimental field visit and lunch to show our appreciation and to share the results of the agricultural experiments with the farmers who, in turn, provided their feedback. This process was very satisfactory for everyone involved, and farmers felt respected and pleased; they learned something new while the researcher benefited further from the farmers' insights.

6. Quality of information

Asking interviewees about slash-and-burn agriculture invoked considerable hesitation. Thus much emphasis was put on gaining trust. This trust was sought for through rules of behavior that were followed consciously by the research team. The rules included being impartial and non-judgmental, not insisting on answers to every question, being aware of the connotations of the vocabulary used, and being transparent and showing respect. In-depth studies were conducted toward the end of the second year of fieldwork, so by that time farmers in the region knew the research team members, and the research team was familiar with the farming system and local customs. The agricultural experimentation was conducted over an 18-month period in the same villages, a circumstance in which researchers could further build on the trust gained from working with farmers.

The collaboration within the research team was of great importance in creating valid data. The close collaboration over two years created a deep understanding of the research questions and the objectives of study on the part of everyone on the research team. This was especially important during the translation process. Of essential help in assuring the highest accuracy in translation and communication was the presence of the farmer-collaborator. He was aware of the interview and research goal while sharing the language of the farmer as part of the farming community. Thus the farmer-collaborator facilitated the communication process in both ways: The researchers could benefit from important insights into farmers' thinking, culture, and farming practices and the farming community could benefit by being able to exchange ideas with the farmer about the researchers' work. All these dynamics were important in gathering truthful information.

Triangulation was used to assess the accuracy of the information. Triangulation is the use of a combination of methodologies in the study of the same phenomenon (Patton 1990). The most important triangulation process was the comparison of the information obtained from the interviews with field observations, especially the inventories of plot histories that allowed the researchers to check on farmers' information and also allowed them to identify, confirm, or refute emerging patterns during the fieldwork. Additional triangulation was applied by comparing information gathered from the in-depth study with information acquired earlier during the farming system description in other villages. Furthermore, during in-depth interviews, more general questions were systematically integrated in open-ended form to either confirm that the interviewers and respondents shared a common understanding of the topic or if not, to clarify the subject under discussion. Triangulation was also achieved by combining farmers' insights with biophysical studies that were conducted as part of this dissertation research. Repeated encounters with selected informants allowed researchers also to verify, confirm, or reformulate certain pieces of information, which is especially helpful when patterns seem to occur. Given all these factors, I am confident that the research results reflect the local reality fairly accurately.

7. Data Analysis

Analysis was the sole responsibility of the principal investigator and began with the transcription of field notes. 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. Topics with consistent information were developed and are presented as results. Quotations are used to exemplify the patterns most clearly. Analytical guidelines were obtained from Patton (1990).

RESULTS

1. Natural resource use and agricultural system change from before 1947 until the present

1.1. Natural resource use and agricultural change according to political periods in Ambavaniasy and Ambinanisahavolo

By reviewing major historical events with elders in Ambavaniasy and Ambinanisahavolo, three major political periods were identified that had a distinct influence on natural resource use:

1. Colonial times and the period after independence, until 1975
2. The Second Republic under Ratsiraka, from 1975 to 1987
3. The recent period, from 1987 to 2001

The changes that occurred during each of the periods are illustrated and summarized in Figure 2 for Ambavaniasy and Figure 3 for Ambinanisahavolo. I now discuss them in greater detail. I elaborate on the hypothesized future scenario for the two villages represented in these two figures in the subsequent discussion.

1.1.1. Colonial times and the period after independence, until 1975

Ambavaniasy existed as a location before colonial times (before 1896) but was developed as a village in 1936 under the colonial wood-extraction timber companies 'Companie Coloniale' and 'Grand Ile'. People immigrated to the zone and worked as woodcutters for the companies. *Tavy* rice production was allowed only on small plots and producers had to pay taxes. Some Betsimisaraka were hiding in the forests from

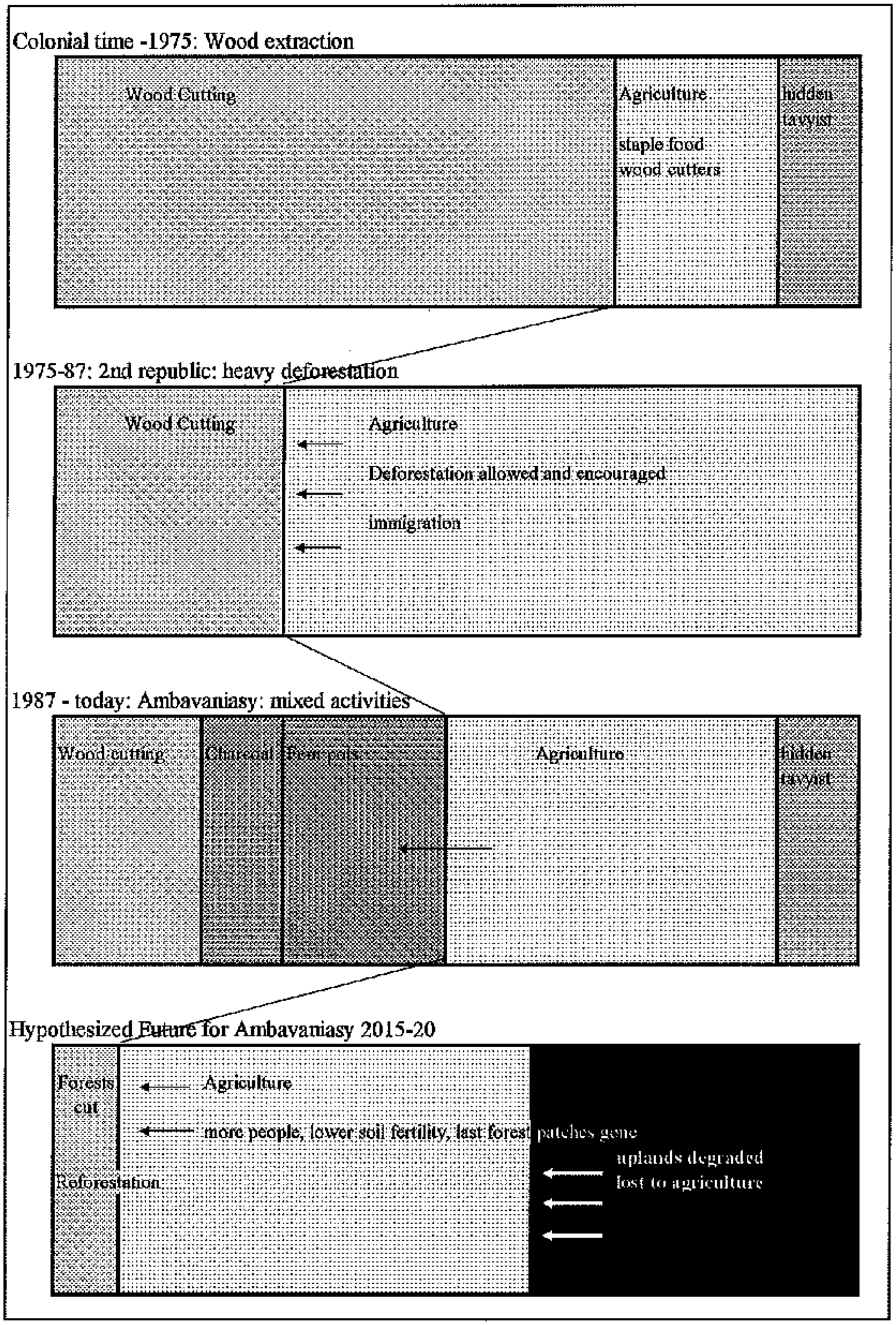


Figure 2: Natural resource use according to political periods in Ambavaniasy, located in the Vohidrazana forest zone

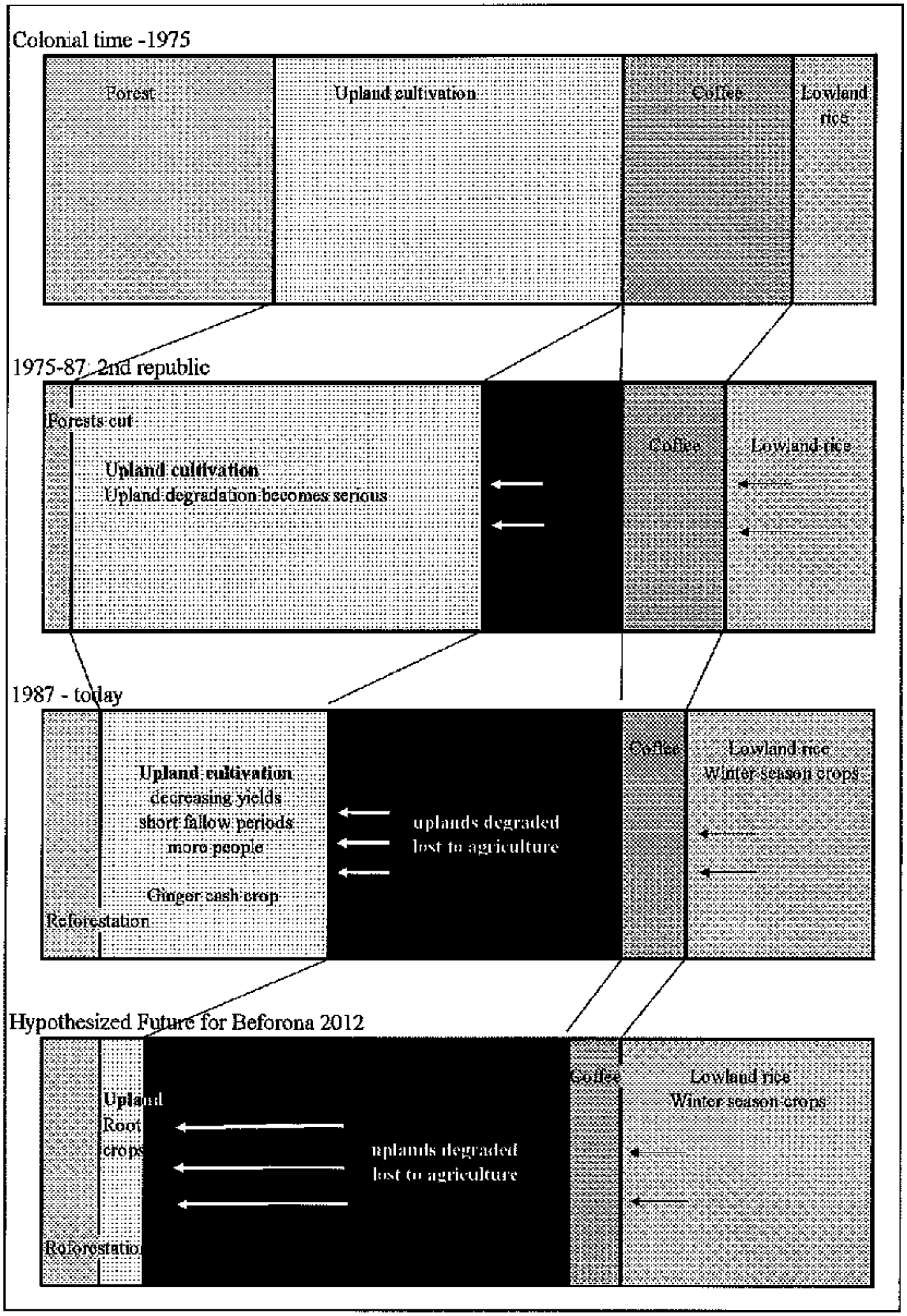


Figure 3: Natural resource use according to political periods in Ambinanisahavolo, located in the Beforona fallow zone

colonial rulers, cultivating their staples and living in independence. After the colonial companies left following independence in 1960, other timber companies arrived and wood extraction continues today. After 1960, deforestation was still forbidden and villagers remember that, until 1975, laws were more or less respected.

Ambinanisahavolo is a traditional Betsimisaraka village that existed before colonial times. It was created by the ancestors of five lineages who distributed the land among each other according to their deforestation activities. They also agreed on the village boundaries with neighboring farmers. During the colonial period, most of the land was already deforested, and therefore no commercial forest product extraction was pursued. But farmers had to plant coffee and pay taxes, and many were taken away to forced labor camps. As for *tavy* cultivation, people were allowed to burn the fallows but not the forests and not the upper one-third of a hillside. After 1960, taxes were abolished and people were able to produce crops on the still-fertile upland soils.

1.1.2. The Second Republic under Ratsiraka (1975-1991)

The biggest change in the state of natural resources came with the second republic under Ratsiraka (1975 - 1991), when the 'Five Year Plan' was initiated. The ban on deforestation was lifted and people were encouraged to cut as much forest as they were able to cultivate during a five-year period. Everybody living next to the forest engaged heavily in deforestation. In addition, immigrants arrived looking for new land.

Villagers in Ambavaniasy dispersed throughout the village territory, built temporary *tavy* houses, and started cutting the forest from there, creating over the years a larger contiguous surface of agricultural land. Rules such as protecting the upper one-third of the hillsides were no longer respected. There was no planning and no conceptualization of how to exploit the resources at the village level. People were free to decide where and when to deforest and to cultivate. The Five-Year Plan was followed by a Seven-Year Plan that maintained the same policies regarding resource exploitation. It was only in 1987 that deforestation was forbidden anew. Farmers remember that in 1975 the village was still located in the middle of the forest, whereas in 1987 the forest corridor had already been pushed beyond the village territory boundaries. In Ambinanisahavolo the last remaining forest patches, especially on the upper third of the hillsides, were cut during this time period.

1.1.3. The recent period, from 1987 to 2001

Although the ban on deforestation had been renewed in 1987, almost no control over the farmers or enforcement of the law has occurred since then. Recent years have seen even laxer control. Villagers have not seen any forest agents in the region since 1995. People continue cutting the forests without much fear of prosecution. Today, villagers in Ambavaniasy pursue mixed activities, combining upland agriculture and forest extraction (timber, fern pots, and charcoal) according to individual inclination. In Ambinanisahavolo, fallows and uplands began showing signs of degradation in the 80s and 90s. People started to concentrate on agricultural diversification. Also at that time, reforestation activities with *Eucalyptus* were initiated. More information on agricultural change will be presented in the next section. In the entire history of Ambavaniasy, no official agricultural extension service has ever worked there. In Ambinanisahavolo, colonial and later national forestry researchers were present in the region as well as an extension agent who worked on coffee for ten years in the 60s. From the 70s to the 90s, various other research and development organizations have been active.

1.2. Changes in the agricultural system and forest resources from circa 1947 until the present

Changes in the agricultural system and natural resource use over time were evaluated with elders from the two villages by using a ranking exercise (Interview reference ID i52, i88, Appendix 1). The ranking was done with scores from 1 to 10 representing the relative importance of land occupation by a given crop. A score of 10 indicates the maximum surface extension of a crop that villagers were aware of during their lifetime. All other numbers were adjusted in reference to it. The results for both villages are reported in Table 5. In both villages, the elders agreed that the surface of the major crop and fallow land increased in parallel with the number of households.

In Ambavaniasy, agricultural activities are entirely concentrated on the uplands. The cropping systems have remained practically the same over the past 50 years. There was no shift in the proportional composition of the planted crops. Crop diversity is not very high. People depend on *tavy* rice, manioc, and sweet potatoes for staples and plant bananas as a cash crop. A few farmers have started to plant ginger. The agricultural surface extension for the annual crops is directly linked to *tavy* rice, because the opening up of agricultural land through deforestation is done exclusively for the *tavy* rice cropping system. The other crops, such as manioc and sweet potatoes, are planted as a second crop on parts of the abandoned rice fields.

In Ambinanisahavolo, agricultural productivity scored highest between 1960 and 1975. During that time, villagers also benefited from agricultural extension services and improved coffee crop and fruit tree production and started to diversify their crops. The diversification became especially important during the 90s with the emergence of such crops as ginger for the uplands, beans, greens, and more irrigated rice field installations in the lowlands. Diversification went hand in hand with the beginning of the decline of

Table 5: Evolution of natural resources in a) Ambavaniasy and b) Ambinanisahavolo

a) Evolution of natural resources in Ambavaniasy

Ranking excercise with 20 villagers, July 11th, 2000 (i52)

Relative ranking with 10: highest score; 1: lowest score: 0: non existant

Comment to time periods: before 1947, when elders were children or teenagers, 1947 uprising against colonial power, 1947-1960 colonial period until independence, from 1960-2000 ranking was done in 10 year intervals

Nat Res. / Time period	bef 1947	1947-60	1960-70	1970-80	1980-90	1990-2000
Population	3	5	6	8	9	10
Land surface						
Uplands						
Rice	2.5	2.5	8	9	10	10
Manioc	2.5	2.5	8	9	10	10
Sweet potato	2.5	2.5	8	9	10	10
Cucumbre	2.5	2.5	8	9	10	10
Corn	2.5	2.5	8	9	10	10
Tanimboly						
Banana	2.5	2.5	8	9	10	10
Lowlands						
Fallow land surface	2.5	2.5	8	9	10	10
Infertile fallow	0	0	0	0	0	1
Good soil (2t/ha ric	10	10	10	8	6	5
Bad soil (0.5t/ha ric	0	0	0	1	2	3
Forest resources						
Forest surface	10	10	9	7	3	1
Precious wood	8	7	7	5	4	2
Construction wood	10	10	10	9	7	4
Fern pots	10	10	10	9	5	1
Orchids	10	10	10	9	5	1
Food from forest	10	10	9	7	5	3
Medicinal plants	10	10	10	10	10	8
Lemurs	10	10	10	10	8	4

b) Evolution of natural resources in Ambinanisahavolo

Ranking exercise with 3 elders, on March 22, 2001 (i88)

Relative ranking 10: highest score; 1: lowest score; 0: non existent, ?: not sure

Comment to time periods: before 1947, when elders were children or teenagers, 1947 uprising against colonial power, 1947-1960 colonial period until independence, 1960-1975: 1st republic, 1975-1990: 2nd republic; 1990-2000 the most recent decade.

Nat Res. / Time period	bef 1947	1947-60	1960-75	1975-90	1990-2001
Population	?	3	5	8	10
Land surface					
Uplands					
Rice	3	6	7	9	10
Manioc	1	2	5	8	10
Sweet potato	10	5	5	9	10
Cucumbre	0	0	2	5	10
Corn	2	2	5	9	10
Ginger	?	0	2	5	10
Tanimboly					
Banana	2	5	8	9	10
Coffee	2	6	10	6	4
Fruit trees	2	6	10	6	4
Lowlands					
Irrigated rice	3	3	3	8	10
Beans	2	2	2	8	10
Greens	0	0	0	5	10
Taro	10	7	7	6	3
Agriculture in general			10		0 - 1
Forest resources					
Forest surface	7	7	5	1	0
Construction wood	10	10	8	6	1
Fire wood	10	10	10	8	4
Eucalyptus	0	0	3	5	10
Food from forest	10	10	6	3	0
Medicinal plants	10	10	8	4	3

tavy rice yields. The elders judge agricultural productivity today as the worst they can remember. Although yields in the uplands have diminished drastically and despite crop diversification, upland production of annual crops is still the main focus for agricultural production. An overview of today's agricultural cropping systems and forest extraction and reforestation activities for both villages is shown in Table 6.

Table 6: Characteristics of current cropping systems, forest extraction, and reforestation activities in Ambavaniasy and Ambinanisahavolo

	Ambavaniasy	Ambinanisahavolo, Beforona
Uplands		
Annual fields	Rice* manioc, sweet potato (beans, corn, sesame, cucumber)**	Rice, manioc, sweet potato, ginger, (beans, corn, sesame, cucumber)**
Tanimbolys: (traditional agroforests)	Banana, *Annona* sp. *Eriobotyra* sp.	Banana, coffee, *Citrus* trees, Litchi, Avocado, Papaya, *Annona* Jack fruit, *Nephelium* sp. *Passiflora*, *Eugenia* sp.
Lowlands	----	Irrigated (*horaka*) or non irrigated rice (*fitaka*), beans, vegetables and greens
New land access	Deforestation	---
Forest extraction	Timber, charcoal, fern pots	---
Reforestation	----	*Eucalyptus*

* Underlined crops: cash crops
** (crops in brackets): associated with tavy rice

Crop diversification in Ambinanisahavolo today is greater than in Ambavaniasy, in particular because Ambinanisahavolo features irrigated lowland rice, ginger as a cash crop, and the diversification of the *tanimboly* with coffee and more numerous fruit tree species. Whereas people in the fallow zone depend essentially on agriculture, inhabitants of the forest zone engage in both agriculture and forest product extraction activities.

Forest extraction in the forest zone complements agricultural production. An estimated 80% of the population in Ambavaniasy either extract precious wood and fern pots, or produce charcoal. Precious wood reserves have dwindled since 1936 and villagers estimate that within the next five to eight years woodcutting will no longer be beneficial. The most precious wood species, 'Palisandre' *(Dalbergia sp)*, for example, is cut today within a distance of 50 km as well as in the National Park of Mantadia. Most wood is cut illegally today. Fern pot extraction is also illegal. The root of an arborescent fern is carved into one flower pot. About 25% of the population of Ambavaniasy is involved in this business, selling in total ca 80 pots/week. At the same time, outsiders are extracting 500-800 pots/week, which are evacuated by truck. Orchid extraction and sales boomed from 1990-1996 but has collapsed since then due to overharvesting. Charcoal production is either a major income activity or is pursued temporarily while cleaning out a forest plot before it is deforested for agricultural purposes.

There is no agreement or plan to protect certain products or forest locations from extraction or to regulate the intensity of extraction. The forest service is not providing help to protect resources from outsiders; according to villagers, it is to the contrary involved in covering up large illegal extractions by unknown outsiders. Because the amounts of products extracted by outsiders are multiple times higher than what villagers are able to harvest, their attitude is oriented to extracting as much as possible and as quickly as possible, even if it means destroying the forest.

In Ambinanisahavolo, the last forest patch was cut in the 80s. People must walk at least 25km to find high-quality construction wood. Subsequently, villagers began reforesting their territory following the 80s with *Eucalyptus grandis* and *E. robusta* and more rarely with *Pinus kesyia*. *Eucalyptus* is used mostly for construction but its wood is not well appreciated. Wildlings are transplanted and plots are managed minimally, making productivity low. In the region, only *Eucalyptus* and pine trees are known as reforestation species. Today people are open to the idea of planting trees because wood has become rare and prices increase constantly. Furthermore, even firewood is becoming rare, especially as the population of the shrubby fallow species *Psiadia altissima* decreases.

2. Current annual upland cropping strategies

The annual upland cropping system is based on *tavy*. Translated by the Betsimisaraka, *tavy* is 'a rice crop after burning' and contrasts to *remby*, 'all other crops than rice'. A cropping cycle always starts with a rice crop and is often followed by manioc, sweet potatoes, or ginger. Today all upland rice is produced after burning, following the *tavy* practice.

2.1. *Tavy* a mixed cropping system

A *tavy* field does not consist of the rice crop only. It is rather a mixed cropping system with other annuals planted simultaneously at a wider spacing. From the outside these crops are hardly noticeable, except for the maize plants that outgrow the rice crop. Crops found in the *tavy* fields include corn, cucumber, melons, sesame, common beans (*Phaseolus vulgaris; Zaramazo*), cow peas (*Vigna unguiculata; Voanemba)*, rice beans (*Vigna umbellate*; *Tsiasisa*), and another bean similar to a Lima bean or *Phaseolus lunatus* but slightly smaller (*Tsidimy*). These are all food crops except for cucumbers, which are harvested and sold during the hunger month in February. None of these crops are planted as single crops in separate fields except for the common beans. Furthermore, a variety of weeds (e.g. *Anamamy*) are harvested as leafy vegetables and prepared like spinach as a side dish to rice.

A rice field is traditionally between one and two hectares in area. Primary or secondary vegetation is slashed between July and September. The biomass is left to desiccate during the hot and dry months of September and October. Planting is done, ideally, between mid-October and mid-November. If planted late, the crop is vulnerable to black beetle *Heteronychus* sp. (Coleoptera, Scarabaeidae) attack. Forest biomass is burned three to four days prior to planting, whereas fallow biomass is burned the evening before planting, to assure the least loss of ash due to water and wind erosion. A dibbling stick is used for planting and three to four grains are added to a hole. The traditional spacing is between 20 and 30 cm. Farmers cultivate up to 20 different varieties in the region, all traditional, and none improved. Immediately after planting, for three to four weeks, and one month before the harvest, the rice field must be guarded against 'Red Fody' birds (*Foudia madagascariensis*; Ploceidae; weavers and allies) that feed on the planted grains, young seedlings and maturing grains. Weeding is done once or twice in January and February and can occupy most of the time during these two months, depending on the size of the available labor force. These traditional techniques have not changed for as long as farmers remember and vary little among farmers.

2.2. Sweet potato and manioc

Sweet potato and manioc complement rice as a staple crop and play an important role in food security, especially if the rice harvest fails. They are often associated with *tavy* rice, and are relay-planted and widely spaced into the *tavy* field. Once the rice is harvested, additional planting is done to bring the field to a normal spacing. Manioc is also planted immediately after the rice harvest or, preferably, between August and October. Several varieties are available that mature at between three and 12 months. Usually the sweet potatoes and manioc do not occupy the same expanse as a rice field, so part of the field goes into fallow as another part continues to be cultivated. These crops can occupy the land for one to three years, depending on soil productivity and locality.

The villages under study are currently experiencing a time of food shortage (*maintsoahitra*, literally: 'when the grass is green'), because today hardly anyone produces enough rice for the entire year. People consume manioc, sweet potatoes, taro, bananas, associated *tavy* crops, and various foods collected from the forest.

2.3. Ginger

Ginger is planted either after a rice crop or, more commonly, on a separately selected plot. Ginger is able to thrive on more degraded soils, and so to grow it farmers select plots that are no longer suitable for rice. Because ginger is a high-value crop, farmers prefer locations in proximity to their homesteads. The fallow is slashed and burned, and soil is hand ploughed before ginger root pieces are planted with the dibbling stick. Germination is very slow, requiring up to one month, and the newly tilled soil is prone to erosion and nutrient leaching with the onset of the rainy season. This is in contrast to the other upland crop plots, where the roots of the fallow species hold the soil in place and germination is much quicker (one week for rice). Ginger can also be attacked by the black beetle *Heteronychus* sp. (Coleoptera, Scarabaeidae) and thus should be planted in early October.

2.4. Soil fertility restoration

Soil fertility restoration on the uplands is based solely on the natural fallows. Other fertilizing techniques such as the application of mulch, green manure, animal manure, or fertilizer are not practiced in the region. The soil fertility restoration potential for the fallows is therefore critical. But fallow periods have decreased rapidly since the 1970s, from 10-15 years to 3-5 years today, causing yields to decrease. Farmers apply the same cropping practices on fertile or degraded soils. What changes is that with increasing soil degradation, farmers shift from planting rice to planting more manioc and sweet potatoes, which are less demanding on soil fertility.

3. Farmer-identified constraints that influence upland productivity

Farmers identified the constraints they perceived as most important for sustainable upland crop production. This was achieved with key-person and in-depth interviews in Study 4 (see the Methodology section under 4.4). The main constraints were ranked by importance. Constraints four to eight will be discussed simultaneously first, followed by a separate discussion for each of the three main constraints.

1 Degrading soils and fallows
2 Difficult access to new land and insufficient land surface
3 Non-satisfactory alternatives to *tavy*
4 Lack of labor and money
5 Delay in planting and crop management
6 Pests and weeds
7 Landslides
8 Climate (e.g. cyclones)

3.1. Constraints four to eight: Lack of labor and money, delay in planting and crop management, pests and weeds, landslides, climate

Constraints four to eight are presented within a framework of their interactions in Figure 4.

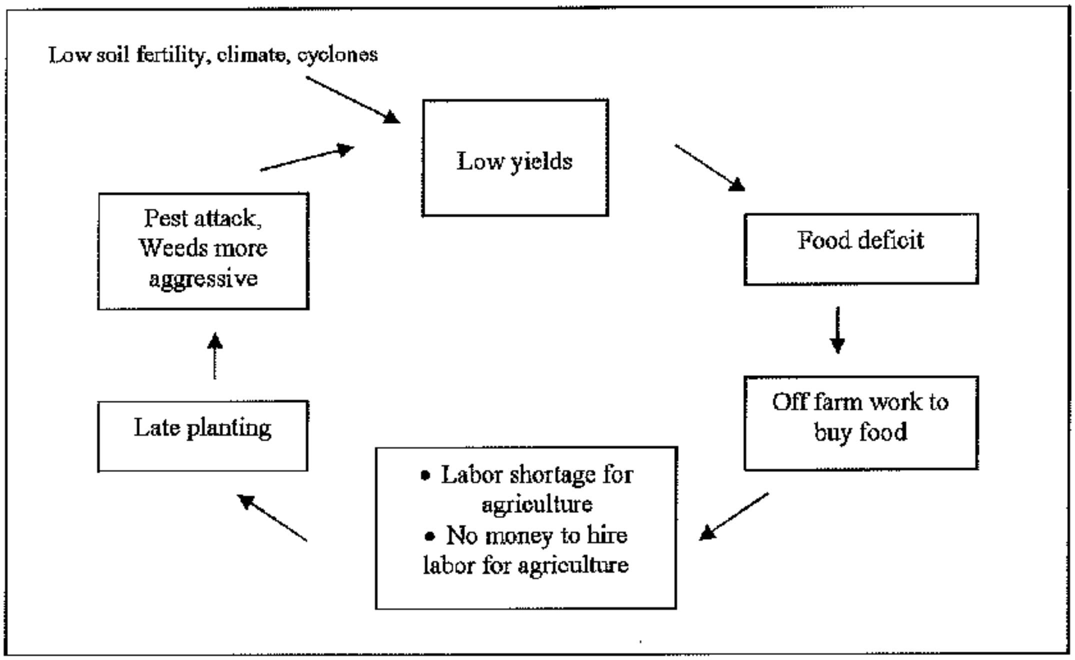


Figure 4: Vicious circle of low agricultural productivity

The interactions often lead towards a downward spiral of agricultural productivity. The spiral can be set off by the condition of lowered soil fertility or by climatic events such as cyclones, with the consequence of reduced crop yields. A season of low rice production can produce a food deficit that forces the farmer to earn money with off-farm work in order to buy food for the family. Farmers who become dependent on money to assure daily survival are often not able to keep up with the agricultural tasks and therefore delay planting and weeding. Labor shortages can also occur due to poor health conditions or family obligations. Farmers may also experience lack of seeds or money to buy the seeds. The availability of labor and money is often interrelated: With an abundant labor force, it is easier to follow up on all the working tasks for the crops, which can guarantee a higher production. In case of a family labor shortage when money is readily available, other villagers can be hired for the field tasks. In the case of late planting, *Heteronychus* beetles can cause considerable damage to the rice crop. In addition, weeds are highly competitive and can outgrow a rice field. This again leads to lower yields and the spiral continues. Farmers depend more and more on money and do not have sufficient time to concentrate on or invest in agriculture. These problems are more obvious in areas with low soil fertility, but they occur as well in the forest region where soil fertility is still good. Of thirteen farmers questioned in Ambavaniasy for the in-depth interviews, five had experienced a complete rice crop failure in the 2000/2001 season, despite good climatic conditions. The essential problem was late planting, which was followed by pest and weed damage. Some quotes that illustrate the constraints are presented in Table 7.

Table 7: Farmers' quotes on upland farming constraints

"When I was a child, my father could easily produce enough rice for the family for the entire year; we never had to buy any rice. At that time, the cropping calendar was respected and the natural enemies were easier to keep under control. Today, people have to run after money and have difficulties to respect the cropping calendar, and the rice has lots of enemies; thus the production is very difficult and erratic. Today we have almost always to buy rice." (i107) (35-year-old farmer)

"Lack of money is at the basis for everything: If I had some, I could employ labor, respect the cropping calendar, fight pests, and install irrigated rice fields. But at this point, I am working for other farmers in the fields, selling charcoal and fern pots, and all the money I earn goes into food!" (i115)

"Almost everybody in Ambavaniasy uses everything produced and earned for daily life, and is not able to invest and advance." (i114)

"This year I was late in planting, it was already December, and the entire harvest got destroyed by the *behatoka* (*Heteronynchus* sp). I planted a field of 0.6 ha and I harvested 2 *kapoaka* (0.6 kg). I was aware that it was a big risk, but I could not agree not to plant. I should have better planted corn or beans, but I didn't have any seeds." (i115) (44 year old single mother with 6 children)

3.2. Constraint three: Alternatives to tavy are not satisfactory

Types of alternatives can be comprehended at various levels:

- Alternatives to the slash-and-burn techniques for upland rice production
- Alternatives through other cropping systems: replacing *tavy* with lowland rice, *tanimboly*
- Non agricultural activities: forest extraction and wage labor

3.2.1. Technical alternatives to tavy

Farmers are currently unaware of any techniques of upland rice production that aren't based on burning vegetation. The research project BEMA had initiated some improved fallow studies in the 90s. Although some farmers had begun to experiment with the new techniques, they abandoned them quickly. The problems were that techniques were developed only in preliminary form and were not fine-tuned to the current system. Farmers lacked sufficient or appropriate knowledge to manage the new practices in the medium to long term and abandoned their attempts at mastering new cropping practices when they were unable to solve emerging problems. It was easier to return to their traditional practices. Another innovation proposed by development projects in the 90s was composting, which is, however, not applicable to upland rice fields of one to two hectares. In conclusion, no alternative techniques have been applied or are being developed on a larger scale within the farming system.

3.2.2. Alternatives through the development of other cropping systems: lowland rice, tanimboly, crop diversification

The two major recommendations to overcome *tavy* made by the research and development projects in the region in the 90s (Terre-Tany, Bema, SAF and LDI) are based on lowland rice extension and developing cash crops in the *tanimboly*s (LDI 2000; Messerli 2000; LDI 2001).

Lowland rice—an alternative to tavy?

The move towards the lowlands became significant in Ambinanisahavolo within the past 10 to 20 years. Farmers had known how to install and manage irrigated rice fields since the colonial era, but the transition to the lowlands is not at all voluntary. Farmers feel forced to do it because of the degrading uplands. Lowland fields are relatively small due to the existing mountainous terrain, featuring narrow valleys and steep slopes. Farmers look at lowland rice production as a good complement but recognize that it cannot provide enough food in the future to sustain the needs of the population.

In Ambavaniasy, irrigated rice production is not practiced. People are unfamiliar with lowland cropping techniques. Because farmers lack the technical knowledge required for irrigated lowland cultivation in Ambavaniasy, the transition would need high-quality technical assistance. Farmers expressed no interest in transitioning to the lowlands, as they still plant on relatively good uplands. Here the terrain is also more mountainous than in Beforona, reducing the available potential surface area. Quotes that illustrate farmers' attitudes about this are shown in Table 8.

Table 8: Quotes expressing farmers' attitudes about replacing *tavy* with lowland rice

Ambinanisahavolo

> "A Betsimisaraka needs to plant rice; if our uplands don't produce anymore, we are obliged to cultivate the lowlands, but it is very hard to give up the life our ancestors taught us." (i101)
>
> "With lowland rice we will not be able to advance in farming; the surfaces are too small." (i97)

Ambavaniasy

> "In my family we own some lowlands but nobody knows how to install irrigated rice fields here. My father tried once but he failed, because water doesn't flow uphill..." (i115)
>
> An immigrant family in the village installed a small rice field three years ago, but failed to produce any rice until now: "First rats and birds destroyed the crop, in the second year a landslide buried large parts of the field, and this year the drainage system was not properly functioning. With the heavy rain storms, the field got inundated and the crop was taken away by the water". (i119)

Cash crops in the tanimboly—can it provide enough cash to buy the missing rice?

The *tanimboly* has been an important production unit during the colonial period and the 60s, when coffee and fruit trees were promoted. Since the 70s, however, its productivity has declined. Coffee quality as well as fruit quality has declined as well, due to aging trees, inappropriate management, and the lack of improved planting material. In addition, coffee prices fell. Farmers have neither the knowledge nor the skills for improved tree propagation. The quality of coffee and fruits except for bananas is not good enough to be sold beyond the local market. Moreover, middlemen are dictating the prices and farmers have no negotiating power. Thus, the combination of all these factors prevents farmers from generating a reliable income with these crops.

Nevertheless, some crop diversification activities initiated by the protestant NGO SAF/FJKM in the early 90s were beneficial to farmers. New crops such as greens and vegetables were introduced to the lowlands during the winter season. Additionally, beans and corn were promoted as well as off-season crops. Off-season farming was new to farmers and is a further step towards diversification and broadening the cropping options, improving food crop production, and providing various products that can be sold on the local market. This development was restricted to the fallow zone, because no lowland cultivation is practiced yet in the forest zone.

Non-agricultural activities: forest extraction and wage labor

In contrast to the case of Ambinanisahavolo, no recent agricultural diversification trends were detected in the forest zone. Diversification in Ambavaniasy is directed towards non-agricultural activities, in particular forest product extraction. Farmers are more cash-dependent than in the Beforona area. This trend is favored by illegal forest product markets that are more stable than agricultural markets in Beforona. Prices are also set and most villagers are trapped in the vicious circle that was depicted in Figure 4. Opportunities to benefit significantly from forest product extraction were and remain very limited. Hardly anyone in the farming community has been able to improve life beyond the self-sufficiency stage. Being more cash dependent, people constantly run after money, try to do many things at once, and finally fail in their agricultural production. The most successful farmers in the village who regularly achieved good agricultural production and exceeded their self sufficiency level concentrated their activities essentially on agriculture and did not engage in forest extraction activities. Some quotes are regrouped in Table 9.

Table 9: Farmers' quotes on forest extraction activities

A 75-year-old woodcutter and agriculturalist who raised seven children explained the dilemma: "When I plant rice, I can only harvest after six months. If I am in need of food or money, I have to go cut wood, which doesn't allow me to do a good weeding. The rice harvest is therefore low and I have to concentrate more and more on the wood." (i113)

"In the times I earned a bit more, I also spent more. Also woodcutting is very hard on the body. The times I had worked harder and earned more, I also had to eat more and needed to rest after that, so there is a limit to what you can earn with it." (i113)

3.3. Constraints 1 and 2: Declining soil fertility and insufficient upland surface

In the key-informant interviews, declining soil fertility and insufficient land surface were the most important constraints for the farmers in Ambinanisahavolo, but not for all the informants in Ambavaniasy. As the goal of this research was to identify how the constraints influence upland productivity, a maximum variation sampling procedure was chosen where selected individuals responded to the extreme conditions of the constraints. The extreme conditions were then associated in a matrix that created the various combinations of the two constraints. The matrix outcome was presented in Table 4 in the Methodology section. The interest was therefore to achieve a deeper understanding, to see whether there are differences in decisions about how uplands are used and managed that influence the different outcomes of these two factors/constraints. For instance: Were there any differences between management decisions made by farmers with good land and those with degraded land? Or were there differences between decisions made by farmers with larger and those with smaller land ownership?

3.3.1. Constraint 2: Difficult access to new land and insufficient land surface

Responding to these constraints provoked mixed reactions in Ambavaniasy, whereas in Ambinanisahavolo all the in-depth interviewees agreed. The major difference is that in Ambavaniasy, forest surfaces are still accessible for deforestation, whereas in Ambinanisahavolo all the land is already distributed. First, then, access to land in the forest and fallow zone will be examined and in a second step the extent of land availability will be examined.

Access to new land

In the traditional land tenure system, a person can access new land through the process of deforestation, obtaining user rights to a piece of land. Traditionally, there is open access to forestland and everyone has the right to cut it. According to governmental law, the forest belongs to the government and cutting forests or forest patches is prohibited. These two tenure regimes are thus strictly opposed to each other. Since there is no law enforcement, though, traditional land tenure persists. In the forest zone, land is still in reach and people are able to secure more land through the deforestation of the forest corridor outside of village territory or by cutting the last remaining forest patches within village territory. In fallow zones, where all the forests have been cut, people access land through inheritance only.

Deforestation in the Ambavaniasy region

According to villagers, much deforestation occurs today within the forest corridor but not on its boundary where it is easily seen. This statement is confirmed by the analysis of aerial photography by Brand and Zurbuchen (1997) showing that between 1987 and

1994, most deforestation happened within the Vohidrazana corridor. For natives in Ambavaniasy, forest clearing is done with the main purpose of securing more land, especially to bequeath as much land as possible to children. Farmers, who emigrate from already degraded areas to the forest zone, use deforestation to access new fertile land. For instance every tenth farmer from Ambianisahavolo had left the village in 2000 for the *tavy* season to deforest land within the forest corridor. After the rice harvest they returned to the village.

The fate of the forest patches

Easiest access to new land is obtained through the forest patches, as they are located within the village territory. Everybody has the right to cut a forest patch, but for the sake of courtesy and as a societal rule, farmers owning land next to the forest patch are considered to have a preferential right to it and are asked for permission. These farmers can intervene in a forest cutting only if they want to deforest the plot themselves and if they are able to lend some land to the person who asks. A forest patch can be protected for one or two years, but no longer. People with land next to forest patches usually hasten to secure that land for themselves before other people come and ask for it. Therefore farmers in Ambavaniasy agree that all patches most likely will disappear in the near future.

Land access concepts where all rainforests have been cut

In Ambinanisahavolo land is obtained through inheritance. Land is presumed to belong to a lineage, a family, and an individual. Boundaries for all these categories are very clear. There are two major concepts through which someone can access land for cultivation: Land is accessed through either inheritance (owning land) or short-term borrowing (using land).

Inheritance is individual and it is usually the sons who inherit the land (through a system of patrilocality). Women can acquire land as well, if they ask for it. The father lends land to his sons for one cropping season at a time as long as he lives. Each year the sons ask for a new location to plant. It is not the father's decision where the sons plant. The person who first asks for a plot gets it. In cases of conflict, the parties who are directly involved are encouraged to resolve their problems themselves. The father or the elders are rarely involved to help settle such conflicts. Before the father dies, he asks his sons to arrange among themselves how they want to split up his land according to their intentions and preferences.

Arrangements between family members are not the only means through which land can be borrowed. Everybody from the village—even outsiders—have the right to ask for land to crop on for one season. At the same time, Betsimisaraka tradition does not allow a person to refuse to share his land. In case an owner wants to use the plot for himself, he can offer a substitute plot. If he does not have a substitute plot, he will share the plot in question. The owner usually takes the best land for himself and offers the more degraded plots to the person who asks. That person can choose between looking for a better plot with someone else or accepting the offer. Earlier on, people were looking for good fallows even if they had plenty of land themselves. But today, as soils degrade quickly, farmers just look for land.

Thus the decision as to what land is cropped is not regulated by the elders, family members, or even the father, but is a decision taken by the individual. Moreover, there are no *dina*s or societal rules linked to upland management regulating which plots are used or not used for cultivation. The only exception concerns land where the lineage tombs are located, the *sembotranos,* where societal rules apply to its use (see Chapter 3). Traditional land tenure is, then, still fully functional. Despite the emerging problem of land scarcity, conflicts over land access (borrowing/lending plots, etc) have not been increasing in recent years, according to the *tangalamena*.

Farmers in the two villages are not looking for individual land titling. People do not have the money to pay for associated administrative procedures and do not feel able to deal with all the paperwork and administrative processes in the regional town. Most importantly, they do not trust the government and are afraid of taxes and costs that could be summarily imposed upon them. Thus villagers prefer to remain without title. Also, from the farmers' point of view, individual titling would favor inequality in the village, as it would weaken the safety net of land access for everyone.

In summary, land in Ambavaniasy is still accessible through deforestation. Nevertheless, many people hesitate to deforest because the forests are becoming rare and more distant, and it is also very hard work and thus easier to borrow land. In Ambinanisahavolo, new land access is not possible, but the traditional land tenure customs allow individuals to borrow some land for one season.

Land surface is too small for satisfactory production

The second statement, that the land surface is insufficient for satisfactory production, again provoked mixed reactions in Ambavaniasy, whereas in Ambinanisahavolo all the in-depth interviewees agreed on it. By saying the land is getting scarce, farmers do not refer to the entire available land within the village area, but only to the fertile and productive land that is declining rapidly in Ambinanisahavolo. In the forest zone, however, soil fertility is still good and farmers agree theoretically that it should be possible to produce enough staples to cover the needs for an entire year. There the problem for good production is rather linked to the other constraints already discussed, such as labor shortages, neglect of the cropping calendar, and a lack of money and food that makes it impossible to concentrate on agricultural tasks. In summary, the proposition that there is insufficient land surface pertains to fertile land and not land in general. Some quotes on this topic are assembled in Table 10.

Table 10: Farmers' quotes in reference to the land surface constraint

> "Look at all the land, even if we have a lot of it, it doesn't help, because the soils turned acid." (i85)
>
> "The surface of arable land is diminishing more and more and the population is getting larger and larger." (i88, i97)
>
> "There will not be enough fertile soils left for my children; they will live in poverty." (i71)

3.3.2. Constraint 1: Soil fertility is decreasing rapidly

Soil degradation was judged by farmers to be the most important constraint on yield reduction since the 70s. Fallow period durations have dropped from 8 to 15 years in the 70s, to 3 to 6 years today. Parallel to the shortening of fallow periods, upland rice production decreased. At the same time, more people need to be fed. Almost nobody today produces enough rice for the year.

This decline in production is especially pronounced in Ambinanisahavolo, where farmers are very worried because the degradation of fallows is progressing very rapidly and in the last decade land started to drop out of production for upland rice. In Ambavaniasy, farmers have witnessed a decrease in productivity on some plots that have been cultivated over several cropping/fallow cycles. People argue, however, that there is still enough good soil in the village territory for good production and thus they are generally not very worried about soil depletion.

4. Farmers' strategies to overcome constraints for sustainable upland production

Farmers' strategies for overcoming the constraints on sustainable upland production were investigated. In addition, farmers' view of the future was examined. Despite the degrading uplands, people in Ambinanisahavolo have still been able, until today, to find land on which to plant *tavy* rice. But good soils for upland rice are diminishing. People foresee splitting the land among each other and planting on smaller plots, which means they will be producing less individually. Farmers also plan to extend their activities into the lowlands and plant more irrigated rice. They share the opinion that production will not be adequate to compensate for lost upland rice yields. In order to cover the food deficit, farmers see themselves increasing manioc and sweet potato production. They will either abandon land that falls out of production or turn to the option of tillage. Tillage is possible only on smaller surfaces, which are located preferably on the lower parts of the hillsides. Despite the negative impact that traditional ginger cropping has on soil fertility, farmers do not want to miss out on it, and take into account that land may fall out of production.

Although people are witnessing the devastating impact of the current practices on their land, they admit to having no choice and continue their *tavy* production. Farmers also mentioned that they would like to invest more in planting *Eucalyptus* trees on the degraded hills because wood products are becoming scarce. But some farmers doubt that trees will grow well on the already degraded land. Furthermore, farmers speculate that if fires could be controlled, some plots could be restored. Today, however, with all the wild fires, no plot is secure in the long run. Opinions on innovations are not very encouraging. Farmers do not believe that soil-improving legumes will grow on the hillsides unless the soil is tilled. Composting may be a good idea, but they do not perceive it to be feasible to apply compost on an entire upland field. In summary, there are no efficient larger-scale strategies at work on how to counter soil fertility loss in the uplands, nor are farmers familiar with any. The outcome is that all the uplands are degrading under current practices. This section ends by citing a young farmer who expressed his view on the present situation and on the future:

> "We have to invest in our soils and improve them for our descendents. Our ancestors have destroyed the forests, leaving us behind with only degraded land. I am angry with them. We have to replant the forest. We have to do it now, because we are still able to produce something and find some plots to plant on, but soon it will be too late." (i100)

DISCUSSION AND CONCLUSION

1. Land use change

Deforestation and forest extraction were restricted during the colonial period until 1975 when, with the advent of the second republic, laws were lifted and deforestation was allowed and encouraged. Excessive use of natural resources without planning and rules made resources deteriorate quickly. When in 1987 deforestation was forbidden anew, not much changed because of the absence of governmental services. This absence meant further open access to all resources and hardly any agricultural improvement work.

In Ambavaniasy, deforestation and forest extraction currently continues and villagers foresee the depletion and collapse of the extraction system within the next five to ten years. This includes the cutting of the last forest patches to secure maximum land for descendents. Thus the forest zone today seems to be rushing headlong towards a treeless village territory, as seen further east in the fallow zone. There are no initiatives to stop this trend, as villagers are also confronted with anonymous outsiders who engage in illegal extraction on a much larger scale. Despite excessive extraction, though, people are not able to benefit substantially from the associated revenues and remain trapped in poverty. The main agricultural activity is *tavy* and all agricultural activities are occurring on the uplands. The agricultural system has not changed much in the past 50 years. *Tavy* is practiced on relatively good soil, but with poor crop management total crop failure is not uncommon. Looking into the future, it will be more difficult for people to diversify or to evolve from traditional activities and make the transition into new farming options. This is because fewer crops are adapted to the higher and cooler conditions and people do not know how to install irrigated lowland fields.

Since the colonial period, the focus in Ambinanisahavolo has been directed towards agricultural development. Diversification efforts were aimed at the extension of irrigated lowland rice, ginger, winter season crops, and crops within the traditional agroforests or *tanimboly*. This diversification has contributed to the improvement of self-sufficiency and provided farmers with various options. The diversification efforts increased in the 80s, after the last forests were cut, upland soils started to degrade, and upland rice or *tavy* yields declined. But farmers still insist today that *tavy* is their first farming objective and intend to continue their practices despite the rapid degradation. Diversification efforts are seen as a necessity by farmers and should therefore not create false enthusiasm because uplands continue to degrade. Without stabilized uplands, the lowland systems are prone to destruction and inundation with any major climatic event. Also, lowland surfaces are limited and will be unable to sustain a growing population. The hypothesis established by Bema/Terre-tany and LDI, that farmers abandon *tavy* once they earn more money, could not be confirmed. According to our findings, the biggest *tavy* fields were cultivated by people with the most money.

2. Farmers' strategies to crop the uplands

Tavy remains the first objective of the Betsimisaraka farmer in the region. Everybody in the forest and the fallow zone is doing *tavy*. *Tavy* is a mixed cropping system providing vegetables, protein-rich, starchy and oily food plants, and cash crops that are consumed and sold during the hardest hunger months. The upland cropping practices vary little between farmers. The cropping techniques and planted varieties are traditional. Whereas in Ambavaniasy most of the uplands are still used for rice, in Ambinanisahavolo parcels with degraded soils are used for manioc, sweet potatoes, or ginger. Ginger, a recently introduced crop, is often planted on more degraded land, and with the current cultivation techniques of tillage on steep slopes, massive erosion of soils dedicated to ginger production is ten times worse (144t/ha per cropping season) than on soils used for upland rice (14.6 ton/ha) (Brand and Rakotovao 1997).

3. Farmers' constraints on sustainable upland production

The three main constraints on sustainable upland production identified by farmers were declining soil fertility, insufficient land, and lack of alternatives. The purposive sampling of farmers to distinguish those who own a great deal of land from those who do not, and to distinguish those having fertile soil from those who do not, did not lead to the identification of different management strategies, as we hoped. These criteria do not strongly influence management practices, which are instead determined by the traditional land tenure system and are independent of how much land someone owned and what the soil fertility status of the land was. In traditional land tenure, it is very common that villagers borrow land from each other to crop it for one season. At the same time it is forbidden to refuse to lend land to someone who requests it. This allows people to have access to land and to look for good land within the village territory. On the other hand, a long-term strategy, for instance pursuing a longer fallow period, cannot be guaranteed even if a person owns a lot of land. In the best-case scenario, a farmer can protect a plot for one or two years, but in that case he needs to be able to lend some other land.

The fallow periods are consequently a direct function of the number of people within the territory who would like to cultivate land. As people always look for the best plots, both on their own land and on other people's land, there is a trend towards harmonization of fallow periods across the village territory. For instance, a farmer who maintains a fallow period of 10 years while others work with three-year cycles will be asked for some of his land. His fallow periods will automatically decrease towards the average village fallow period. In the study zone, this is between three and five years, which is not sufficient time to restore soil fertility satisfactorily. Thus degradation occurs in parallel across the entire village territory.

This land tenure regime may resemble communal land access, as Moor (1997) had concluded, but the land is owned individually. This is an important fact because it gives the farmers the opportunity to invest in some permanent land improvement. This can involve the installation of lowland fields and the planting of perennial crops or trees. Importantly, by improving the land, a farmer can protect it from further degradation through borrowing and he is then free to plan with a longer time horizon. This can encourage farmers to adopt such improved techniques as, for example, planting anti-erosion hedges. The traditional land tenure therefore opens a window that can be taken advantage of when proposing agricultural improvement techniques.

4. Farmers' strategies to overcome constraints

Farmers are aware of the current degradation process. They know that frequent cropping and fire use are its major causes. Nevertheless, people will continue *tavy* as long as possible, because it is the only technique they know. The result is that all uplands degrade and there is no reversal of this trend in sight.

5. Recommendations

Although we know that the uplands are degrading, there is very little known about the dynamics, how rapidly it occurs, or which management practices reinforce, slow down, or prevent degradation. Moreover, we do not know when the degradation process falls below the critical level causing the agricultural production system to collapse, thereby losing its resilience and buffering abilities. A better understanding of these dynamics would allow the orientation of management interventions towards restoring and maintaining the system to a satisfactory level of production. Further research was therefore oriented towards the study of the upland and fallow degradation dynamics under current management practices (Chapter 3 and 4), and to the proposal and testing of alternatives to the current *tavy* system (Chapter 5).

Chapter 3

Fallow characterization along a land degradation sequence: Species succession, indigenous fallow characterization, agricultural productivity, and implications for landscape management

INTRODUCTION

Farmers have identified soil and fallow degradation as the major constraint on sustainable upland production (Chapter 2). Upland degradation in eastern Madagascar has been described as a process in which vegetation transitions from rainforest to a *Savoka* or fallow stage, eventually developing into secondary grasslands or pseudoclimax vegetation. *Savoka*, a Malagasy term, equates with the general term 'fallow,' and most authors refer to it as secondary vegetation or fallow, which regenerates after deforestation and cropping (FAO, 2000; Humbert, 1927; Kiener, 1963; Koechlin, 1972; Lowry II et al., 1997). Thus *Savoka* is an agricultural term denoting an integral component of the slash-and-burn agricultural system that dominates the eastern region.

Until today, however, few studies have attempted to show the interrelationship of *Savokas* with agricultural productivity. Most descriptions of *Savokas* remain static in describing species composition and associations (FAO, 2000; Faramalala, 1988), relating it to some vegetation series (Lowry et al 1997 summarizing Humbert's and Perrier de la Bâtie's findings from the early twentieth century), or relating different botanical groups to soil properties (Dandoy, 1973; Pfund, 2000; Razafintsalama, 1996). These studies concentrate on botanical description of vegetation groups and fail to make the link to agricultural productivity. Moreover, excepting some interest in the use of fire, researchers have paid scant attention to the way agricultural practices influence the degradation dynamic. Even then, descriptions of fire use remain quite general. For instance, it is claimed that Malagasy primary vegetation is very susceptible to human disturbance and fire (Humbert, 1927; Jolly et al., 1984), but little serious research has tested this assertion. According to Koechlin (1972), the secondary forest flora in Madagascar is weakly developed; therefore, instead of being colonized by secondary forests, most of the land area is invaded by exotic, fire resistant species. It has been recognized that not only the primary vegetation but also fallows are susceptible to fire and that each time fallow vegetation is cleared and burned, the forest species weaken. Eventually an essentially gramineous formation will occupy the land (Chauvet, 1972; Humbert, 1927; Koechlin, 1972). Nor is there sufficient information available explaining the main causes of change in vegetation in relation to the ecology of the species. Finally, there are no studies available on soil/plant symbionts and soil organisms under rainforest or secondary vegetation in the eastern region of Madagascar.

Even though these degradation trends and dynamics are well accepted today, however, there remains very little in-depth knowledge about fallow vegetation change in respect to agricultural practices or about how fast this degradation process occurs. Farmers are the primary agents influencing vegetation change, but we know little about how this vegetation change impacts agricultural productivity or about what can be done to prevent further degradation and secure long-term sustainable agricultural productivity.

Given that rainforests are deforested primarily for agricultural purposes and that, within the ecotone of *Savoka*, these soils are used for agriculture until they are abandoned due to degradation, and given a growing population with its need for healthy and productive agriculture, this study is oriented towards identifying the dynamic of this degradation process, determining how rapidly it occurs, and discovering how management practices influence the degradation. This research aim was pursued by exploring farmers' indigenous knowledge through qualitative in-depth interviews and was complemented by field observations and plot histories that inventoried precisely which management practices have been applied to a given plot of land since deforestation and how the fallow vegetation has changed and evolved on it.

The objectives of this study were to:

1. Determine the current fallow/cropping regimes and how they influence the fallow degradation dynamic and agricultural productivity of the uplands.
2. Explore indigenous knowledge on fallow succession and agricultural productivity associated with fallows.
3. Identify easily determinable indicators for agricultural productivity through fallow characteristics.
4. Learn about farmers' strategies to remedy the degradation problem.

Hypothesis:

> Fallow vegetation, cropping cycle, and time since primary forest was cut is indicative of cropping system productivity and the rate and severity of land degradation

METHODOLOGY

1. Timeline, study area, village selection, and the research team

Field research extended over 25 months from June 1999 to June 2001. The study area was located at the margins of the Mantadia-Zahamena rainforest corridor in eastern Madagascar. Nine villages were selected for interviewing, which are shown in Figure 5.

The two villages of Ambavaniasy (located close to the forest corridor, Vohidrazana area) and Ambinanisahavolo (located in the fallow zone with no remaining rainforest, Beforona area) were selected for in-depth studies. The research team consisted of the principal investigator, a researcher, and two farmers native to the two selected villages. More details on these topics can be found in the Methodology section of Chapter 2.

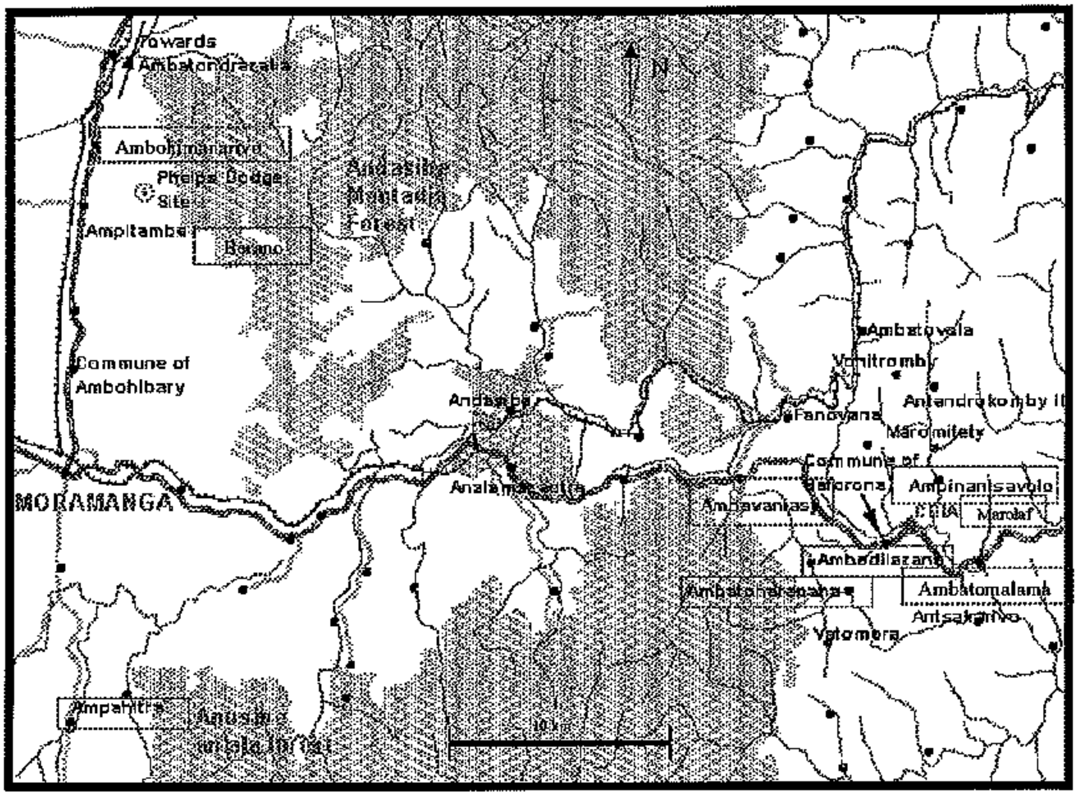


Figure 5: Study area with villages of intervention

2. Fallow characterization studies: objective, selection of respondents, and methods

Fallow characterization was part of all four major studies that were conducted in the region. An overview of the timeline and the number of interviews for all the studies is given in Table 11. The list of interviews is presented in Appendix 1. Whereas information from Study 1: Farming System Description and Study 3: Farming System History provided important baseline information for a general understanding of the system, the main information was obtained with Study 2: Fallow Characterization and Study 4: Upland Farming Strategies. These two studies consisted in a total of 54 individual interviews and seven group interviews (group interviews involve more than two people). The questionnaire-guides are provided in Appendix 2.

Table 11: Timeline of four studies and number of interviews

Year	1999	2000	2001	
Month	6 8 10 12	2 4 6 8 10 12	2 4 6	Total Interviews
1 Farming system description	20 IN, 3 GR *	4 IN, 9 GR	12 IN	36 IN, 12 GR
2 Fallow characterization		20 IN, 6 GR	1 GR	20 IN, 7 GR
3 Farming system history	3 IND	3 IND 2 GR	1 GR	6 IN, 3 GR
4 Farmers' upland farming strategies		12 IND	22 IND	34 IN
Total Interviews				**96 IN, 22 GR**

* IN: Individual interview, GR: Group interview (>2 people)

Study 2: Fallow characterization

The objective of this study was to identify the fallow species succession dynamic in relation to the cycles that occur after deforestation. This aim was combined with the exploration and definitions of indigenous fallow characterization and terminology. The interviews were held in all nine villages. In the individual interviews, respondents were either identified as key informants or selected opportunistically. A few focus group discussions with key informants were added.

Study 4: Individual strategies of upland management and plot inventory

This study was conducted in the two villages of Ambavaniasy and Ambinanisahavolo. Farmers were selected purposefully according to the maximum variation sampling procedure. More details on this selection process are provided in Chapter 2. Fallow characterization was an integral component of the process of retracing the histories of farm plots. The information gathered focused on determining the number of years in fallow/cropping periods for each cycle following the time of deforestation, and on fallow species composition during each of the cycles. The interview process was analogous to the process described in Chapter 2.

3. Quality of information

The reported information is believed to be accurate. This conclusion is based on two years of field research by a competent, smoothly functioning research team that was familiar with the culture and with the farming system. In addition, the sampling size may even have been too large, as confirmation of emerging patterns became evident before the end of the study. On the other hand, the process allowed the research team to put exceptional findings that emerged from in-depth inquiry into the appropriate context. A very good triangulation of the collected information was obtained through the combination of interview information with the findings from plot histories. In respect to the indigenous fallow categories, they are site specific. The described findings can be confidently applied to the larger Beforona-Vohidrazana area. It is not certain, however, how far beyond this area the same fallow terminology applies, as minor variations could be observed on the western side of the corridor.

4. Data Analysis

Data analysis was done by the principal investigator and began with the transcription of field notes and the plotting out of farm plot histories. The information was then regrouped and systematically examined for emerging patterns. The patterns were checked for consistency. The results as presented concentrate on these consistent patterns and do not include the exceptional findings.

5. Some remarks about the presentation of results

The information in the result section is comprised solely of farmers' testimonies that were consistent with field observations. Researcher's interpretations and conclusions can be found in the discussion and conclusion section. As referred to in the text, soil productivity and soil fertility are congruent with classes established in collaboration with farmers. Thus 'good' productivity refers to ca 2 t/ha of upland rice, 'medium' productivity to 1.25 t/ha, and 'low' productivity to ca 0.5 t/ha.

RESULTS

1. Respected and optimal fallow periods and time needed to restore soil fertility

The restoration of soil fertility in the upland cropping system 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.

1.1. Respected and optimal fallow periods

Fallow periods have been decreasing in the region since the 1970s. In Ambinanisahavolo, the time of fallowing was 8-15 years in the 70s, decreasing to 6-10 years in the 1980s and eventually to its current period of 3-4 years. In the forest zone in Ambavaniasy, fallow periods have also decreased since the 1970s and are currently 3-8 years in length with an average of five years. The actual fallow periods were not always congruent with what farmers judged to be the optimal fallow periods. Farmers in the forest zone and those in the fallow zone had differing views about the optimal fallow period needed to restore soil fertility. In Ambavaniasy, farmers shared the opinion that five years is enough to let the soil recover to obtain a good rice crop. Thus the respected fallow periods are in line with what is considered to be optimal. But in the fallow zone, farmers agreed on eight years as the minimum fallow length, whereas on more depleted soil at least 12 to 20 years are needed.

1.2. Characteristics of an optimal fallow

Fallow age is not the primary criterion by reference to which farmers judge a fallow. It is rather the appearance of the vegetation that is critical. Important characteristics are the vegetation aspect, which should be dark green, tall, and dense. Woody species should have broad stem diameters. In addition, species composition and the life form of a species are essential indicators. According to farmers, the time for a fallow to rehabilitate soil productivity is linked to inherent soil fertility, the severity of previous soil degradation, the position in the catena, and the species composition of the fallow vegetation.

1.3. Time needed to regenerate soil fertility

Thus the time needed in the fallow zone for a fallow to regenerate the soils is today much longer then it was in the 70s and early 80s, where the minimum fallow period to obtain good yields was five years in the Beforona area. Thus farmers' estimate of an optimal fallow period in the 70s in the fallow zone is analogous to today's optimal fallow period in the forest zone. This information has been taken further and linked to the cycles that follow deforestation. According to farmers, the time needed to restore soil fertility increases with each fallow cycle following deforestation. In order to produce a good crop of rice (ca 1.5 t/ha), a fallow period is three years for the first two cycles (C1, C2), five years for C3, eights years for C4, 12 years for C5, and 20 years for C6. This information is presented in Figure 6.

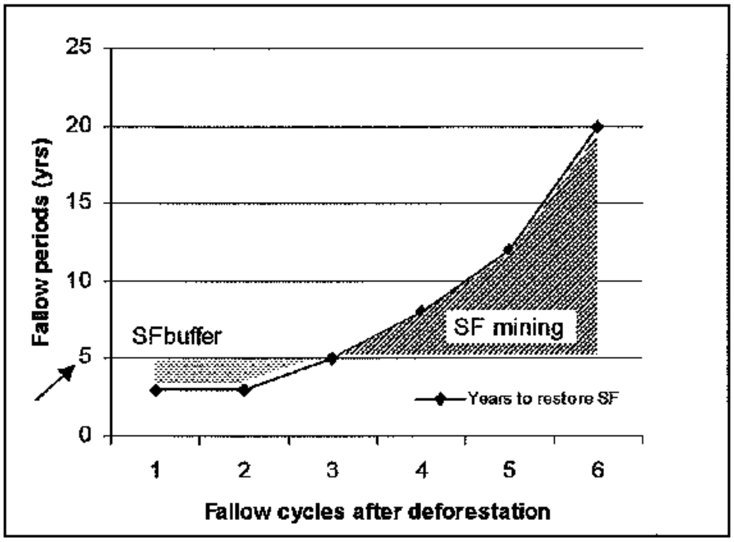


Figure 6: Time needed to restore soil fertility according to cycles after deforestation for the production of a 1.5 t/ha rice crop with five-year fallow periods: Soil is buffered until the third cycle after deforestation; beyond the third cycle, soil fertility (SF) is mined.

Farmers do often vary the cropping and fallowing time in the first two cycles without impairing crop productivity very much (>1.5 t/ha rice yields). Fallow periods can vary from three to ten years, and between one and three crops are planted in one cropping cycle. Soils are still relatively fertile and have a production-buffer capacity. At that point, farmers aren't worried about soil fertility. There is enough good land available within village territory and, even if some plots show signs of degradation, farmers can easily find good land to crop. There is also the option of deforesting another plot or borrowing land from neighbors (see Chapter 2). This situation is encountered today in Ambavaniasy, in the forest zone.

After the last forest patches were cut in Ambinanisahavolo, the expansion of land was not longer possible, so the number of cropping and fallowing cycles following deforestation was advancing across village territory. With increasing cycles, the fallow periods should theoretically have become longer, but in reality they were shortened. The moment when the actual fallow period became shorter than the time required to restore soil fertility, land use was switching from buffered soil fertility levels to levels where soil fertility is mined.

With finite land resources and increasing population, soil mining continues and worsens to a degree where land falls out of production first for upland rice and later for root crops. Available land therefore decreases further and people have to share less and less fertile land. Thus degradation occurs very rapidly once it has crossed the threshold from buffered to mining conditions. This dynamic is very harmful, because farmers above the threshold seem not to worry about the ongoing dynamic as long as the soils still have buffering ability. Also, as seen in Chapter 2, under traditional land tenure, fallow and cropping lengths and practices are fairly uniform across village territory. Thus approaching and crossing the critical threshold may happen without much awareness at first, but suddenly things start to change rapidly across the landscape and farmers no longer have any efficient large-scale strategies to counteract the rapid soil mining processes.

This latter situation can be witnessed today in the Beforona area. According to farmers' estimates, half of the village territory, especially the hilltops, has fallen out of production for the rice crop over the past ten years. Farmers also foresee that ten years from now, all the hillside land will be degraded to an extent that it will be lost for upland rice production. Thus while farmers had the opinion that farming in Beforona some 20 to 30 years ago was excellent with good upland production, they now fear losing all their upland soils within ten years.

2. Species succession in relation to crop/fallow cycles after deforestation

2.1. Major fallow species in the study region

One of the most striking features in the eastern region of Madagascar is the existence of seemingly mono-specific stands of fallow vegetation. This phenomenon can be observed in the entire eastern region, although species occurrence may vary in other areas. For instance, in the Ranomafana area in the Fianarantsoa province, mono-specific stands of *Psidium guajava, Psidium cattleianum* (Myrtaceae), or bamboo are common. In the Beforona/Vohidrazana area, fallows are often dominated by a single tree, shrubby, or herbaceous species or appear in mixtures of a few major species. The presented results summarize the findings on species succession under the current fallowing/cropping practices with fallow periods of three to five years and result from inquiry and observations over a two-year period. The major fallow species in the Zahamena – Mantadia forest corridor zone are shown in Table 12.

Table 12: Major fallow species in the Zahamena – Mantadia forest corridor zone, along the Beforona – Moramanga axes: Scientific name, family, origin, dispersal mechanism, propagation, and vernacular name.

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, R	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, A, M	W	Rh, SP	Rangotohatra
Imperata cylindrica (L.) Raeusch.	Poaceae	PT	W	Rh, S	Tenina
Aristida similis Steud.	Poaceae	IN (A, M) ?	W	S	Kofafa, Bozaka
Hyparrhenia rufa (Nees) Stapf	Poaceae	IN (A, M)	W	S	Kofafa, Bozaka

Legend:
Origin: EN: endemic, IN: Indigenous, EX: exotic, PT: pantropical, A: Africa, M: Madagascar
Dispersal: B: Bird, W: Wind, R: Rodent
Propagation S:Seed, V: Vegetative, SP: Spores; Rh: Rhizomes

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

The findings on species succession according to fallow cycles following deforestation are summarized in Figure 7 and further discussed below.

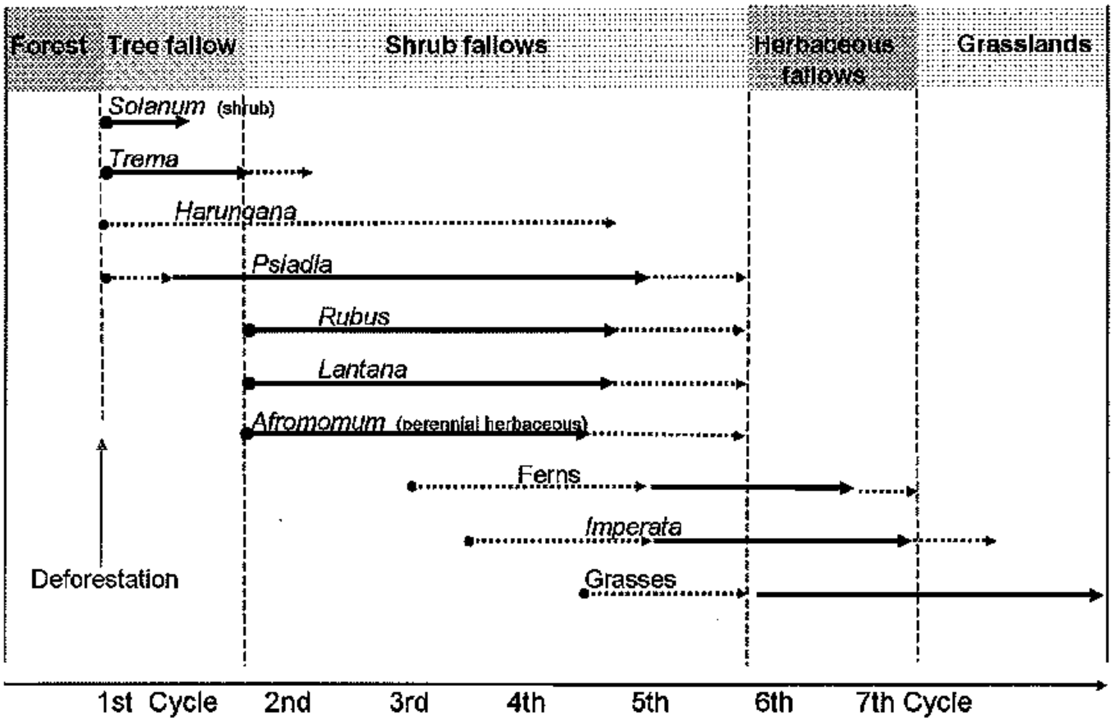


Figure 7: Fallow species succession as a function of cropping/fallow cycle and time since primary forest

2.2.1. First cycle after deforestation, Trema orientalis and Harungana madagascariensis

The first fallow after deforestation is in most cases dominated by the trees *Trema orientalis* (Ulmaceae) and *Harungana madagascariensis* (Clusiaceae). The shrub *Solanum mauritianum* (Solanaceae) is sometimes associated, having a very rapid initial growth reaching 3-3.5 m in six to 12 months but then dying back and giving way to *Trema*. *Trema* is a typical pioneer species, forming a dense and uniform stand. *Harungana* is often associated with *Trema*, but is rarely dominant. They have similar growth rates and reach ca 4 to 8 m within six to eight years. Natural thinning starts in the first year and species tree density diminishes continuously, yielding space to the regenerating indigenous species that germinate under their shade. Whereas *Trema* is found only on good soils, *Harungana* grows also on degraded soils, but then with much slower growth than under fertile soil conditions. *Psiadia altissima* (Asteraceae), an endemic shrub, is present in the first fallow at low density but it can also dominate the first cycle, as in Ambavaniansy.

2.2.2. Second to fifth/sixth cycle after deforestation - Psiadia altissima, Rubus moluccanus, Lantana camara, Aframomum angustifolium and associated species

In the second fallow after deforestation, a major shift in species composition occurs. The shrubby species *Psiadia altissima* dominates the fallow and the tree species are associated in low density. Shrubby species are the dominant species up to the fifth cycle. *Psiadia* either continues to dominate the following cycles or experiences severe competition and is finally replaced by either *Rubus moluccanus* (Rosaceae) or *Lantana camara* (Verbenaceae), two exotic and invasive species. According to Razakanirina (1989), *Lantana* was introduced into Madagascar at the end of the nineteenth century and *Rubus moluccanus* was introduced in 1932. Elders remember that these species weren't present in the first half of the century in the region. *Aframomum angustifolium* is another indigenous species that forms mono-specific stands. Species that become associated with the third cycle but rarely form dominant stands are *Clidemia hirta* (Melastomataceae) and *Tristemma virusanum* (Melastomataceae). This is also the case for herbaceous species that increase in density with each additional cycle. Some characteristics of the four dominant shrubby species are presented in respect to growth characteristics and species behavior.

Psiadia altissima is an endemic species. It is an indicator species for good soils but persists also on more degraded land—albeit with a less vigorous appearance. In fact, *Psiadia* is the most adaptive and plastic species among the dominant fallow species in the region and appears from the first fallow following deforestation until the beginning of the herbaceous fallows. Part of the pioneer vegetation, *Psiadia* dies back in a forest environment after 30 years in fallows close to the forest, while on fertile soil its life span is 15 to 20 years (Ambavaniasy). On the more degraded soils in Beforona it perishes after eight years.

Rubus moluccanus grows on medium fertile soil and rarely invades land where ferns and *Imperata* dominate. *Rubus* has a shrubby and viny habit and is the dominant shrubby species in the Beforona area. It forms a dense, thick, spiny stand that is not penetrable without a machete. After canopy closure at 2.5 to 4 meters in height, the stand no longer increases in height and from the outside it is very difficult to distinguish a 5-year from a 20-year fallow. The life span is not known, as farmers haven't observed *Rubus* fallows dying back. If an individual plant perishes, a new regenerating cane replaces it. *Rubus* is the most aggressive among the shrubby species and it outcompetes and suppresses *Lantana*, *Aframomum*, or *Psiadia*. This is also the case for regenerating indigenous tree species, in which case *Rubus* impedes the development of a potential secondary forest. *Rubus* is rare in Ambavaniasy and for unknown reasons cannot be found on the western side of the forest corridor. It may be that higher and drier conditions on the western side are not suitable for it.

Lantana camara is among the dominant fallow species on the western side of the corridor, where it forms thick stands and behaves similarly to *Rubus* on the eastern side. In Beforona and Ambavaniasy, *Lantana* is loosely associated within the shrubby fallows and only rarely forms monospecific stands. Farmers can't always explain the mixture of species that appear in the field, but several observed that *Rubus* more likely grows on lower parts of the hillside, whereas *Lantana* is more often observed on the hilltops in mixture with *Psiadia*. If *Lantana* is associated with *Psiadia* in a fallow without any management intervention, *Lantana* most likely suppresses *Psiadia* and dominates the fallow completely. If the fallow is cut, however, *Lantana* dies back and *Psiadia* will dominate the fallow. Also *Lantana* starts to die back after ten years, and thus at that point it can be replaced by *Psiadia*.

Aframomum angustifolium is indigenous to Africa and Madagascar and is commonly found on the forest fringe and throughout the eastern region. It grows mostly on the lower part of the hill, next to water, but if the soil is good, it climbs up the hillsides. It is an herbaceous species, but behaves similarly to other shrubby fallows. Its biomass production also seems higher than that of other herbaceous fallows. *Aframomum* is not very aggressive and gives way when in competition with *Rubus* or *Lantana*.

2.2.3. Beyond the fifth cycle—fern species and Imperata cylindrica

Ferns and *Imperata* start to appear in low density in the third to fourth cycle following deforestation. Land management, position on the relief, and soil fertility status determine how quickly ferns and *Imperata* become established. They begin appearing, typically, on the top of the hillsides where the soils are the shallower and degrade more quickly. Once established, the species descend further down the slope with each intervention, cropping, or burning, and after a few cycles dominate the entire hillside. The ferns usually appear earlier in the succession than *Imperata*. In many cases, *Imperata* gradually replaces ferns within a sequence. But *Imperata* and ferns can also be associated in mixtures, and either of the species can dominate over the others depending on location. We could not explain why either ferns or *Imperata* dominate each other in some cases but remain in mixture in others. Farmers refer to *Imperata* and the ferns as 'sisters,' so in one way or another, they often appear simultaneously on a plot. Fern and *Imperata* fallows are abandoned for upland tavy rice, but are still cultivated with manioc and ginger.

2.2.4. Grasslands

Vegetation succession reaches the final stage when *Imperata* and ferns finally give way to a few dominant grass species, including *Aristida similes, Aristida* sp. *Hyparrhenia rufa, Paspalum conjugatum, Panicum brevifolium,* and *Pennisetum sp*., among others (Dandoy, 1973; Pfund, 2000). Grasslands are still rare in the Beforona area, but can be witnessed further east over vast expanses. Agriculture is abandoned on grasslands that are characterized by organic matter depleted and hardened red soils.

2.3. Speed of succession

The appearance of a particular species within this successional sequence can vary across locations, and so does the speed of succession, which depends on initial soil fertility, relief position, distance to seed sources, and seed banks. With longer fallow periods the number of cycles may be extended for the successional shifts; with shorter fallow periods or longer cropping periods, the shift may be even more rapid. Within the current fallow periods of 3-5 years, it can be concluded that within 20 years (1-2 crops/cycle, 3-year fallow x 5 cycles) to 36 years (1-2 crops, 5 year fallow x 6 cycles) a rainforest is transformed into herbaceous fallows. The total production of a location was a maximum of five to seven rice crops and two to three manioc or sweet potato crops.

2.4. Fallow characteristics in Ambavaniasy and Ambinanisahavolo

In Ambavaniasy, *Psiadia* is the dominant species in all cycles. Its species association and its vigor indicate the state of soil fertility and the cycles following deforestation. In the first cycle *Psiadia* is associated with *Trema, Harungana, Croton* sp., and

Macaranga sp. In the second cycle *Psiadia* occurs in an almost pure stand, whereas in the third cycle *Clidemia hirta* is associated and in the fourth cycle *Psiadia* is mixed with *Pteridium* and *Imperata*.

In Ambinanisahavolo, species composition has changed much over the past decades. A relative ranking exercise on the importance of surface coverage of the most important species was done with the elders and is shown in Figure 8. *Trema orientalis* was still present in the 60s and 70s in Ambinanisahavolo, but it vanished rapidly after the last forest patch was cut and the first fallow cycle passed. *Psiadia* dominated the fallow vegetation until the 70s, when it began to be replaced by *Rubus* and *Lantana*, which were most abundant in the 70s and 80s. In the 90s, ferns and *Imperata* proliferated in the landscape.

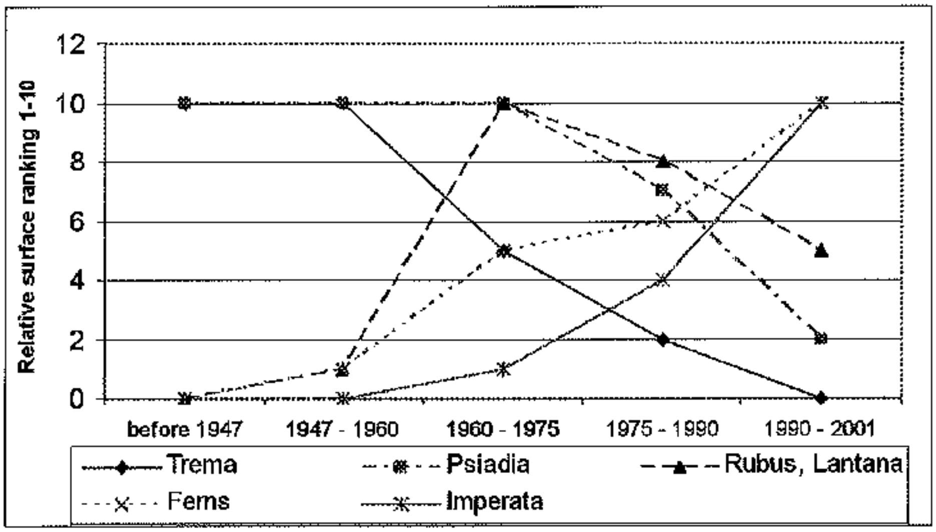


Figure 8: Major species occurrence in fallow vegetation in Ambinanisahavolo
Relative ranking with 10: highest score; 1: lowest score; 0: non-existent (10 represents the maximum surface expanse per fallow type that villagers were aware of; all other numbers were adjusted in relation to it)

In summary, there are two major applications of these findings on species succession as a function of cropping cycles after deforestation: on a plot level as well as on a landscape level where the dominant vegetation types in a village territory directly reflect the management history and time since deforestation. Thus by looking at the dominant fallow vegetation and comparing it with the data in Figure 7, it can be concluded that the village territory of Ambavaniasy is between the first and fourth cycle following deforestation, whereas the fallows in the Beforona area are already in the fourth to seventh cycle.

3. Indigenous fallow characterization

A rich fallow terminology was identified and through the interviewing process fallow types were characterized, described, and a schema established in collaboration with the farmers that integrated the findings and showed the interrelationship between the fallow types. This schema is presented in Figure 9. Each fallow type integrates a range of attributes that responds to various characteristics. A definition of a fallow type is multi-layered, including aspects of vegetation composition, life form of a species, growth rate and appearance of vegetation, height of fallow, 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. In addition, farmers follow management guidelines that go along with each fallow type. This is a valuable addition to the findings on species succession so far, providing a deeper insight into the interrelationship between species succession, management, and agricultural potential.

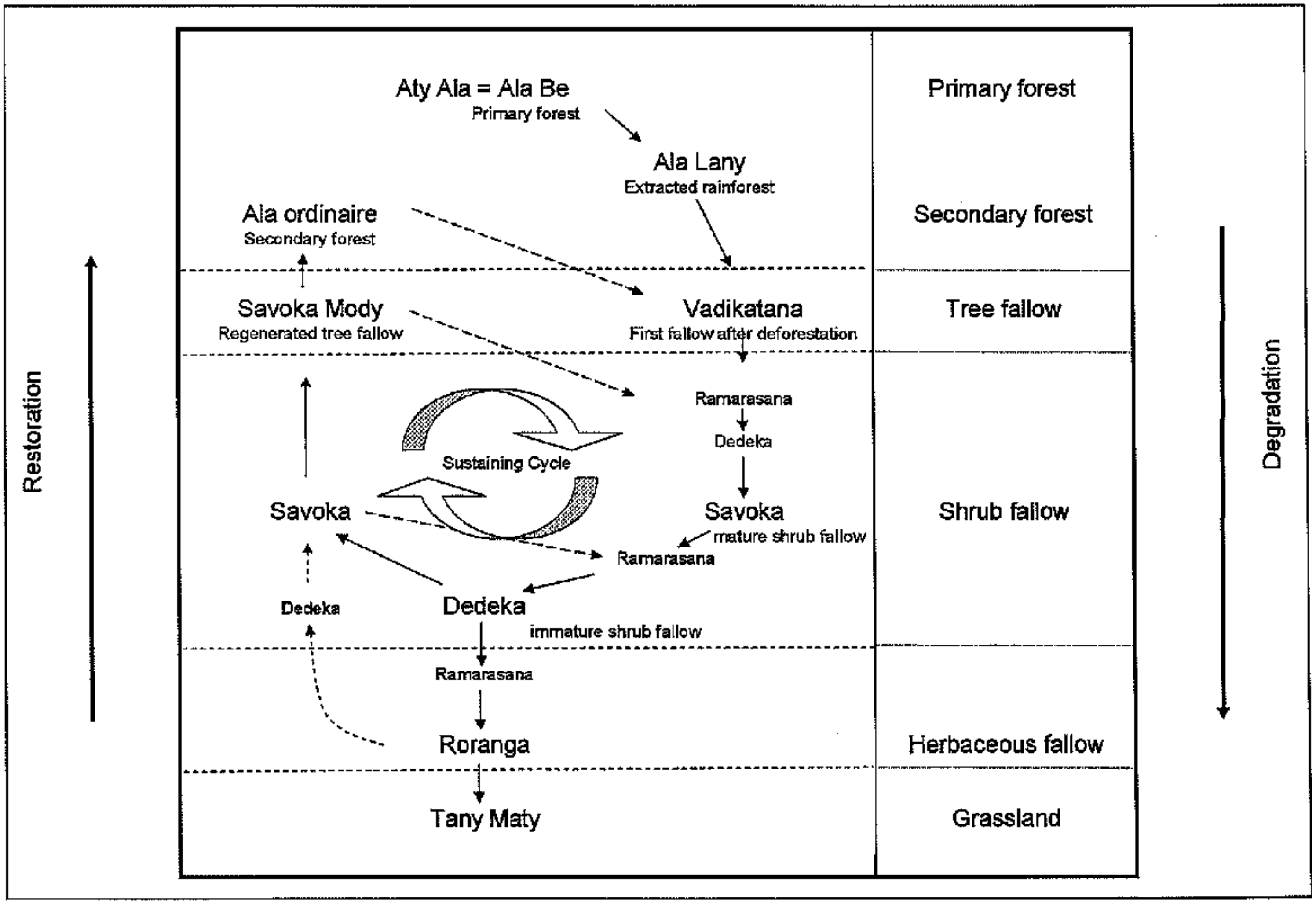


Figure 9: Indigenous fallow characterization by the Betsimisaraka from the Beforona region

3.1. Traditional land categories

Before describing the fallow categories, an overview of the traditional land categories is given because the general fallow land or *jinja* is part of it. These categories are also characterized by different access rights. They include: *sembotrano*, *jinjaranto*, *jinjaliana*, and *jinja*.

A *sembotrano* is a piece of land where the tomb of a lineage is located. The land can be cultivated only every even year and demands the sacrifice of a zebu *(joro)*, which is performed by the *tangalamena* (spiritual leader). There is only one year of rice allowed and no other crops can be planted. When fallow land was plenty, the *sembotrano* wasn't cultivated very often, but today in Ambinanisahavolo, where farmers find it difficult to locate good fallows, a *sembotrano* is cultivated every 6 to 8 years. There are three *sembotranos* in Ambinanisahavolo. Everybody can participate in planting if they contribute towards buying a zebu. Farmers benefit from that land because fallow periods are longer than on the individually owned land and land productivity is better than on the average village land.

Jinjaranto is all other land than *sembotrano*. It can be divided into *jinjaliana* and *jinja*. The *jinjaliana* land is possessed by a bad spirit and requires a zebu sacrifice before being planted. Fallow periods tend to be longer, because people need money for a zebu. Although everybody respects the sacrifices required for the *sembotrano*, some people with magical power sometimes crop a *jinjaliana* without performing any sacrifices. All the rest of the fallow land is referred to as *jinja*, which is the most generic category and term for fallow. It can be accessed and planted without restrictions. Farmers gave the following definition: *A jinja is momentarily abandoned land after a rice crop or other crops following a rice crop. Jinja* can also be translated with "cut." It is therefore an expression that directly relates to upland rice cultivation based on slash- ('cut-')-and-burn agriculture or *tavy*. This shows once again the cultural bond of the Betsimisaraka to *tavy*. Within the *jinja* category, the fallow types that farmers distinguish are described in the following section.

3.2. Traditional fallow categories

3.2.1. Vadikatana

Characteristics and species: A *Vadikatana* is the first fallow after deforestation that establishes following a rice crop. The term *Vadikatana* is used only after a primary forest (*aty ala* or *ala be*) or a secondary forest (*ala ordinaire*) is cut. A *Vadikatana* is a tree fallow with the dominant species being *Trema orientalis*, *Harungana madagascariensis*, *Solanum*, and *Dombeya* sp (*Hafotra lady*). *Vadikatana* is the expression used on the eastern side of the forest. On the western side it can be called *Pokatana* (Berano, Ambatovy) or *Vadikala* (Ampahitra).

3.2.2. Ramarasana

Characteristics and species: The term *Ramarasana* is linked to the rice crop. The traditional definition is: *A Ramarasana is the initial phase of a fallow, from the moment the rice harvest is complete until the standing rice straw in the field is no longer visible.* The Betsimisaraka harvest the rice by clipping the panicles one by one with a little knife. All the rice straw remains standing in the field together with the weeds. Once the rice straw decays, decomposes, or is outgrown by the regenerating vegetation and the straw is no longer visible, the stage of *Ramarasana* is ended. Depending on location, climate, and the productivity of rice straw this varies between six months and two years. The species composition of a *Ramarasana* is initially characterized by herbaceous weeds that have developed since the last weeding. The woody fallow species composition is influenced by the species remaining from the previous fallow, by the fire and cultivation regime, and by the vegetation composition of the neighboring fallows.

Agricultural implications: Traditionally the cropping of a *Ramarasana* is neither desirable nor recommended, as the soil has not restored its fertility and the herbaceous plants are too aggressive as weeds. This is especially true for the rice crop, but farmers sometimes clear a *Ramarasana* and plant manioc, sweet potatoes, or ginger. After the disappearance of the rice straw, the fallow turns into a *Dedeka*.

3.2.3. Dedeka

Characteristics and species: A *Dedeka* is a shrubby fallow that is small in height (1-1.5m), featuring yellowish or light green leaves indicating nutrient deficiencies. The wood growth is poor and stem diameters are thin compared with the species average. In a *Dedeka*, the shrubby species progressively replace the herbaceous species established during the *Ramarasana* stage. The most common shrubby species are *Psiadia*, *Rubus*, *Lantana*, and *Clidemia*, as well as *Aframomum*. Fern species and *Imperata* can be present in lower densities.

Agricultural implications: The *Dedeka* is the transitional fallow stage between a *Ramarasana* and a *Savoka*. It is difficult to fix a time period in which a fallow is in the *Dedeka* stage. It depends on soil fertility and the position in the relief. On a good soil in Ambavaniasy, the *Dedeka* stage is ca 3 to 5 years. Farmers in the fallow zone of Beforona estimate that on a medium fertile soil, the *Dedeka* stage varies between five, six, and eight years depending on whether it is found on the lower part of the slope, the mid slope, or the upper part of the hill, respectively. With each additional cropping/fallowing cycle, however, the *Dedeka* stage is longer.

In regard to its agricultural potential, farmers stress that the *Dedeka* stage is the most critical in fallow development. It is very risky to crop a *Dedeka*, which should be left to transition into a *Savoka*. If cropped, the woody species are at risk of being killed off and the next fallow could possibly become an herbaceous fallow or *Roranga*. In the Beforona area, *Dedeka* is today the dominant fallow type. As soil degradation advances, the *Dedeka* stage consumes more and more time. In order to maintain upland productivity, it is critical to wait until the *Dedeka* stage has passed, which could easily take more than 10 years and coincides with farmers' estimates of optimal fallow periods (see under 1.3). A *Dedeka* transitions into a *Savoka* and sometimes a *Dedeka* is referred as a 'small *Savoka*' (*Savoka madinika*).

3.2.4. Savoka

Characteristics and species: A *Savoka* develops from a *Dedeka*. It is also a shrubby fallow but taller in height (2 to 4 meters), and the color of the leaves is darker green. The fallow has a 'thick,' dense aspect. The woody biomass is well developed with larger 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. The shrubby species are essentially the same as in the *Dedeka*, although more herbaceous species are out-shaded. Tree species such as *Trema* and *Harungana* can be present in low numbers and diminish with each fallow/cropping cycle following deforestation.

Agricultural implications: The principle farmers must respect in order to avoid losing their land for rice production is that one should cultivate a fallow only when it is in the *Savoka* stage and crop it for only one year before leaving it to fallow again.

3.2.5. Savoka Mody

Characteristics and species: A *Savoka Mody* develops from a *Savoka*. It is characterized by the presence of forest species that regenerate in the fallow. Tree height exceeds 4 to 5 m, and tree diameters are between 15 and 20 cm. *Psiadia* altissima dies back and disappears little by little. A *Savoka Mody* is at least 10 to 20 years old. At that age the fallow is composed mostly of species with mediocre wood quality. Precious wood species, if present, are in the seedling stage.

The most common regenerating forest species that appear in the fallows are 'soft' wood species such as *Croton* sp., *Macaranga* sp., *Dombeya* sp. Belavenona, *Ficus* sp. (Voara), Hazombary, Malemyravine, Macaranana, *Dombeya* sp. (Hafotra), Saranto, and *Albizia gummifera* (Volomborona). Other common species with variable wood quality are Dipaty, *Ilex mitis, Weinmannia* sp. (Lalona and Irihitsika), *Ocotea* sp. (Varongy), *Ravensara* sp. (Tavolo), *Pachypodium* sp. (Montaka), *Salacia madagascariensis* (Voamasoandro), *Canarium madagascariense* (Ramy), *Dilobia thouarsii* (Vivaona). The common names were inventoried with the local population and the references used for the scientific names were from Direction des Eaux etForêts (1996); Pfund (2000); and Styger et al. (1999).

Agricultural implications: *Savoka Mody* are preferred fallows that assure the best chance for good crop production. These fallow types are getting more and more rare.

3.2.6. Ala ordinaire

Characteristics and species: A *Savoka Mody* develops into a secondary forest or *Ala ordinaire*, which is characterized by stem diameters that allow the extraction of timber boards from soft wood species. It can take 50 to 60 years for an *Ala ordinaire* to get established. Early pioneer species such as *Trema* and *Harungana* die back, allowing soft and hardwood species to establish themselves. *Ala ordinaire* have become very rare in the landscape.

3.2.7. Roranga

Characteristics and species: A *Roranga* is an herbaceous fallow, with the most abundant species being *Imperata cylindrica*, and the ferns *Pteridium aquilinum* and *Sticherus flagellaris*. Woody species no longer grow. When the fallow vegetation regrowth is arrested by herbaceous species, upland rice production ceases. Soils are used only for root crops or pineapple. According to farmers, the key element in restoring agricultural productivity is the presence of woody species in the fallows.

Agricultural implications: *Imperata* and ferns fallows are no longer cultivated for upland rice or sweet potatoes. It is possible to plant ginger on a *Roranga*. Manioc can be grown with ferns but the sharp *Imperata* rhizomes often pierce the manioc roots, causing rot. The last crop grown on a *Roranga* is pineapple; following that, the land is abandoned to crop production. *Imperata* indicates a more acidic soil than the ferns do, but *Imperata* is easier to manage and to recover for agriculture. More information on *Roranga* is presented in the next section.

3.2.8. Tany maty/masina

Characteristics and species: *Tany maty* (dead land/field) or *Tany masina* (sour land/field) refers to sterile land on which all cropping is abandoned. *Tany maty* is created when a *Roranga* is burned once or several times. *Imperata* and ferns are replaced by *Aristida* sp. *Hyparrhenia rufa*, *Paspalum conjugatum*, *Panicum brevifolium*, *Pennisetum* sp among others. This is the end stage of succession and is also known as the pseudoclimax stage. Vast expanses of land further east of Beforona and also on the highlands are covered with these grasses, representing 'biodiversity deserts.'

In summary, it can be concluded that land productivity can be maintained when fallows are given sufficient time to regenerate into a dark green and dense *Savoka* before they are cultivated anew. From a *Savoka,* further restoration can occur, changing into *Savoka Mody* (tree fallows) and *Ala ordinaire* (secondary forest). If a fallow is cultivated in the *Dedeka* stage, degradation is further driven by creating *Roranga* fallows that turn eventually into *Tany maty* land.

4. The critical phase for the agricultural system—the transition from a *Dedeka* into a *Roranga* fallow

According to farmers, the critical point where the agricultural system loses its resilience and can no longer recover soil fertility through fallow vegetation happens when the fallow transitions into the *Roranga* stage. This finding calls for examination of the management practices that favor the transition into the *Roranga* stage. They include:

<u>Fire use on a *Dedeka*:</u> Fire needs to be absolutely avoided during the *Dedeka* stage. If a fire passes over a fallow at this stage, it kills the woody species and favors the pyrophilic herbaceous species such as ferns and *Imperata* that colonize the empty surfaces quickly.

<u>Cultivation of a *Dedeka*:</u> A *Roranga* is also most likely created if a *Dedeka* is cultivated once or twice. This underscores the necessity of allowing a fallow to develop into the *Savoka* stage before returning it to cultivation.

Insufficient weeding: A method that prevents the development of *Roranga* is a thorough weeding of herbaceous species during the cropping cycle. This allows shrubby species to grow back and develop rapidly. If weeding is neglected, many opportunistic herbaceous species, including *Imperata* and ferns, establish during the cropping cycle. The shrubby species will find it much harder to compete and grow within this species composition.

Other diagnostic features that indicate a possible transition into a *Roranga* are:

The presence of ferns and *Imperata* in the previous fallow: If ferns or *Imperata* are present in a seemingly good fallow (*Savoka*), that plot is at high risk for degrading rapidly if cultivated. The proportion of ferns and *Imperata* will increase in the next fallow cycle. It would therefore be important to give a fallow the time to out-shade and out-compete any associated ferns or *Imperata* even if it is already a seemingly 'mature' *Savoka*.

The physical properties of soil: Another indicator of the risk of degrading into *Roranga* is the hardness of the soil during soil preparation or planting. Soils harden after multiple cropping cycles, fire use, and erosion, even with the zero tillage practice of upland cropping. At the same time, the soil becomes reddish, indicating organic matter loss. This is reflected also in the local soil characterization terminology, which for infertile soils is *tany mena* (red soil) or *tany mafy* (hard soil) and for fertile soils is *tany mainty* (black soil) or *tany malemy* (soft soil).

5. Restoration of *Roranga*—the dynamic of natural regeneration, and farmer methods

5.1. Natural restoration of Roranga

Imperata and fern fallows stop accumulating biomass after the population is established. In order to restore soil productivity for agricultural crops, the establishment and biomass production of woody species is necessary. The time frame for natural regeneration of woody species was therefore investigated. In a pure stand of *Imperata*, the first woody species may start to reappear after five to seven years and from there grow slowly back. Once the density of woody species becomes important and allows canopy closure, there is a chance that *Imperata* will be out-shaded and thus eliminated over time. The soil can then be recovered for cropping. Fifteen to 20 years is at the lower end of the required time scale. In a fern fallow, the reappearance of some woody species can easily take 20 years or more and, until these species get established and become dominant, it can take an additional 10 years or even more. This is among the better scenarios for a fern fallow because it is also possible that few woody species will regenerate in it. These restoration times also require no fire passage at all. These fallows have almost no use value—although some *Imperata* may be harvested to thatch some houses—but no other products can be harvested and zebu do not eat the vegetation.

One major reason for the slow establishment and growth of woody species is the competition they experience from herbaceous plant roots. The small leaved ferns (*Sticherus* sp), for example, create a more hostile soil environment than big leaved ferns (*Pteridium* sp) and farmers often abandon these fallows completely. *Imperata* is the least aggressive among the three species. The fern fallows form a thick and dense root mat on the soil surface. A five-year-old small-leaved fern fallow can create a root layer of 20 cm thickness. It is very difficult for a woody species to get established and grow in this environment. With the onset of the hot season, which is the rainy season, the superficial root mat absorbs the sun's heat, creating a very hostile and hot environment for any other plant to grow in. In addition, the soil underneath the fern roots dries out and gets hard, thereby inducing soil structural changes. The only way to bring these fern fallows back into cultivation is tilling. In the first year the soils are still hard, and it may start to recover only in the second year. The soils under *Imperata*, on the other hand, have a much better structure and farmers appreciate them even for growing ginger.

5.2. Farmers' methods for restoring a *Roranga* fallow

The methods that farmers are aware of that can be used to restore a *Roranga* and bring it back to cultivation are, after natural regeneration and tilling, the planting of bananas with the goal of eventually out-shading the herbaceous ground cover, applying fertilizer (which farmers have never practiced), and cutting back the *Imperata* during the winter season with the aim of letting the plant stumps get soaked in water to induce rotting and dying back. For the last method, no confirmation on how effective this method really is could be obtained. As for the other methods, they are applicable to the present situation only for small surfaces on a small scale. Thus it has to be concluded that in the present situation, farmers have neither the knowledge nor the means to restore a *Roranga* efficiently and are not able to control the spread of the herbaceous species on a large scale.

DISCUSSION

1. Current fallow periods and time required to restore soil fertility

A significant reduction of fallow periods in the region occurred within the past 30 years, from 8-15 years previously to the current rate of 3-5 years. These short fallow periods allow only for the first three cycles to produce yields between 1.5-2 t/ha of upland rice, but beyond the third cycle—and with each additional cycle—the fallow periods need to increase to assure a similar level of productivity. A fallow period of five years, for instance, has a completely different value in respect to soil fertility restoration if it occurs in the second or in the fifth cycle after deforestation. This leads to the conclusion that the fallow period as a parameter per se does not support any statements or assumptions about agricultural productivity recovery if it is not discussed in relation to the cycle number following deforestation. If the cycle numbers are not known, a fallow period should in any case be related to the degree of soil and vegetation degradation within a given ecological zone. This fact is usually ignored in the literature and in many studies fallow periods are often the sole parameter used to estimate the restoration of soil fertility (Brand and Pfund, 1998; Kato et al., 1999; Silva-Forsberg and Fearnside, 1997; Van Reuler and Janssen, 1993). In addition to soil fertility restoration, it is recommended that the discussion of fallow vegetation recovery and growth, as well as of fallow species composition, should use as its point of departure the comparison of cycle numbers following deforestation.

2. Species succession as a function of cycles after deforestation

With each additional cycle after deforestation, the dominant fallow species composition changes, from tree to shrubby to herbaceous species. This shift is influenced by the frequency of slashing, burning, and cropping. Under the current 3-5 year fallow period, the only tree fallow that is established from the beginning of the fallow cycle is a *Trema orientalis* fallow in the first cycle. Tree fallows would be preferred because of their superior potential to accumulate biomass compared with that of shrubby and herbaceous fallows, which translates directly into the ability to restore soil fertility (Nye and Greenland, 1960). To obtain any other tree fallows from the second cycle onward, 10 to 20 years are needed for secondary forest species to regenerate within the shrubby fallows. Furthermore, the exotic shrubs *Rubus* and *Lantana*, which form very dense stands, often suppress the regeneration of trees. Also with each additional cycle, fewer indigenous trees regenerate in the fallow vegetation.

In conclusion, the establishment of tree fallows and, finally, secondary forests is a delicate process that should occur within the first few cycles after deforestation. For early cycles this still takes a lot of time (>20years), and a plot needs to be protected from fire. Beyond the third cycles, the time period stretches even longer. These conditions are rarely fulfilled, leading to the picture of the current landscape where the regeneration of secondary forest is absent. The agricultural system depends therefore on the shrubby fallow species for soil fertility regeneration. But these species are susceptible to frequent slashing, burning, and cropping and finally give way to the most dominant vegetation in Madagascar, which is grasslands with extreme floristic impoverishment, covering 63-72% of the country's surface. (Humbert, 1927; Koechlin, 1972; Lowry II et al., 1997) These grasslands yield almost zero productivity from an agricultural point of view. These landscapes are dominant further east of the study region and are managed by farmers with annual fires that provide young vegetative regrowth for cattle grazing. The grasses are palatable only as young regrowth and their productivity is extremely low.

3. Speed of degradation

Looking back in history, we see that the Beforona area began to be deforested 150 years ago (Brand and Zurbuchen, 1997). The fallow cycles at that time were much longer. The only approximation and description of fallow periods and degradation speeds for the eastern region was done by Chauvet (1972), who predicted that forests turn into grassland within maximum 10 to 15 cycles with an average fallow period of 10 years. Thus the time span from forest to secondary grasslands would have been between ca. 110 and 160 years. In the 70s, fallow periods were still between eight and 15 years and the last forests were cut in the Beforona region during that time. Thus although some transitions into more advanced degradation had occurred on some plots at that time, it was not a dominant landscape feature and most fallows were still productive. Furthermore, when forests are still available for deforestation, which is the case in Ambavaniasy today, many fallows are within the first three cycles and various management regimes that might be applied yield satisfactory outcomes for farmers because the system is still buffered. Brand and Pfund (1998) concluded, taking into account Chauvet's estimates and noting when deforestation first occurred in the territory, that it takes five slash-and-burn cycles from rainforest to shrub fallow, another 10-20 cycles from shrub to degraded fallows, and 50-100 years from degraded fallows to grasslands. They arrived at the conclusion that it takes between 200-250 years for the land to arrive at the arrested succession of grasslands. These estimates do not take into account the historical dynamics as described in Chapter 2, the population increase, and the decrease in the length of fallow periods over the past 30 years. Thus under the current situation, these estimates are no longer valid and, as our results indicate, the dynamic and speed has increased drastically with shorter fallow periods. Thus with the current fallow periods of three to five years, the transition from rainforest to herbaceous vegetation happens within five to eight cycles or from 20 to 30 years with a maximum of 40 years.

4. Driving forces for species succession

There are no studies available from the region that explain the ecological factors and variables that influence the observed species succession. This includes the regeneration abilities and ecological requirements of the species, what influences and determines the competitiveness of one species over another, and how the species react to management interventions such as slashing, burning, and cropping. Farmers have offered limited explanations on these topics. The restricted observations and assumptions that were made during this study are presented below. They need to be confirmed, revised, or tested through ecological studies.

It seemed that, closer to the rainforest, endemic and indigenous secondary fallow vegetation (*Psiadia, Harungana* and *Trema)* is more abundant and better able to resist competition from exotic invasive species for a longer period, whereas at a further distance from the rainforest border, the exotic naturalized species (*Rubus* and *Lantana*), having already invaded large territories, are more competitive against and more successful in suppressing the native flora. This may most likely be related either to the seed source, distance from the seed source, the seed dispersal mechanism, or multiplication strategies.

The exotic species (*Rubus, Lantana*) and the herbaceous species (*Imperata*, ferns) seemed to be less susceptible to fire and cultivation than indigenous species (*Psiadia, Aframomum*, *Trema*). Many of the exotic and herbaceous species do have vegetative multiplication strategies that complement seed dispersal, whereas *Psiadia, Trema*, and *Harungana* depend exclusively on seed multiplication. The species that are able to propagate vegetatively from the root system may also have the advantage of being able to store nutrients below ground and resprout more easily after having been cut and burned. Ferns and *Imperata* thrive on fire and are favored over more susceptible species with each burning cycle—a point which is widely acknowledged in the literature (Chikoye et al., 2000; Grist and Menz, 2000; Hartemink, 2001). Contrary to what is reported from other countries (Grist and Menz, 1997), *Imperata* in eastern Madagascar is not a persistent fire-climax species because it is replaced with *Aristida* sp. and *Hyperrhenia* sp., among others, if burned several times.

There is also no information available on soil microbial dependencies or on synergies with either the major fallow species or the rainforest species of eastern Madagascar. The first species description, of endo-mycorrhizal fungi, was initiated by myself, indicating a decrease in species diversity with increasing fallow degradation (Styger et al, unpublished). These findings are not reported or discussed further in this dissertation.

5. Indigenous fallow characterization

The exploration of indigenous knowledge on fallows revealed an elaborated fallow characterization that combines various factors such as species composition, vegetation appearance, agricultural potential, and guidelines on management interventions. Indeed, the classification scheme can be used as a versatile diagnostic tool. It allows us to deduce the fallow cycle by looking at a fallow vegetation plot following deforestation, to determine its agricultural potential, and to formulate precautions to be taken in the course of management interventions. These findings have opened up a new understanding of fallow/cropping system dynamics by integrating the ecological, agricultural, and management components of the system. To obtain the same insights would have occupied many years of experimentation.

Clear management guidelines accompany each fallow type. There are critical phases within a fallow vegetation development as well, and depending on the management decisions applied during these phases, the fallow proceeds either towards restoration or degradation. The chief insight taken from the indigenous characterizations is that the critical moment in the history of a fallow for soil fertility restoration is when woody species no longer grow back but instead are supplanted by herbaceous species. Such indigenous knowledge provides us with clear guidelines for avoiding that outcome.

There is no danger in cultivating a tree fallow, either a *Vadikatana* that occurs after the deforestation of a primary or secondary forest, or a *Savoka Mody* that has regenerated from a shrubby fallow or *Savoka*. The next fallow will regenerate into a fallow with woody species. Within the shrubby fallows, however, it is of ultimate importance to give the fallow enough time to develop into a *Savoka* before being cultivated anew. The *Savoka* needs to have a dense, dark-green appearance and at the same time out-shade the herbaceous fallow species to a maximum degree. The critical point in the system occurs when a shrubby fallow is in the *Dedeka* stage, characterized being small in stature with yellowish leaves and accompanied by ferns and *Imperata*. If a *Dedeka* is either cultivated or burned only (e.g. by an escaped fire), the land will almost certainly drop below the critical threshold of productivity and turn into a *Roranga* fallow in the next cycle. Once the fallow is dominated by these herbaceous species, it is very difficult for woody species to get established, due in part to the very aggressive root competition. The soils under *Roranga* can be used for root crops, but after a few cycles *Imperata* and ferns are replaced by secondary grassland species and the land becomes *Tany Maty* or 'dead land'. These guidelines refer to the principal of planting only one crop per cropping cycle. If more than one crop is planted or if a wild fire passes accidentally over a fallow, it is possible for a *Savoka* to develop directly into a *Roranga*.

By applying the indigenous categories at the village territory level, it can be concluded that upland fallows of Ambavaniasy are mostly in the *Vadikatana* and *Savoka* stages, whereas most of the fallows in Ambinanisahavolo already belong to the *Dedeka* stage. Given the advanced cycles following deforestation, these uplands theoretically should remain under fallow at least 15 years, but this is not an option for farmers, as they have no additional land to plant on. It is therefore easily foreseen that, once the *Dedeka* fallows are cropped, land productivity will fall below the critical production level. Moreover, a very alarming finding is that farmers have neither the knowledge nor the means to engage in efficient land use restoration that might at least partially preserve their uplands from complete degradation.

6. Integration of findings on species succession as a function of time passed since rainforest status, indigenous fallow classification, and agricultural production potential

The findings on species succession as a function of time that has passed since the land was rainforest, indigenous fallow classification, and agricultural production potential have been integrated and presented in Figure 10. Agricultural productivity is added to the first two major findings that have just been discussed. It represents yield estimates for upland rice obtained through farmer interviews.

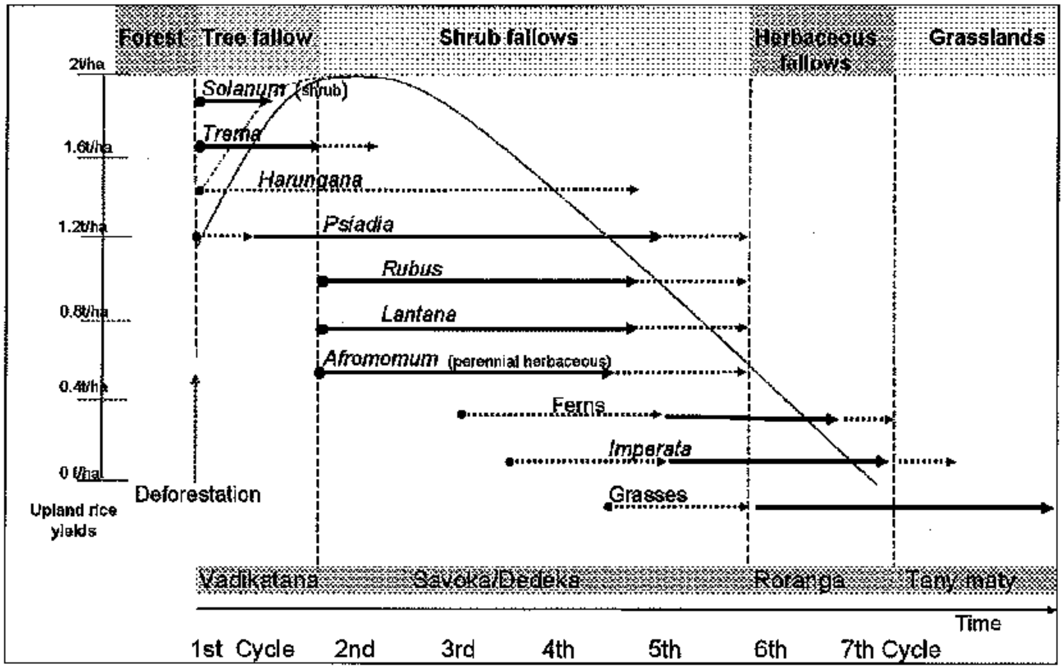


Figure 10: Fallow species succession as a function of time passed since rainforest status, indigenous fallow classification, and agricultural production potential in the Beforona region of eastern Madagascar.

Upland rice yields attain ca 1.5t/ha in the very first cropping seaso. This may be due to several reasons. The woody biomass that hasn't burned entirely still covers the soil surface, resulting in lower planting density. The soil is in a transitional phase between that of a forest and agricultural soil. 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 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 cycle, this layer has decomposed and the soil resembles an agricultural soil much more, with a thin litter layer and plant roots growing within the mineral A-horizon that is rich in organic matter. Yields are highest with 2 – 2.5t/ha. With each further cycle, yields decrease rapidly and when the *Roranga* stage is reached, farmers stop cropping rice. Theoretically, if the land is tilled, farmers may still produce ca 500 kg/ha of rice but the management requirements of *Imperata*, fern rhizomes, and other weeds are too excessive. All agricultural cropping is stopped when grassland gets established.

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. The various phases characterizing how the landscape evolved can still be observed today by moving from the forest zone towards the fallow zone. The chronological transformation of the landscape is presented in Figures 11a, 11b, and 11c, and are described in what follows.

a) When colonizing a forested valley, farmers begin cutting forests in the lower parts of the valley, establish their houses on a slightly elevated location, and with each cycle 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. From a historical perspective, it was also forbidden from throughout the colonial time until 1975 to deforest the upper one-third of a hillside. With low population densities, fallows were either reused when in a *Savoka* stage or developed back into *Savoka Mody*'s or secondary forests (*Ala Ordinaire*).

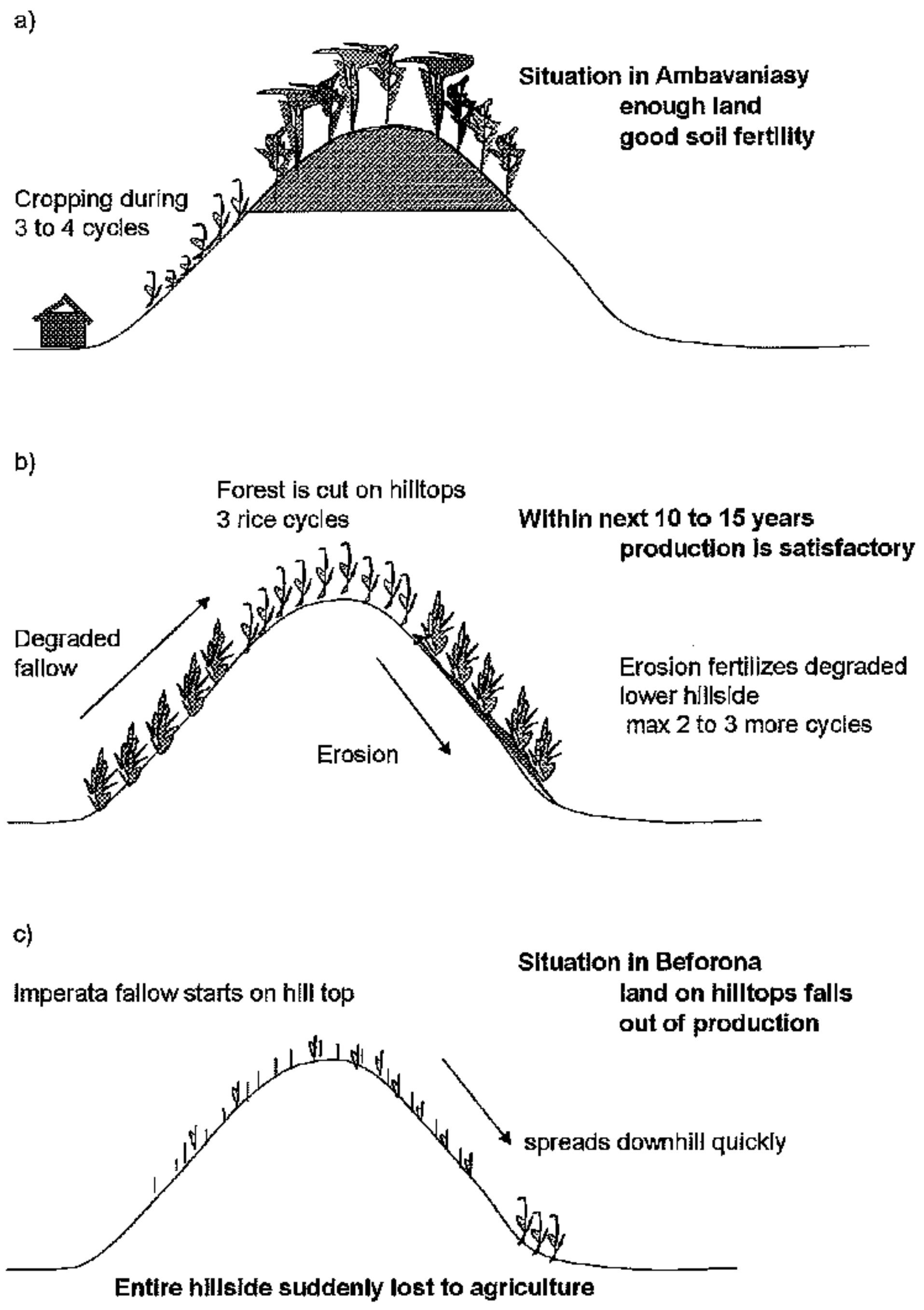


Figure 11: Landscape implications of cropping history

b) After 1975, no one respected the rule for maintaining the forest on the hilltops anymore. With more people using the land, fallow periods became shorter and farmers rotated among their lower hillside fields and achieved satisfactory yields for several cycles. With the subsequent decrease in productivity and the desire to secure more land, farmers moved further uphill and cut the hilltop forests. The lower hillside plots benefited from eroded surface soil and continued to be productive. Thus it was possible to rotate between plots from the upper and lower hillside. This arrangement may have worked for a few cropping cycles until the lower fields were first being overused. At the same time, the hilltop fields became degraded after only a few cycles due to their shallower soils that had been subject to erosion since deforestation.

c) *Imperata* and ferns were established first on the hilltops and from there spread downhill with each additional cycle. This situation can be observed today in Ambinanisahavolo. Farmers there are concentrating again on cropping the lower hillside fields that are already in the *Dedeka* stage. When the lower hillsides are burned, the fire escapes uphill easily and it is almost impossible to protect the upper hill slope from fire. Thus the entire hillside is turned into a *Roranga* fallow and falls 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 (Brand and Pfund, 1998)(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 devastating impact of fire becomes more and more prominent the further along the land is in the degradation sequence and poses a much greater problem for reversing the dynamic. This is because herbaceous vegetation catches fire more easily than woody vegetation. More fires therefore escape as wildfires beyond the designated field boundaries that farmers intended to respect, thus burning and damaging neighboring plots. With the increasing scarcity of available cropland and the shortening of fallow periods, burning frequencies increase across the landscape. The vegetation is therefore more likely to be burned at higher frequencies. At the same time, it is difficult to protect land from escaping fires. Fire-loving herbaceous plants are perpetuated and the natural regeneration of woody plants is impeded all the more. At that point, without abandoning the use of fire, the landscape is hardly able to restore woody species. In respect to biodiversity conservation, indigenous woody flora still present in *Savoka Mody*, *Vadikatana*, and even under *Savokas* has vanished and no longer regenerates.

To summarize, there are three critical stages within the land use system dynamic that perpetuate the degradation process and should be avoided in all circumstances. The first is to avoid deforesting the hilltop forests, because once they are cut, erosion processes are initiated, inducing rapid soil and vegetation degradation on the hilltops. This degradation moves quickly downhill and is very difficult to stop. Eventually the entire hillside is ruined for agriculture. Second, the cultivation of a fallow in the *Dedeka* stage should be prevented because the following fallow will be a *Roranga* and the land is lost for upland rice cultivation. And third, once the woody vegetation is lost, the *Roranga* fallow is very susceptible to catching fire. With each additional fire the chances that woody species regenerate become smaller and smaller, leading to the arrested vegetation of secondary grasslands. The frequent and erratic fires within the landscape condemn any tree-planting endeavor to failure. When advocating a fire-less management system, it is important to acknowledge that fire use does not have a cultural meaning for the Betsimisaraka but is instead considered just a management tool. Thus if alternative cultivation practices could be found that would obviate the use of fire, there should be little in the way of culturally anchored hesitation in changing the practices.

CONCLUSIONS

1) Fallow periods and their ability to regenerate soil fertility need to be discussed in relation to fallow/cropping cycles following deforestation, fallow species composition, and the specific dynamic of fallow species recovery within a given ecosystem. In the Beforona region, after the third cycle following deforestation, fallow periods should be longer than the current periods, in order to restore soil fertility satisfactorily. The observations also imply that, after the third cycle, a rapid degradation dynamic is initiated.

2) As the frequency of slashing, burning, and cropping increases (or as fallow periods decrease) a rapid change in fallow species composition is induced that shifts with each cycle. Tree fallows disappear after the first fallow cycle and the agricultural system depends on the shrubby fallow species to restore productivity. Indigenous species, which are still dominant in the first cycles, are replaced with exotic species that have sexual and vegetative propagation mechanisms and adapt better to fire than the indigenous species.

3) The indigenous fallow categories represent a powerful identification tool that allows observers to deduce the numbers of cycles after deforestation, determine the agricultural production potential of an area, and inform the precautions taken in performing management interventions—all by looking at fallow vegetation.

4) Most of the upland fallow land in the Beforona region is in the very critical stage of *Dedeka*, with a very high risk of being lost to agriculture if it is cultivated again. Farmers have neither the knowledge nor the means to keep these soils productive and prevent them from suffering further degradation.

Two major recommendations are:

1) Technical agricultural innovations are urgently needed to stop the degradation process and to reverse it by developing agricultural techniques that rebuild and maintain soil fertility levels, allowing long-term sustained agricultural productivity.

2) All use of fire should be abandoned in the land use system. Agricultural techniques should be fire-less to give the ecosystem the chance to preserve and rebuild its nutrient stocks that contribute to agricultural productivity, and to provide a safe environment for the regeneration and growth of woody species in view of restoring the tree population to the landscape.

Chapter 4

Biomass production, nutrient stocks, and soil nutrient availability of four fallows types along a degradation sequence in eastern Madagascar

INTRODUCTION

The fallow phase in a slash-and-burn cultivation cycle is responsible for soil fertility restoration, in which nutrients are taken up from the subsoil and surface soil over a period of several years and stored in the vegetation. These nutrients are released and mobilized through burning and made available to subsequent crops. In subsistence cropping systems, the fallow stage, therefore, plays the central role in soil fertility regeneration, thereby directly determining crop productivity (Nye and Greenland, 1960; Sanchez, 1976).

The success of a fallow in improving soil conditions depends on the extent of past soil degradation, the characteristics of the successional community, and the length of the fallow (Kleinman et al., 1995). It therefore depends on the rate and magnitude of nutrient accumulation in plant biomass and surface soil pools. Fallow species vary in the quantity and quality of nutrients they accumulate. The successional community therefore influences the effectiveness of the fallow in improving degraded soil conditions for future cropping periods (Uhl, 1987). Biomass production in a fallow is a direct index of the ecosystem's primary productivity and nutrient cycling (Whittaker and Marks, 1975). The quantification of organic matter accumulation and nutrients stored in the vegetation are thus important measures in ecological studies (Vann et al.,

1998) and allow comparisons to be made between different vegetation types, or between similar vegetation types in different localities (Overman et al., 1994).

In previous chapters I have shown that land degradation is accelerating in eastern Madagascar, due mostly to the shortening of fallow periods in recent decades. I have also shown that this land degradation is characterized by a vegetation succession in which the dominant fallow aspect transitions from tree to shrub to herbaceous fallow across increasingly frequent cropping cycles. The eventual outcome is the collapse of the system when land is abandoned for cropping, which is indeed the actual trend in the current land use system.

Brand and Pfund (1998) have studied nutrient stock dynamics under shifting cultivation in the Beforona area, which they related to fallow age and independently to broad vegetation categories along a degradation sequence. In their analysis, neither the link between fallow periods and cycles nor the link between degradation categories and species composition was made, thus bypassing two major findings from Chapter 3. They neglected also to integrate agricultural productivity into their analysis, again missing a key focus of this study.

The main objective of this study was therefore to characterize natural fallows in quantifying their biomass, nutrient stocks, and soil nutrient availability along a gradient of degradation by taking into account fallow age, the cycle number following deforestation, and species composition. Four fallow types were selected that were representative of the degradation sequence and were dominated by a single species. They were: *Trema orientalis* fallow (tree fallow), *Psiadia altissima* fallow and *Rubus moluccanus* fallow (both shrub fallows), and *Imperata cylindrica* fallow (grass fallow). In addition, the first four fallow cycles following deforestation for *Psiadia altissima* fallow was studied in order to eliminate the species effect. The study concentrated on fallow ages ranging from 1 to 10 years.

As biomass harvesting is impractical and laborious, allometric methods can be used in which a functional relationship between easily measured variables such as stem diameter and biomass is established through regression analysis. (Overman et al., 1994; Vann et al., 1998). As no regression models were available either for eastern Madagascar, for the studied species, or for small trees (<10 cm dbh diameter), it was decided to perform regression analysis to establish species-specific regressions for the various biomass components.

Objectives

1) Determine site- and species-specific allometric equations based on easily measurable parameters for the estimation of above- and belowground biomass components for the species *Trema orientalis, Psiadia altissima, Rubus moluccanus* and *Imperata cylindrica*
2) Quantify above-and belowground biomass components for four species and four cycles of *Psiadia altissima* ranging from 1-10 years in age
3) Identify nutrient concentration from leaf, wood, and root components of the studied species
4) Determine nutrient and carbon stocks for four fallows and four cycles for ages 1-10 years
5) Assess soil nutrient availability and soil nutrient stocks for rainforest and the four fallow

Hypotheses

1) Biomass production from the tree fallow will be superior, followed by that of shrubby fallows and herbaceous fallow, respectively, and from Cycle 1 to Cycle 4 of the *Psiadia* fallow for all the years from 1 to 10 years in age.
2) Nutrient concentrations from leaves, wood, and roots will decline along the degradation sequence from *Trema* to *Psiadia,* to *Rubus,* and finally to *Imperata.*
3) Nutrient stocks will be superior for the tree fallow, and subsequently decrease for the shrubby and herbaceous fallows, respectively, and from Cycle 1 to Cycle 4 of the *Psiadia* fallow for all the years from 1 to 10 years in age.
4) Soil nutrient availability will decrease with increasing fallow degradation.

METHODOLOGY

1. Site characteristics

1.1. Location and climate

Madagascar's eastern region has a humid, tropical climate and is characterized by a mountainous geography, extending from north to south across the entire 1500 km length of the island. Along this mountain range, the last rainforest corridors can be found. Wind and precipitation arrives from the east, so the escarpment acts as a rainfall barrier for the rest of the island (Donque, 1972). Our study area lies in the central part of the eastern escarpment, next to the Mantadia-Zahamena rainforest corridor. Three study sites were chosen in proximity to the forest corridor and National Road Number 2 (RN2), which crosses the forest from west to east and links the capital, Antananarivo, with the major port of Tamatave. The sites were 1) Berano, located within the forest on the western side of the corridor and characterized by tree fallows; 2) Ambavaniasy, located on the eastern forest border, with shrubby fallows; and 3) Beforona, situated ca 12 km east of the forest border and characterized by shrubby and herbaceous fallows. The position of the three sites is indicated on a map in Figure 12 and in a schematic map that indicates the relief, the altitudes, the GPS coordinates, and dominant fallow vegetation (tree, shrub, grass fallow) in relation to proximity to the forest (Figure 13).

In this region, the rainfall at the foot of the escarpment, between 400 and 700 m a.s.l, is > 2000 mm, increasing to its highest level at the Vohidrazana crest, between 1000 and 1200 m a.s.l., with > 3500mm of rainfall. Further west, beyond Vohidrazana and the Betsimisaraka cliff, lies the Manongoro-Alaotra hollow, where rainfall is lower—between 1000 and 1500 mm—at altitudes between 700 and 900 m. (Donque, 1972)

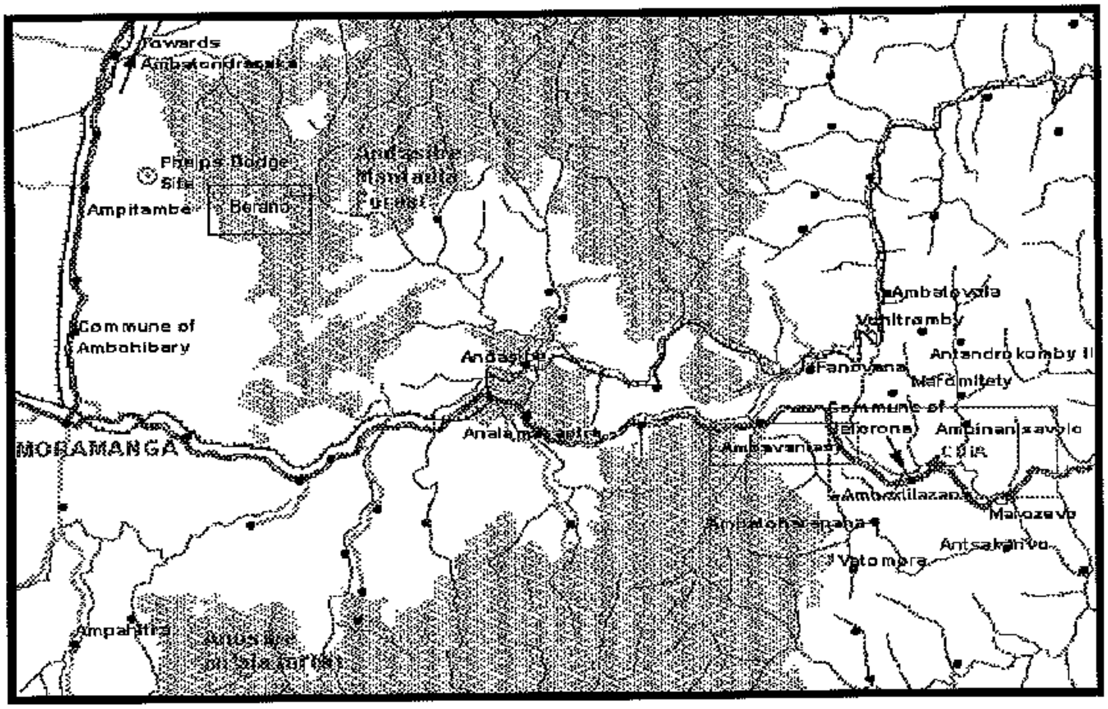


Figure 12: Study area and study sites: Berano, Ambavaniasy, and Beforona, including the village territory of Ambinanisahavolo and the CDIA Farmer Center

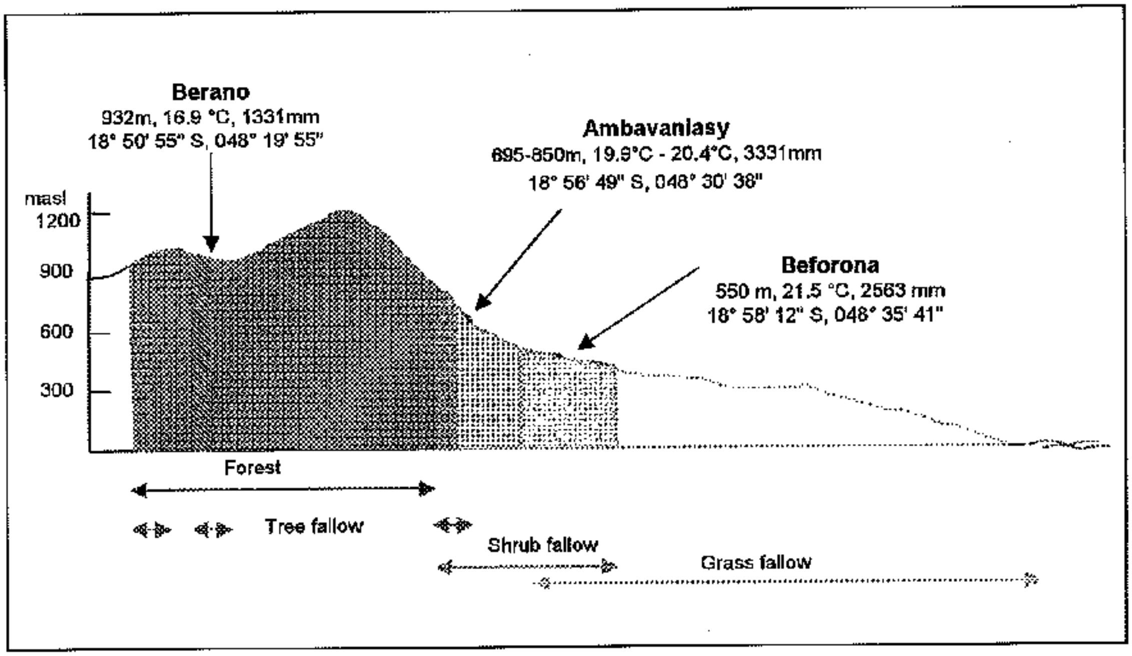


Figure 13: Schematic map of the eastern escarpment and study sites

Monthly temperatures and rainfall of the three locations is presented in Table 13 and, for Marolafa, located in the Beforona area, in Figure 14.

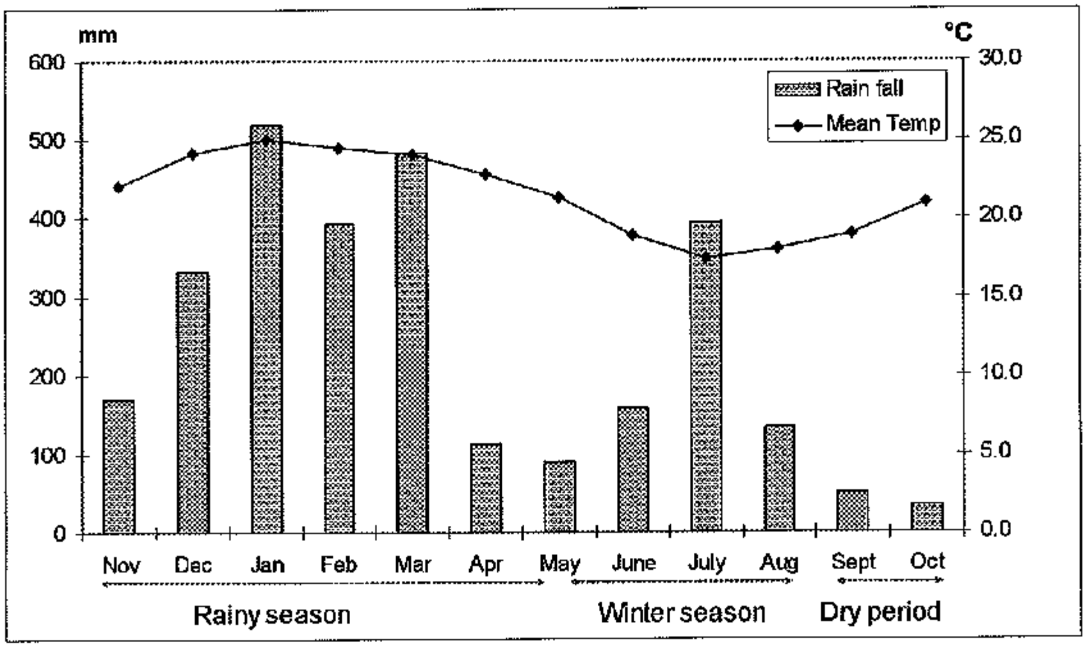


Figure 14: Monthly rainfall and mean temperature for Marolafa, Beforona; 550 m a.s.l, mean annual T 21.5 °C, mean annual rainfall 2563 mm, with indication of rainy, winter, and dry seasons.

Table 13: Monthly air temperatures (°C mean, maxima and minima) and monthly rainfall (mm) for Marolafa (Beforona), Ambavaniasy and Berano

a) Marolafa, 550m a.s.l.

Average of 3 years 1999-2001

	Temperature (°C) Mean	Max	Min	Rarinfall (mm)
JAN	25.0	27.5	22.5	409
FEB	24.5	25.7	22.2	299
MAR	24.1	26.2	21.5	420
APR	22.8	25.8	20.2	94
MAY	21.4	25.8	18.5	84
JUN	18.9	22.3	16.3	127
JUL	17.3	20.3	14.8	330
AUG	18.0	20.0	16.0	169
SEP	19.0	21.8	16.5	87
OCT	21.0	24.8	17.3	29
NOV	22.1	24.5	19.3	186
DEC	24.1	26.8	21.0	329
Annual *	**21.5**	**24.3**	**18.8**	**2563**

*Annual: Annual mean temperatures and total annual rainfall

b) Ambavaniasy, 695m a.s.l.

Average of 3 years 1993 - 1995

	Temperature (°C) Mean	Max	Min	Rarinfall (mm)
JAN	23.7	27.5	20.5	703
FEB	23.5	26.5	20.5	524
MAR	22.7	26.3	19.7	645
APR	22.0	25.5	19.0	167
MAY	20.0	22.5	17.3	238
JUN	17.5	21.0	14.7	149
JUL	16.5	19.3	13.2	209
AUG	16.8	19.8	13.3	232
SEP	17.8	21.5	14.8	78
OCT	19.9	23.7	16.0	102
NOV	21.2	24.5	16.5	51
DEC	22.8	26.0	19.7	333
Annual *	**20.4**	**23.7**	**17.1**	**3431**

d) Berano, 932m a.s.l.

Average of 3 years 1999-2001

	Temperature (°C) Mean	Max	Min	Rarinfall (mm)
JAN	19.9	20.0	19.8	216
FEB	19.6	19.7	19.6	195
MAR	19.0	19.0	18.9	235
APR	17.7	18.0	17.5	82
MAY	17.1	17.2	17.0	30
JUN	14.6	14.7	14.5	55
JUL	12.9	13.0	12.8	105
AUG	13.4	13.6	13.3	59
SEP	14.8	14.8	14.7	98
OCT	16.7	16.8	16.6	73
NOV	17.9	18.0	17.7	41
DEC	19.0	19.1	18.9	141
Annual *	**16.9**	**17.0**	**16.8**	**1331**

There are three distinct seasons: The rainy season extends from November to April, bringing two-thirds of the annual rainfall with much stormy weather. The winter period is misty and features almost constant light precipitation (drizzle) and cooler temperatures (May to August). The dry season occupies September and October, during which only 6 to 8% of annual rainfall occurs (Brand, 1997). It is during these two months that vegetation is slashed and left to dry before it is burned in November to start a new cropping cycle. Tropical cyclones coming from the Indian Ocean are a real threat to the region, being most prevalent between January and March. Over a 50-year period, 66 cyclones have visited the eastern region, creating considerable damage to the landscape, human settlements, infrastructure, and crops (Donque, 1972).

In summary, with increasing altitude, rainfall increases and temperatures cool. As clouds discharge their moisture on the eastern side of the escarpment, rainfall decreases further west. Beforona is the warmest of our research sites, with > 2500 mm rainfall. In Ambavaniasy the temperatures are slightly cooler and rainfall can increase up to 3500 mm. Berano, the highest location, has cooler temperatures and a lower annual rainfall of 1330 mm.

1.2. Geology

The geology of the eastern region is characterized by metamorphic and igneous rock, including crystalline rocks such as granites, migmatites, and schists. These rocks are either covered by a thick blanket of lateritic clays or exposed on the steeper slopes of the eastern escarpment as cliffs (Besairie and Collignon, 1960; Du Puy and Moat, 1996). Du Puy and Moat (1996) overlaid the map of the remaining primary vegetation (Faramalala, 1995) on the 'Simplified Geology Map' they established based on Besairie's geology map from 1964, producing a map of the remaining areas of primary vegetation types, subdivided according to the substrate on which they occur. From this map it became evident that the eastern evergreen forests occur mainly on the metamorphic and igneous basement rocks, and are rather uniform in the categorization using underlying rock types. Although the full geology map indicates various categories of granites and migmatites, it seems improbable that these different rock categories would greatly affect the forest cover they support (Du Puy and Moat, 1996). Thus we can assume that we would find similar soil types in the eastern region, along the rainforest border. This seems to be confirmed by comparing soil studies of the eastern region by various authors (Roederer, 1972; Johnson, 1992; Brand and Rakotondranaly, 1997).

1.3. Relief

The eastern escarpment has slopes of 10 - 50%, representing a high-risk erosion area, especially if vegetation is removed. Yearly loss of 9 t/ha of soil under cultivation was measured by Bailly et al (1974) in Andasibe.

1.4 Soils

Roederer (1972) determined that the main group of eastern region soils are 'Sol ferralitique jaune ou rouge' (yellow or red) according to the French Soil Classification. Razakanirina (1989) confirmed that soils of the Andasibe region are 'Sol ferralitique'. Brand and Rakotondranaly (1997) analyzed the soils in the Beforona region with the FAO Soil Classification System and concluded that the forest soils and secondary forest vegetation soils are Humic Ferralsols, while soils on degraded hillsides are Haplic Ferralsols. Brand and Rakotondranaly (1997) found that their results were comparable to Johnson's (1992), who characterized the soils in Ranomafana, Fianarantsoa, in the southeastern region of Madagascar with similar altitudes, climate, and forest formations.

Johnson's work is the only soil classification according to Soil Taxonomy, as far I am aware of, pertaining to from the eastern region of Madagascar. Theoretically, the upland soils evolve towards Ultisols, but their argillic or kandic horizons don't meet the requirements, and thus they are classified as Inceptisols. As the upland soils under the forest contain relatively high concentrations of organic carbon within the upper meter of soil, Johnson (1992) classified most soils as Humitropepts. The soils over the Precambrian basement are composed of lateritic clays containing hydroxides of aluminium and iron. The clay mineralogy of most upland soils is kaolinitic, while the sand fraction is dominated by quartz and sand-sized kaolinite. Chemical composition is relatively uniform on a landscape-scale basis. The pH ranges from 3.5-5.0, with aluminum saturation between 60 and 90%. Nutrient contents in the surface horizons and in the subsoil are extremely low, especially in phosphorus, and are considered to be below the critical level for crop production. There are no significant reserves of weatherable minerals in the soil (Battistini, 1972; Jenkins, 1987; Johnson, 1992; Brand and Rakotondranaly, 1997).

1.5. Vegetation

The largest areas of remaining forest in the eastern region are classified as evergreen humid forest at low altitude (0-800m) and mid altitude (800-1800m) (Humbert, 1955; Faramalala, 1995; Du Puy and Moat, 1996). The characteristics of the fallow or secondary vegetation in the study region have been described in Chapter 3. The fallows are subject to permanent and ongoing degradation. They change from tree fallows to shrubby fallows to herbaceous fallows until they reach the pseudoclimax stage of secondary savannas that are characterized by a few mostly exotic fire-resistant grasses (Koechlin, 1972).

2. Research design

2.1. Fallow selection

For this biophysical characterization of fallows along the degradation sequence, a representative subset of fallows was selected for further in-depth studies. The four fallow types selected were dominated by a single species and were 1) a tree fallow with *Trema* orientalis; two shrubby fallows with 2) *Psiadia altissima*; 3) *Rubus moluccanus*; and 4) an herbaceous fallow characterized by *Imperata cylindrica*. The position of these species along the degradation sequence is shown in Figure 15. Four cycles following deforestation were also examined separately for *Psiadia altissima*, in order to study the cycle effect independently from the species effect. Some species characteristics are shown in Table 14.

Table 14: Characteristics of selected fallow species

Species	Family	Origin	Dispersal	Propagation	Vernacular Name
Trema orientalis	Ulmaceae	pantropical	B	S	Vakoka
Psiadia altissima	Asteraceae	endemic	W	S	Dingadingana
Rubus moluccanus	Rosaceae	exotic	B	S, V	Takoaka
Imperata cylindrica	Poaceae	pantropical	W	R, S	Tenina

Dispersal: B: Bird, W: Wind
Propagation S:Seed, V: Vegetative, R: Rhizomes

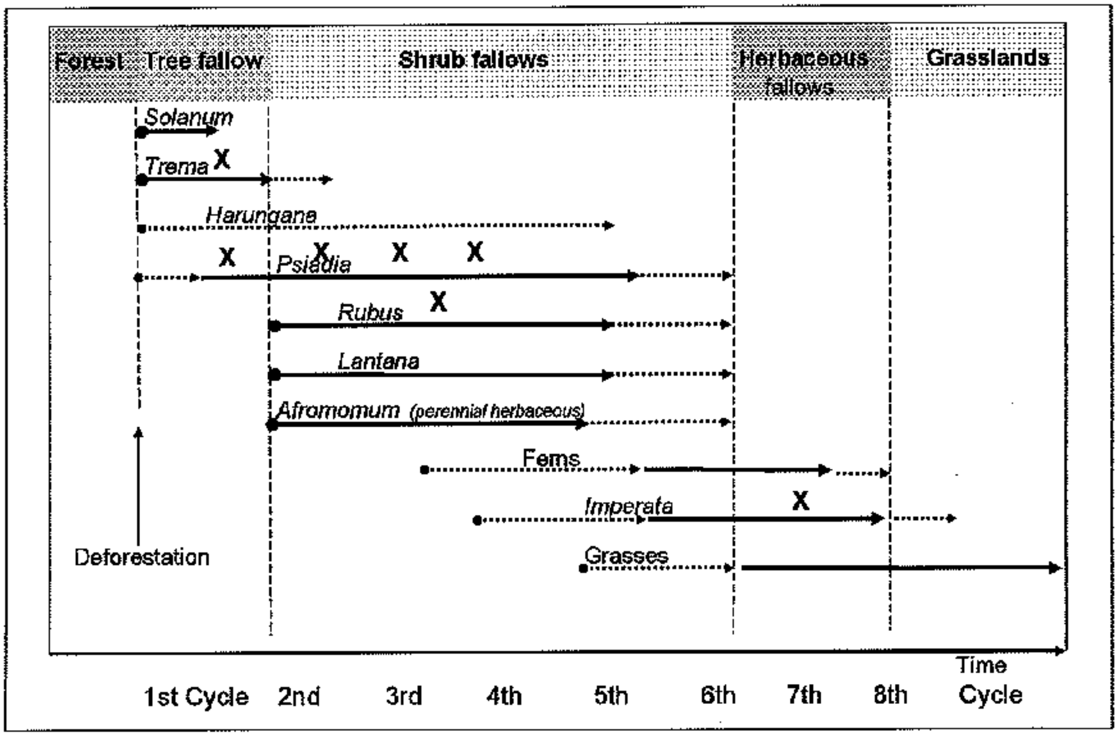


Figure 15: Fallow selection within the species-succession framework under current cropping/fallowing practices. (Position of the species selected within the respective cycle information is indicated by 'X' in the Figure)

2.2. Fallow plot selection

The fallow field plots within the study sites were selected in proximity to the agricultural experimental sites, to assure similarity of conditions. Usually a fallow plot is 1 to 2 ha in extent, the average size of upland rice fields. Criteria used to select a field were uniform growth of the fallow vegetation, a nearly mono-specific stand of the studied species, and a fallow that had a closed canopy. Five fallow fields were selected for each of the four species representing replicates. Within a selected fallow field, a transect was delimited where all the measurements and harvests were completed. The methodological approach for biomass harvest and population characterization differed among the species. For *Trema* and *Psiadia*, it was possible to measure and harvest single specimens. *Rubus* forms a thick, spiny, impenetrable stand and was therefore harvested on a surface basis, which was the method chosen for *Imperata* grass as well.

2.3. Transect layout

The transect dimensions varied by species. For *Trema* and *Psiadia,* transects of 2 m x 20 m were laid out in the mid-slope parallel to the slope, avoiding crests and hill bottoms but covering some of the variability of soil conditions that influence plant growth on a slope (Philip, 1994). As *Rubus* forms a thick, spiny, and impenetrable stand, five plots of 3 m x 3 m (9 m^2) were positioned along a 20 m transect line. For *Imperata,* the layout was the same as for *Rubus,* except that plot size was 1 m x 1 m (1 m^2), a standard size for grass plots (Kent and Coker, 1992). The layouts are presented in Figure 16. Thus while *Trema* and *Psiadia* were measured and harvested per individual, *Rubus* and *Imperata* were harvested per surface and measurements on the plants were done after harvesting.

For *Trema* and *Psiadia,* three to five additional transect surfaces were plotted out randomly within the field, and tree density (trees/ha) and diameter measurements were taken. Although the transect for biomass harvest was selected as being representative within the field, the additional transects helped in comprehending variability within the field. The results of all three to five transects were later used to calculate biomass production with the established regression models.

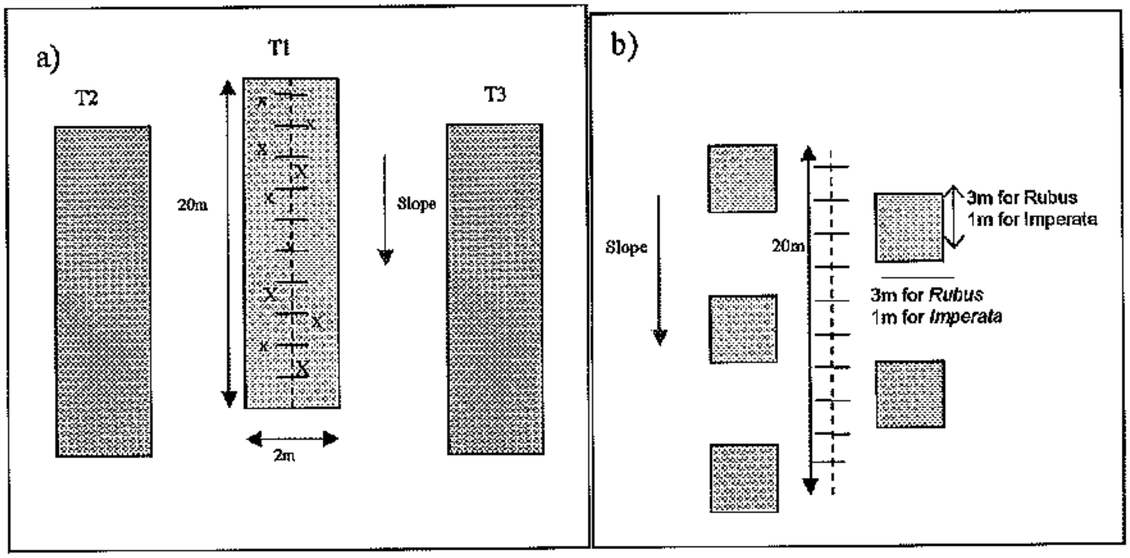


Figure 16: Transect layouts within a field for a) *Trema* and *Psiadia* and b) *Rubus* and *Imperata*. Under a) T1 marks the transect where all measurements and biomass harvest was done. T2 and T3 were additional transects for tree density determination and diameter measurements.

2.4. Transect characteristics

The transect characteristics are summarized in Table 15. For each of the transect sites, GPS coordinates, transect dimension, estimated average stand height, orientation, slope, and fallow age are noted. For *Trema* and *Psiadia,* fallow cycles following deforestation are mentioned, which wasn't conclusive for the other two species, as they had longer plot histories. In addition to the fallow sites, five rainforest sites were identified, where only soil sampling was done.

Table 15: Transect characteristics

Transect Numb	1	2	3	4	5
Primary Forest					
Site	Berano	Marolafa-Beforona	Ambavaniasy	Ampahitra	Ankeniheny
GPS S:	18° 50' 55"	18° 57' 51,03"	18° 57' 03"	19° 04' 29"	
GPS E:	048° 19' 50"	48° 35' 09,26"	048° 29' 46"	048° 14' 01"	
T length/dim [a]	20m [b]	20m	20m	20m	20m
Exposition	E	N	W	S	NW
Slope	35%	40%	50%	50%	30%
Trema orientalis					
Site	Berano	Berano	Ambavaniasy	Beforona	Beforona
Location	Berano valley	Berano valley	Analambalo	Ambatomalama	Beforona village
GPS S:	18° 50' 55"	18° 51' 05"	18° 57' 03"	18° 58' 12"	18° 57' 14"
GPS E:	048° 19' 50"	048° 19' 38"	048° 29' 46"	048° 35' 00"	048° 35' 14"
T length/dim	2m x 20m	2m x 20 m	2 x 2m x 10 m	2m x 20m	2m x 20m
Stand height	5.5 to 7 m	6 to 7.5 m	4.5 to 5.5 m	2.5 to 4 m	4 to 5 m
Exposition	W	W-NW	EEN	SSE	SSE
Slope	15%	13%	40%	25%	25%
Fallow age	4 years	7 years	5 years	2 years	4 years
Fallow cycle	Cycle 1	Cycle 1	Cycle 1	Cycle 1	Cycle 2
Psiadia altissima					
Sites	Ambavaniasy	Ambavaniasy	Ambavaniasy	Ambavaniasy	Ambavaniasy
Location	Ambatosenegal	Ambatosenegal	Ambavaniasy	Ambatosenegal	Andranonampango
GPS S:	18° 57' 19"	18° 57' 14"	18° 56' 49"	18° 57' 03"	18° 56' 28"
GPS E:	048° 29' 41"	048° 29' 42"	048° 30' 38"	048° 29' 46"	048° 30' 57"
T length/dim	2 T x 2mx10 m	2m x 20 m	2m x 20 m	2m x 20 m	2 T x 2mx10 m
Stand height	3.5-4.5 m	4 - 4.5 m	3.5-4.5 m	4-5 m	4.5-6m
Exposition	EE	EE	NE	SSE	ENE
Slope	15%-20%	10%	45%	35%	35-45%
Fallow age	6 years	6 years	6 years	8 years	7 years
Fallow cycle	Cycle 2	Cycle 4	Cycle 1	Cycle 3	Cycle 2
Rubus moluccanus					
Site	Beforona	Beforona	Beforona	Beforona	Beforona
Location	CDIA-Marolafa	Ambinanisahavolo	Amalomananika	Ambatomalama	Ambatomalama
GPS S:	18° 57' 52"	18° 58' 11,63"	18° 56' 48,52"	18° 58' 26,23"	18° 58' 14,42"
GPS E:	048° 35' 14"	48° 35' 40,71"	48° 35' 15,95"	48° 35' 50,24"	48° 35' 39,68"
T length/dim	5 x (3mx3m)	5 x (3mx3m)	5 x (3mx3m)	5 x (3mx3m)	5 x (3mx3m)
Stand height	3m	2m-2.5m	2.5 m	3m-3.5 m	2.5 - 3m
Exposition	Sud	N	SE	E	S
Slope	20-30%	20-30%	30-40%	45%	10-15%
Fallow age	4 years	6 years	4 years	5 years	10 years
Imperata cylindrica					
Sites	Beforona	Beforona	Beforona	Beforona	Beforona
Location	CDIA-Marolafa	CDIA-Marolafa	Ambinanishavolo	Fotsihalanana	Amalomanarika
GPS S:	18° 57' 34,33"	18° 57' 04,05"	18° 56' 52,24"	18° 56' 46,42"	18° 56' 46,47"
GPS E:	48° 35' 16,55"	48° 35' 22,03"	48° 35' 21,33"	48° 35' 07,16"	48° 35' 16,31"
T length/dim	5 x (1mx1m)	5 x (1mx1m)	5 x (1mx1m)	5 x (1mx1m)	5 x (1mx1m)
Stand height	70 cm	55 cm	65 cm	45 cm	85 cm
Exposition	W	E	E	NE	E
Slope	45%	55%	65%	25-30%	30-35%
Fallow age	7 years	6 years	3 years	15 years	10 years

a: Transect length/ dimension

b: only soil and mycorrhiza samples were taken along a transect line of 20m

3. Field measurements and data collection

The measurements and data collection had different purposes for the creation of results and will be summarized here briefly before the methodology is presented in greater detail.

1. Preliminary measurements: Determination of diameter size range for the fallow population of from 1 to 10 years in age, to identify sampling range for biomass harvest
2. Population characteristics measurement
3. Biomass harvest of above- and belowground components of 57 *Trema* and 54 *Psiadia* trees and 25 plots of each of the species *Rubus* and *Imperata*. Together with diameter measurements and population characteristics, these data were used to establish regression models to predict biomass
4. Diameter measurements in a range of populations to which the newly established regressions were applied to calculate their biomass

3.1. Preliminary measurements

Determination of diameter size ranges in the population of *Trema* and *Psiadia* of 1 to 10 years in age in the region. This led to the establishment of the sampling range for the biomass harvest, assuring the coverage of all size classes. In greater detail: The measurements were done in fallows at the ages of 2, 4, 6, 8 and 10 years. A hundred trees were measured randomly within a field, including some of the smallest and largest tree diameters. The data was plotted out and, according to the distribution frequency, the 50 trees to be harvested were distributed proportionally within 10 mm diameter classes.

3.2. Population characteristic measurements: Stem diameter, tree density, cross-sectional area

Stem diameters were measured for *Trema orientalis* at 130 cm or at breast height (=DBH), from the downhill side of the tree. For the shrub *Psiadia*, diameter was measured at 10 cm because branching typically occurred below 130 cm. For *Rubus*, diameters were measured at 5 cm, which was done after having slashed and removed the above-ground biomass. Two diameters (d=diameter in mm) were measured with a caliper at right angles for which the mean is reported: $d = (d1 + d2)/2$. For a few of the larger trees, a measuring tape was used to determine the circumference. Diameter measurements were used 1) if in combination with biomass harvest, to establish the diameter-biomass regressions; 2) to apply the regressions to each of the diameters measured per surface and calculate the standing biomass; and 3) to report the mean diameter of a population.

Density is defined as the number of individuals in a given unit or area or the reciprocal of the mean area of space per individual (Bonham, 1989). Density measurements require that individual plants be countable. This can be difficult for grasses. Density can still be estimated, however, if a standard individual is defined properly (Bonham, 1989). For *Imperata*, the shoots of which are connected by rhizomes, it is very difficult to determine a single individual. Our density refers therefore to the shoot number per unit surface, which was easy to determine.

Cross-sectional area and basal area: With the diameter and density information, the cross-sectional area or basal area of trees can be determined. The basal area of a tree is defined as the cross-sectional area of the stem, measured at breast height (130cm). It is derived from the tree diameter, measured by a caliper twice at a 90° angle (van Laar and

Akca, 1997). The cross-sectional area or basal area can be expressed per tree (*g*) or per hectare (*G*), where the cross-sectional areas of all trees on a surface of one hectare are summed up as m^2/ha (Philip, 1994). The formula for cross-sectional area (g) is expressed as $g = \pi * d^2/4$, where d = diameter in meters (Philip, 1994). Basal area is a useful measure by which to compare the stocking of two stands of the same species. In undisturbed, un-thinned forests or stands, it is a good measure of site potential (Philip, 1994). Given the foregoing definition, we report the basal area only for *Trema*, and use the term 'cross-sectional area' for *Psiadia* and *Rubus* because their stem diameter was measured at 10 cm and 5 cm above ground, respectively.

3.3. Above- and belowground biomass harvest

Biomass was harvested for individual trees in different size classes; diameter was then measured. The data obtained was used to establish the biomass-diameter regressions.

3.3.1. Trema orientalis and Psiadia altissima

Within each transect, 10 trees were selected for biomass harvest, covering the possible largest range of diameter classes within that stand. In addition to that, seven *Trema* trees and four *Psiadia* trees were harvested outside of the studied transects, representing the larger diameter trees that couldn't be found within the transects. For *Trema*, a total of 57 trees with a DBH range of 8 mm to 205 mm were harvested for above-ground biomass. From the 57 trees, 23 root systems were excavated. Out of the 23 root systems, 14 were divided into primary, secondary, and fine roots and weighed separately. For *Psiadia*, 54 trees were harvested for aboveground biomass, out of which 36 total root systems were excavated. From the 36 roots, 18 were divided into primary, secondary, and fine roots. The diameter range was between 6 mm and 120 mm.

Aboveground biomass harvest: The selected trees were cut at ground level. The biomass was separated into stem, branches, and leaves and weighed immediately in the field to determine fresh weight. Depending on the weight, suspended spring scales were used of either 20 kg (with 200 g precision) or 5 kg (50 gram precision) capacities.

Belowground biomass harvest—root excavation: Three out of the 10 trees harvested for aboveground biomass were selected within each transect for root excavation. They represented the small, medium, and large diameter classes within the transect. The excavation was accomplished by digging the soil away from roots by hand and with small sticks. In some locations, trenches were dug at safe distance from where the digging towards the root/shoot interface was undertaken. After excavation, the root system was wrapped in a fine mosquito net and dipped briefly in a nearby stream to remove superficial soil. A drawing was made of each of the 15 roots/species showing the morphology and arrangement of the respective root systems. The length of the primary roots was measured. The roots were separated into primary roots, all other coarse roots >2mm diameter (referred to later as 'secondary roots'), and fine roots < 2mm. The components were weighed separately and samples were taken for each component.

3.3.2. Rubus moluccanus

The five plots of 3 m x 3 m (9 m^2) per transect were cut at ca 8 cm above ground level and the entire biomass harvested. The harvested aboveground biomass was divided into *Rubus* and 'other species.' For *Rubus*, leafy and woody biomass was weighed separately and a sample taken for analysis. The other species were inventoried and weighed only if they contributed substantially to the biomass of the plot. Fresh weight was determined and woody and leafy samples were taken. Three stumps per transect were randomly selected and their root systems were excavated. A drawing was made of each of the total of 15 excavated roots considering the orientation on the slope. Primary root lengths were measured. The root system was separated into four parts: root bulb, primary roots, other coarse roots >2mm diameter, and fine roots <2mm. Weighing and sampling was done for each of the components. Because surface litter was a very substantial component in this fallow system, we collected the material from the entire plot surface that was easily removable from the floor and not contaminated with soil. A substantial part—I estimate one-third—was thus left behind. A composite litter sample from 10 sub-samples was taken from each plot. Number of plants, number of stems/plant, and diameter at 5 cm were evaluated after the plot was cleared from vegetation. Diameter was measured on six randomly selected plants per plot, thus covering 30 plants per transect.

3.3.3. Imperata cylindrica

Following a standard method for herbaceous biomass harvest, the plants within the quadrates were clipped 2 cm above ground level to avoid soil contamination (Bonham, 1989; Kent and Coker, 1992). *Imperata* was separated from the biomass of 'other species,' which consisted of *Pteridium aquilinium* and *Sticherus flagellaris* only, two fern species. Their biomass was determined and samples taken if their contribution to the total biomass was relevant. Shoot density (the number of shoots/m^2) was determined after the plot was harvested.

In each of the five transects, three *Imperata* root systems were excavated per shoot. Plant height and above- and belowground biomass were measured for all 15 shoots. Root biomass was separated into coarse roots > 2 mm and fine roots <2 mm, then weighed and sampled separately. A drawing was made of each shoot, showing the spatial arrangement and branching of the rhizomes. The diameter of primary roots at 5 cm from the root/shoot interface was measured. The rhizomes of *Imperata* most often connect to other shoots, making it very difficult to distinguish an individual plant. To evaluate the root system for one shoot, the rhizomes were excavated starting from the root/shoot interface following the roots through the various root ramifications until reaching the ramification where the next root piece was connected to another shoot. Root biomass and root length were measured per shoot, and results were computed together with shoot density to surface units (m^2 and ha).

3.4. Plant sampling

For each biomass component, a sample comprising at least five to eight sub-samples was taken. Sub-samples were randomly chosen from the different locations of the trees or plots to take into account within-tree and within-plot variability. Wood and root samples were < 300 g and leaf samples were < 100 g fresh weight. Spring scales of 1000 grams (10-gram precision) and 100 grams (1-gram precision) were used in the field and an electronic balance (precision to 0.1 gram) was used at the research site. Sample fresh weight was measured in the field. The samples were transported from the field to the research site the same day in plastic bags, where they were transferred immediately into paper bags. Samples were then air-dried in a dry, warm, and well-ventilated place until an oven, which was located in the capital, was made available. There the samples were dried at 50°C until no further weight loss was observed. Dry weight of samples was measured with an electronic balance.

3.5. Soil sampling

Soil sampling for nutrient analysis was done from each transect. Along the middle line of the transect of 20 m in length, 10 soil samples were taken every two meters with a soil auger, to a depth of 20 cm. The 10 auger cores were combined in a plastic bucket, rocks and organic debris were removed, and the remainder was mixed well. A sample of 500 grams was removed and transported in a plastic bag to the research site, where it was weighed and placed in a paper bag and dried in the open air for a minimum of two to three weeks. Dry soil was packaged into plastic bags and exported to CALS laboratories, Cornell University, Ithaca, NY. Three samples per transect were taken to determine bulk density for 0-5 cm and 5-10 cm in depth.

4. Analysis

4.1. Plant and soil nutrient analysis

The collected samples from one transect (between 5 and 10) were combined to form one sample per transect for analysis. Macro- and micronutrients in plants were analyzed through acid digestion with HNO_3, and ICP spectrometry. Nitrogen and carbon were identified through stable isotope analysis and mass spectrometry. Soil nutrients were analyzed with Morgan's extraction and ICP spectrometry and the total elemental analysis for N and C was done with stable isotope analysis and mass spectrometry.

4.2. Statistical analysis

The analysis of difference between the five vegetation categories of the studied parameters was done with an ANOVA Analysis with computer program SAS (release 8.02), using the adjusted Tukey-Kramer as a test of significance at a level of $p < 0.1$.

4.2.1. Regression analysis and allometric equation establishment

Regression analysis was done with the computer programs Minitab™ Statistical Software Release 13.1 and with JMP Version 3.2.2. (Copyright 1989 - 1997 SAS Institute Inc.). The objective was to establish regressions that estimate the biomass components (dependent variable y) through a predictor variable (x), which was diameter or some other biomass component. Relationships were tested for above- and belowground biomass components in kg dry weight per tree against diameter in millimeters. Prediction accuracy of the different models was evaluated using graphical and statistical methods. The data obtained through biomass harvest was first plotted out in a scatter plot, which served as a visual aid to help establish whether the relationship was linear or not. In case of nonlinearity, the standard allometric formula $y = \alpha x^{\beta}$ (Vann et al., 1998) was applied, as well as a set of transformations of either x or y or both, which included natural logarithm, square, square root, and binomial transformations as recommended by van Laar and Akca (1997).

Among all the transformation outputs, the four to five regressions with the highest coefficient of determination (R^2) and a high significance level of < 5% were tested for the fulfillment of the assumptions of normal distribution and homogeneity of the variance. This was done with histograms of the residuals, normal probability plots of the residuals, and residuals versus fitted values. Finally, the transformed regressions were plotted out to witness their linearity. The accuracy of the regressions was also checked by comparing predicted values with the field weights measured for the felled trees. The regression model that responded best to the fulfillment of the underlying assumptions and the comparison to measured values was selected as the best fit regression even if it didn't have the best R^2 and p-values compared with other regressions.

With the regression evaluation of *Trema* (8 mm to 205 mm DBH range), the problem of creating a negative intercept for the small-tree diameters was encountered. This problem can occur when the diameter range is large and small trees are included (Verwijst and Telenius, 1999). Finally the regression that seemed to fit best was found to be a ln(y) and ln(x) regression. But when compared with the observed data from the harvested trees, the regression output would show larger increases for the larger diameters than observed and for the smaller diameter the approximation was somewhat imprecise. I therefore decided to test the data with a segmented regression analysis (Hunt, 1982) by dividing the data into two groups, those with diameters <50 mm and those with diameters between 50 and 205 mm, proceeding as described above to find the best-fit regression. Both regressions were tested against the harvested data set, resulting in a more precise output with a maximum of 5% deviation for the segmented equations compared with up to 20% for the single equation. Average diameter for a 5-year-old fallow is smaller then 50 mm (see result section).

4.2.2. Application of allometric equations

The allometric equations were applied to a population at various ages and cycles. We had measured diameters of populations of *Trema* of from 1 to 10 years in age in the first cycle and of *Psiadia* of from 1 to 8 years in age, from the first to the fourth fallow cycle. Trees were measured within three transects of 2 m x 20 m (for a total area of 120 m^2). The equations were applied to each of the measured trees. The individually calculated biomass was then summed up to get the biomass/area and then computed to biomass in kg/ha for each of the biomass components. When transformations were used, the biomass parameters were converted back to arithmetic units to make them comparable and to present them in commonly used units.

RESULTS

1. Allometric regression model establishment for biomass estimation

In order to estimate the biomass production of a fallow plot, allometric regression models were developed that allow the use of easily measurable parameters to predict biomass components such as leafy, stem, and branch biomass as well as primary, secondary, and fine-root biomass. Sixty-six regression models for *Trema orientalis, Psiadia altissima, Rubus moluccanus*, and *Imperata cylindrica* are reported in Table 16. Best-fit regressions for the four species varied in form. For *Trema*, a segmented approach resulted in a natural log transformation of y for the smaller diameters (< = 50mm), and in linear regressions for the larger diameter (> 50-205mm). For *Psiadia altissima* a natural log transformation of y and x for all the parameters yielded the best results. For *Rubus* and *Imperata*, for which biomass was estimated through other biomass components, a square and x and y transformation suited the *Rubus* data best and linear regressions were adopted for the *Imperata* data. If not otherwise mentioned, p-values were 0.00 for most regressions. An example of a scatter plot and a regression corresponding to one of the parameters for each species is shown in Appendix 3.

1.1. *Trema orientalis*

The strength of biomass predictability was slightly lower with the equations for diameters < 50 mm than for diameters > 50 mm. For the smaller-diameter group, regressions for wood, aboveground, total root, and total biomass yielded high accuracy with $r^2 > 0.79$, but obtained poorer precision for leafy biomass and fine roots with r^2=0.327 and r^2=0.365 respectively. For the larger diameter range, the R^2's were highest for the parameters > 0.9, except for branches (r^2=0.862), leaves (r^2=0.79), secondary roots (r^2=0.887), and fine roots (r^2=0.623).

Table 16: Allometric equations for biomass estimation for four fallow species (r2: coefficient of determination, p: level of significance, SEE (β): Standart error of slope, n: number of data pairs, more information in legend)

Species	x	y	Equation	α	β	r^2	p	SEE(β)	n
Trema orientalis									
	Diameter < 50 mm								
		Leaves	$\ln(y) = \alpha + \beta x$	2.22	0.069	0.33	0.001	0.0192	29
		Branches	$\ln(y) = \alpha + \beta x$	1.85	0.085	0.67	0.000	0.0115	29
		Stem	$\ln(y) = \alpha + \beta x$	3.22	0.102	0.83	0.000	0.0091	29
		Wood	$\ln(y) = \alpha + \beta x$	3.53	0.097	0.84	0.000	0.0081	29
		Above-ground biomass	$\ln(y) = \alpha + \beta x$	4.15	0.085	0.93	0.000	0.0044	29
		Primary roots	$\ln(y) = \alpha + \beta x$	2.583	0.072	0.71	0.035	0.0233	6
		Secondary roots	$\ln(y) = \alpha + \beta x$	0.825	0.104	0.95	0.000	0.0119	6
		Fine roots	$\ln(y) = \alpha + \beta x$	-2.163	0.072	0.37	0.204	0.0475	6
		Total roots	$\ln(y) = \alpha + \beta x$	3.274	0.063	0.79	0.000	0.0101	12
		Total biomass	$\ln(y) = \alpha + \beta x$	4.55	0.078	0.95	0.000	0.0054	12
	Diameter 50-205 mm								
		Leaves	$y = \alpha + \beta x$	-1858	38	0.78	0.000	4.66	21
		Branches	$y = \alpha + \beta x$	-4051	78	0.86	0.000	7.16	21
		Stem	$y = \alpha + \beta x$	-15671	322	0.98	0.000	10.51	21
		Wood	$y = \alpha + \beta x$	-19900	400	0.98	0.000	13.2	21
		Above-ground biomass	$y = \alpha + \beta x$	-21800	438	0.98	0.000	15.46	21
		Primary roots	$y = \alpha + \beta x$	-1591	36.7	0.93	0.000	4.19	8
		Secondary roots	$y = \alpha + \beta x$	-1391	29.6	0.89	0.000	4.33	8
		Fine roots	$y = \alpha + \beta x$	-3.21	0.081	0.62	0.019	0.026	8
		Total roots	$y = \alpha + \beta x$	-2921	65.5	0.93	0.000	6.148	11
		Total biomass	$y = \alpha + \beta x$	-17200	377	0.96	0.000	25.26	11
Psiadia altissima									
	Diameter								
		Leaves	$\ln(y) = \alpha + \beta \ln(x)$	-2.8	2.07	0.86	0.000	0.1137	54
		Branches	$\ln(y) = \alpha + \beta \ln(x)$	-3.29	2.62	0.89	0.000	0.1315	54
		Stem	$\ln(y) = \alpha + \beta \ln(x)$	-1.08	2.16	0.94	0.000	0.0742	54
		Wood	$\ln(y) = \alpha + \beta \ln(x)$	-1.62	2.45	0.96	0.000	0.071	54
		Above-ground biomass	$\ln(y) = \alpha + \beta \ln(x)$	-1.28	2.38	0.96	0.000	0.0633	54
		Primary roots	$\ln(y) = \alpha + \beta \ln(x)$	-4.17	2.48	0.90	0.000	0.2065	18
		Secondary roots	$\ln(y) = \alpha + \beta \ln(x)$	-4.89	2.69	0.89	0.000	0.2396	18
		Fine roots	$\ln(y) = \alpha + \beta \ln(x)$	-4.39	1.55	0.69	0.000	0.2624	18
		Total roots	$\ln(y) = \alpha + \beta \ln(x)$	-3.72	2.59	0.95	0.000	0.1024	36
		Total biomass	$\ln(y) = \alpha + \beta \ln(x)$	-1.33	2.44	0.96	0.000	0.0875	36
Rubus moluccenus									
	Above-ground biomass								
		Leaf	$y^2 = \alpha + \beta x^2$	2006383	0.0242	0.65	0.000	0.0049	15
		Wood	$y^2 = \alpha + \beta x^2$	-6413972	0.708	0.99	0.000	0.0215	15
		Bulb	$y^2 = \alpha + \beta x^2$	-6095814	0.069	0.82	0.000	0.0089	15
		Primary root	$y^2 = \alpha + \beta x^2$	-24692759	0.205	0.73	0.000	0.0342	15
		Secondary root	$y^2 = \alpha + \beta x^2$	-781398	0.01446	0.49	0.004	0.0041	15
		Fine root	$y^2 = \alpha + \beta x^2$	-43500	0.00049	0.35	0.020	0.0002	15
		Total root	$y^2 = \alpha + \beta x^2$	-75897811	0.724	0.79	0.000	0.1030	15
		Total biomass	$y^2 = \alpha + \beta x^2$	-210000000	3.45	0.92	0.000	0.2761	15
	Root bulb								
		Leaf	$y^2 = \alpha + \beta x^2$	4797314	0.295	0.56	0.001	0.0724	15
		Wood	$y^2 = \alpha + \beta x^2$	78078047	8.38	0.80	0.000	1.1502	15
		Above ground biomass	$y^2 = \alpha + \beta x^2$	119000000	11.9	0.82	0.000	1.5442	15
		Primary root	$\sqrt{y} = \alpha + \beta x$	20.8	0.0129	0.88	0.000	0.0013	15
		Secondary root	$\sqrt{y} = \alpha + \beta x$	16.6	0.00617	0.71	0.000	0.0011	15
		Fine root	$y = \alpha + \beta x2$	122	0.000008	0.41	0.010	0.0000	15
		Total root biomass	$y = \alpha + \beta x$	-1278	3.35	0.93	0.000	0.2479	15
		Total biomass	$y^2 = \alpha + \beta x^2$	144600000	45.68	0.94	0.000	3.2020	15
	Wood								
		Leaf	$y^2 = \alpha + \beta x^2$	2759456	0.0312	0.55	0.002	0.0078	15
		Above ground biomass	$y = \alpha + \beta x$	1035	1.13	0.98	0.000	0.0429	15
		Bulb	$y^2 = \alpha + \beta x^2$	-5196132	0.0959	0.80	0.000	0.0132	15
		Primary root	$y^2 = \alpha + \beta x^2$	-20282742	0.274	0.67	0.000	0.0535	15
		Secondary root	$y^2 = \alpha + \beta x^2$	-556926	0.01988	0.47	0.005	0.0058	15
		Fine root	$y^2 = \alpha + \beta x^2$	-37500	0.00068	0.34	0.021	0.0003	15
		Total root biomass	$y^2 = \alpha + \beta x^2$	-62986456	0.986	0.75	0.000	0.1597	15
		Total biomass	$y^2 = \alpha + \beta x^2$	158000000	4.748	0.89	0.000	0.4678	15

Table 16: (Continued)

Species	x	y	Equation	α	β	r^2	p	SEE(β)	n
Imperata cylindrica									
	Leaves (dw)								
		Roots	$y = \alpha + \beta x$	-1,263	0.548	0,85	0,00	0.0197	25
		Total biomass	$y = \alpha + \beta x$	-1,516	1.52	0.98	0.00	0.0482	25
	Roots (dw)								
		Leaves	$y = \alpha + \beta x$	86.1	1.55	0.85	0.00	0.1126	25
		Total biomass	$y = \alpha + \beta x$	84.6	2.55	0.94	0.00	0.1362	25
		Primary roots	$y = \alpha + \beta x$	-5.63	0.942	0.99	0.00	0.0347	25
		Fine roots	$y = \alpha + \beta x$	5.59	0.0578	0.50	0.00	0.0122	25
	Shoot density (shoots/m2)								
		Leaves	$y = \alpha + \beta x$	365.7	2,462	0.41	0.001	0.6111	25
		Roots	$y = \alpha + \beta x$	176.9	1.639	0.52	0.00	0.3298	25
		Total biomass	$y = \alpha + \beta x$	542.5	4.1	0.47	0.00	0.9109	25
	Leaves (fw)								
		Leaves	$y = \alpha + \beta x$	10.5	5.03	0.89	0.00	0.0375	25
		Roots	$y = \alpha + \beta x$	-9.877	0.2886	0.83	0.00	0.0276	25
		Total biomass	$y = \alpha + \beta x$	0.6231	0.791	0.90	0.00	0.0559	25

Legend: *Trema orientalis*: Biomass in kg/tree dw (y) and stem diameter at 130cm in mm (x); *Psiadia altissima*: Biomass in kg/tree dw (y) and stem diameter at 10 cm in mm (x); *Rubus moluccanus*: Biomass in kg/ha dw for x and y; *Imperata cylindrica*: Biomass in g/m^2 for x and y.

1.2. *Psiadia altissima*

Diameter measured at 10 cm in stem height is a very good indicator of biomass. Best estimates were obtained for total aboveground biomass (r^2=0.964) > wood and total biomass (both r^2=0.958) > total root biomass (r^2=0.949) > stem (r^2=0.944) > primary root (r^2= 0.90) > branches (r^2=0.89) > secondary roots (r^2=0.888) > leaves (r^2=0.864) > fine roots (r^2=0.686).

1.3. *Rubus moluccanus*

For *Rubus moluccanus,* unlike the other woody species studied, diameter (at 5 cm) was not strongly related to biomass (r^2=0.23, p=0.07 for the prediction of total biomass), nor was plants per hectare (r^2=0.07; p=0.36) or the number of stems/plant (r^2=0.15, p=0.15). Best but still an unsatisfactory predictor among the more easily measurable variables was cross-sectional area (r^2=0.51, p=0.02). Hence, in order to estimate biomass components, some level of biomass harvest needed to be undertaken. All the combinations for biomass component prediction by other biomass components was undertaken and the best-performing predictors were identified as total aboveground biomass (AGB), wood, and root bulb. Among the three variables, total AGB was the best predictor for leaves (r^2=0.65) and wood (r^2=0.988), while bulb performed best for the belowground biomass: Total root biomass (r^2=0.934), primary roots (r^2=0.876), secondary roots (r^2=0.712), and fine roots (r^2=0.408, p=0.01), but both parameters had high predictability for the other components as well. Wood showed lower prediction accuracy than AGB and bulb for most of the parameters. The regressions for these three predictors are reported in Table 16.

The selection of the predictor has practical implications, especially considering the spiny habit of *Rubus*, which forms an impenetrably thick stand. The handling of *Rubus* biomass is delicate and can easily cause injuries due to its sharp spines. Thus the easiest way to handle a stand of *Rubus* is to slash it at ground level. Direct weighing of the total aboveground biomass is certainly an easier option than adding the additional step of separating the woody from the leafy biomass. But this still involves dealing with a large amount of spiny biomass. The most convenient and efficient option seems to be to slash the above ground biomass, remove it from the plot, and then dig out the root bulbs that lie just underneath the surface. The root bulb biomass can be used to predict all the other biomass components with satisfactory accuracy.

1.4. *Imperata cylindrica*

The interest in regression analysis for *Imperata* biomass was to establish the relationship between above- and belowground biomass, and to discover whether shoot density, an easily determinable parameter, can be used to predict biomass. Unfortunately, the latter did not yield satisfactory results with coefficients of determination between 0.414 and 0.518 and with p=0.001 and p=0.00 respectively. For all the reported regressions in this section, p-values were 0.0 and will therefore not be mentioned hereafter. On the other hand, the prediction of total biomass and root biomass through leaf dry weight biomass were highly precise (r^2=0.978 and r^2= 0.849 respectively). The fine roots (<2mm) weighed 7.8% (+/- 0.6 SE, n=15) of the total root biomass. Their biomass estimation through total biomass was weak, with r^2=0.496.

Considering the practical implications, regressions with fresh weight leaf biomass were established, which represents the easiest parameter to determine directly in the field. The results were satisfactory with r^2 = 0.826 for roots and r^2=0.897 for total biomass. Moisture content in fresh leaves was 48.7% (+/-0.88 SE, n=25). This falls within the range of dry matter contents for *Imperata cylindrica*, between 35% and 55% measured by Hartemink (2001) in the humid lowlands of Papua New Guinea. The most useful outcome from this regression analysis is therefore that accurate estimates for belowground and total biomass can be gained through dry or fresh weight leaf biomass. The latter may be the most useful regression in cases where the dry matter content is relatively stable.

2. Population characteristics

The following population characteristics are reported below, depending on the species: mean population diameter, plant density (plants/ha), basal area or cross-sectional area, and diameter distribution.

2.1. *Trema orientalis*

2.1.1. Mean population diameter, stem density, and basal area from 1 to 10 years in age

The results on mean population diameter (at breast height: dbh or at 130 cm above ground level), tree density, and basal area from the first to the tenth year are given in Table 17. The measured observed values from the field are reported, as well as the fitted values, which represent the output of a regression established with the observed values. These regressions were established to create values for the missing years that could not be sampled and to alleviate the variability between the years of the observed data. This is of interest because our measurements couldn't be done in a chronological sequence; they were instead collected in different populations for the various ages. The best-fit regressions are reported in Appendix 4.

Table 17: Population characteristics for *Trema orientalis* from 1 to 10 years in age for observed values and fitted values

Observed values							Fitted values		
Age years	DBH mm	SE	Density trees/ha	SE	Basal area m^2/ha	SE	DBH mm	Density trees/ha	Basal area m^2/ha
1	6.5	0.10	12167	870	0.42	0.01	15.82	16681	0.43
2	20.7	0.47	11292	1258	4.71	0.52	15.45	13684	3.72
3	32.5	1.13	7917	1200	6.85	0.54	18.92	11226	7.01
4	22.7	2.52	13200	2019	6.92	1.11	26.23	9210	10.3
5	35.2	3.20	11369	1655	14.05	2.04	37.38	7555	13.59
6							52.37	6198	16.88
7	64.4	4.30	6139	675	24.05	2.64	71.2	5085	20.17
8							93.87	4171	23.46
9							120.38	3422	26.75
10	154.0	10.66	2407	485	28.38	4.37	150.73	2807	30.04

The observed average population diameter was 6.5 mm at year 1 and reached 154 mm at the age of 10. Until the age of 5 years, diameters were still at 35 mm but increased rapidly after that. Tree density data for the measured plots didn't show very clear trends for the first 5 years, where maximum tree density was observed with 13,200 stems/ha at the age of 4 years. The fitted values on the other hand showed a maximum density of ca

16,700 trees/ha at year 1 followed by an exponential decrease in stem density down to ca 11,200 at 3 years, to 7,550 trees/ha at 5 years, eventually reaching 2,800 trees/ha in year 10. The behavior of the curve of the fitted values is congruent with the observation of density of secondary trees after forest clearance in Ghana by Swaine and Hall (1983). There the density of trees increased rapidly to reach a maximum at 1 year with ca 23,000 secondary trees/ha. After that there was an exponential decline in density, falling to ca 14,000 at 3 years and 6,000 trees/ha at 5 years. The observed values fluctuated because of plot characteristics and variability. On the other side, the variability was evened out with the observed basal area, a parameter that integrates stem density and diameters. Basal area showed a linear yearly increase of 3.29 m^2/ha up to 10 years (r^2=0.954, $p<0.001$). Linear growth of basal area was also observed by Uhl (1987), who studied secondary regeneration following a farm plot abandonment near San Carlos de Rio Negro, Venezuela. Basal area was 0.5 m^2/ha at year 1, 4.0 m^2/ha in the third year, and 7.0 m^2/ha in the fifth year representing only ca one-half of our reported data. Linear increase in cross-sectional area at 10 cm was also observed for *Psiadia* (see next section).

2.1.2. Diameter distribution

Dbh diameter distribution in classes of 10 mm from 1 to 10 years is shown in Figure 17. The Table is reported in Appendix 5. These results are typical for a pioneer species. Germination was abundant in the first year after plot abandonment under full sunlight, a finding that is congruent with Cao et al. (2000) from China. All diameters were smaller than 10 mm. From age 2 to age 5, populations occupied the same diameter classes with maximum diameters < 70 mm. At age 7 the population was spread over a wide range of diameters with the largest diameters < 120mm. The picture changed at the age of 10 years, when the diameter range was within a relatively narrow band between 120 mm and 170 mm. This indicates that, once the canopy is closed, *Trema* no longer germinates

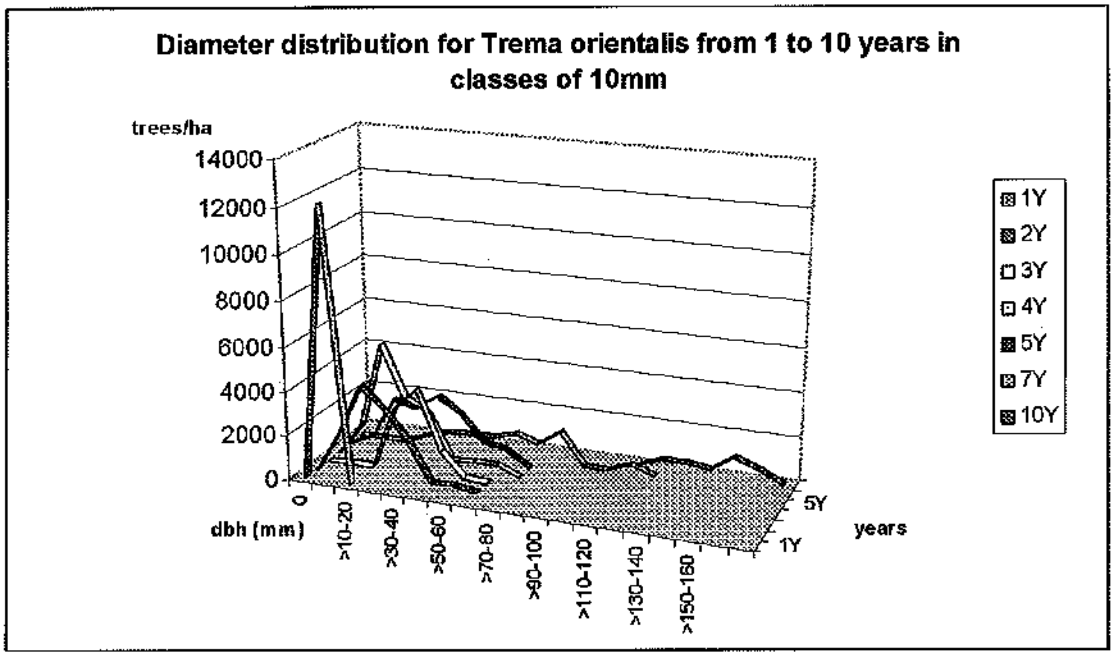


Figure 17: Diameter distribution for *Trema orientalis* from 1 to 10 years of age in classes of 10 mm

in partial or full shade (Chang, 1996), so the small diameters are missing completely. With the decrease in density and dieback, *Trema* gives way to other regenerating secondary and primary forest trees (Swaine and Hall, 1983; Vazquez-Yanes, 1998).

2.2. *Psiadia altissima*

2.2.1. Mean population diameter, stem density, and cross-sectional area from 1 to 8 years in the first to fourth cycles following deforestation

Change of diameter, stem density, and basal area over the first 8 years of fallow growth for the first to fourth cycles (C1 to C4) following deforestation is presented in Table 18 and further represented in Figures 18-21. Linear regressions were established for each cycle, estimating the yearly increase for the parameters, resulting in high precision (Appendix 6). We were not able to find plots for all the years in all four cycles. The missing years in Table 18 are therefore added as fitted values by applying the regressions from Appendix 6. Each parameter is discussed in greater detail below.

Table 18: Population characteristics for *Psiadia altissima* (4 cycles, ages 1 to 8 years)

CYCLES	Age Years	Diameter mm	SE	Density trees/ha	SE	CSA m2/ha	SE
CYCLE 1	1	9.5	0.10	27500	804	2.23	0.07
	2	17.6	0.19	30083	1446	8.19	0.39
	3	23.3	0.11	23167	722	11.11	0.35
	4	26.0	0.21	20833	1083	12.73	0.66
fitted *	**5**	**28.9**		**19813**		**13.78**	
	6	31.2	0.94	18750	948	14.32	0.72
fitted	**7**	**37.1**		**15533**		**18.29**	
fitted	**8**	**41.2**		**13393**		**20.54**	
CYCLE 2	1	9.3	0.08	25000	289	1.95	0.02
	2	15.3	0.25	19583	712	5.75	0.21
	3	22.1	0.64	19667	795	8.88	0.36
	4	22.1	0.74	18833	983	9.35	0.49
fitted	**5**	**27.2**		**17978**		**12.91**	
	6	29.9	0.90	17250	1466	15.39	1.31
	7	35.9	1.18	14792	1559	18.14	1.91
fitted	**8**	**39.5**		**14015**		**20.61**	
CYCLE 3	1	9.1	0.06	21750	1588	1.58	0.12
	2	14.1	0.24	17333	1083	2.99	0.19
	3	18.4	0.24	16417	928	5.07	0.29
	4	21.7	0.89	13167	741	7.37	0.41
fitted	**5**	**24.8**		**14432**		**8.37**	
fitted	**6**	**28.5**		**13182**		**10.07**	
	7	32.9	0.60	13417	2222	12.40	2.05
	8	39.9	1.20	10750	925	15.22	1.31
CYCLE 4	1	8.6	0.16	17250	878	1.14	0.06
	2	13.9	0.38	15567	3196	2.54	0.52
	3	15.9	0.54	13917	583	3.04	0.13
	4	19.0	0.60	11750	1000	3.71	0.32
fitted	**5**	**19.5**		**12751**		**4.54**	
	6	21.2	0.64	12500	1125	4.44	0.40
fitted	**7**	**24.0**		**11037**		**6.15**	
	8	27.0	0.41	10667	804	7.52	0.57

* fitted values: application of linear regression (Appendix 6) for the missing years.
All other values: observed values are means and 1 standard error of 3 transects (2mx20m)
CSA: Cross-sectional area

2.2.2. Diameter evolution of population

Mean diameter development for the population (Figure 18) was similar for the first three cycles, with yearly increases of between 3.7mm and 4.1mm. At the age of 8 years, the average diameter was between 39.5mm and 41.2 mm for the three cycles. The plants in C4 showed remarkably slower diameter growth compared with those in the first three cycles. Yearly increase was only 2.25 mm, resulting in a mean population diameter of 27 mm at 8 years.

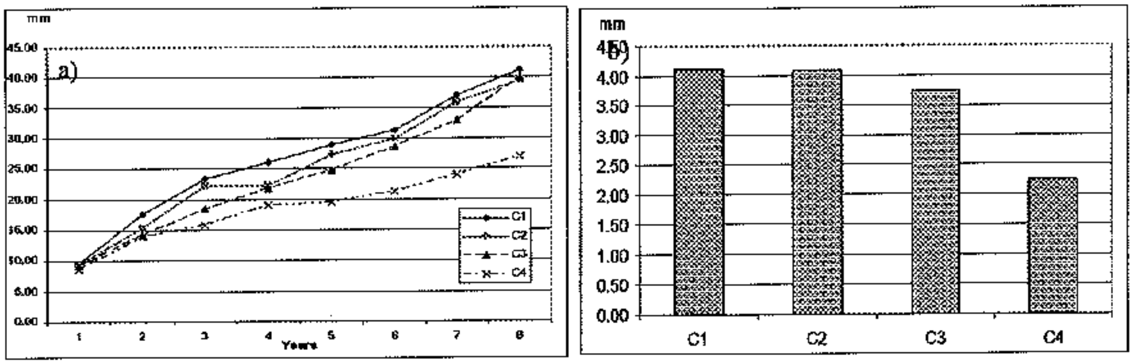


Figure 18: a) Mean population diameter (mm) evolution from 1 to 8 years for four cycles and b) yearly increase of mean population diameter for four cycles C1-C4 (the data are linear regression slopes, see Appendix 6)

2.2.3. Stem density

Initial stem density was highest in C1 and was lower for each consecutive cycle (Figure 19). At the age of 1 year, 27,500 trees/ha were present in C1, 25,000 trees/ha in C2, 21,750 trees/ha in C3, and 17,250 trees/ha in C4. The natural thinning, or yearly decrease, was highest in C1 (-2,140 trees/ha) and lowest in C4 (-857 trees/ha). Despite the higher rate of natural thinning in the early cycles, stem frequency at the age of 6 was still highest in C1 and lowest in C4. At the age of 8, stem density for the first two cycles and for the third and fourth cycles were similar.

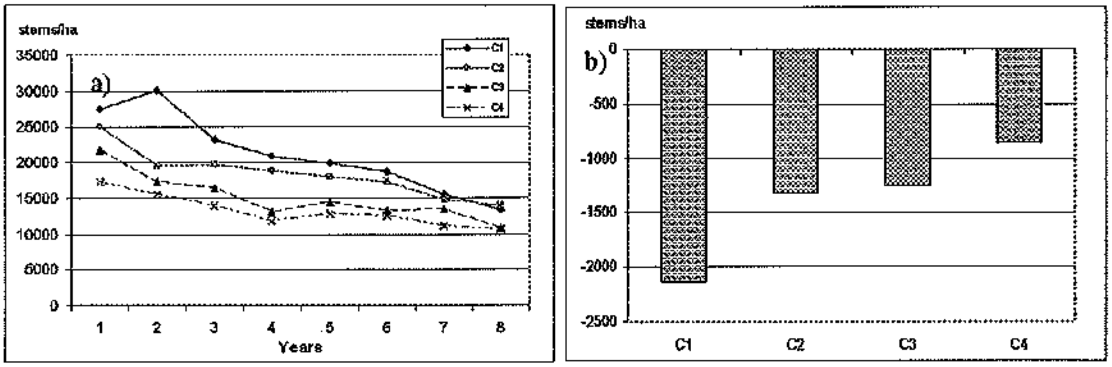


Figure 19: a) Tree density (stems/ha) from 1 to 8 years for four cycles and b) yearly decrease of stem density for four cycles (the data are linear regression slopes, see Appendix 6)

2.2.4. Cross-sectional area

Cross-sectional area (CSA) evolution for C1 and C2 was similar. At the age of 8 years the CSA was 20.5 m^2/ha in C1 and 20.6 m^2/ha in C2, with a yearly increase of 2.25 m^2/ha and 2.57 m^2/ha, respectively. This slightly higher yearly increase in C2 compared with the C1 increase, as shown in Figure 20, results from slower growth in the first years that was compensated for later with an accelerated increase, thus giving the regression of C2 a slightly steeper slope than the one for C1. A noticeably slower augmentation of CSA was observed for C3 and C4. In C3 the yearly increase was 1.71 m^2/ha and CSA at the age of 8 was 15.22 m^2/ha. In C4, CSA grew by only 0.81 m^2/ha a year and reached 7.52 m^2/ha at the age of 8, which is half that of C3 and a third that of C1 and C2.

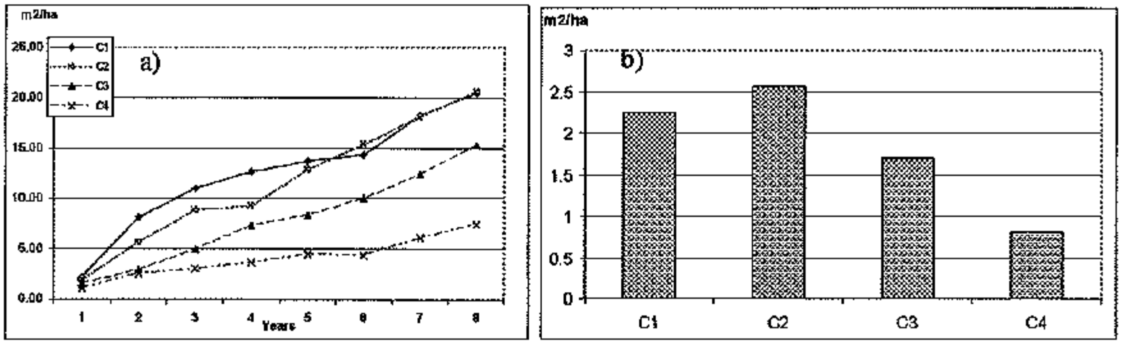


Figure 20 a) Cross-sectional area (m^2/ha) from 1 to 8 years for four cycles and b) yearly decrease of stem density for four cycles (the data are linear regression slopes, see Appendix 6)

2.2.5. Diameter distribution

Diameter distribution for the four fallow cycles and from 1 to 8 years of age in diameter classes of 10 mm is shown in Figure 21. The diameter distribution in classes of 5 mm is reported in Annex 8.

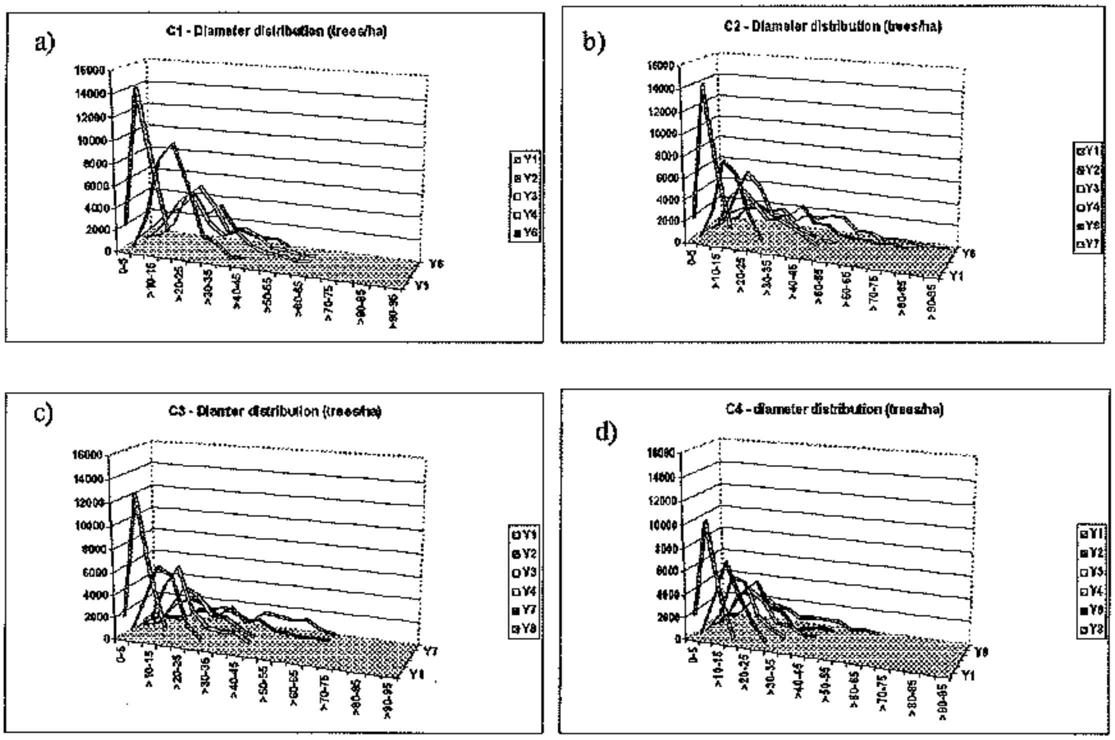


Figure 21: Diameter distribution of four cycles for *Psiadia* from 1 to 8 years old; a) cycle one, b) cycle two, c) cycle three and d) cycle four.

In the first three years, diameter classes were similar for all cycles; the differences among the cycles lay mostly in the number of trees per diameter class. At age 4, C1 had the highest proportion of larger diameters. The percentage of trees with a diameter above 30 mm was 27%, whereas it reached only 20% in C2, 17% in C3, and 8.5% in C4. Direct comparisons after the age of four are not possible due to missing information for certain years in the various cycles. Nevertheless, the tendency seems to continue that the proportion of larger diameter classes increased more quickly in the earlier cycles, especially in C2.

2.3. *Rubus moluccanus*

Mean population stem diameter (at 5 cm), plant density (plants/ha), number of stems per plant, and cross-sectional area at 5 cm (m^2/ha) for five fallow transects of various ages are presented in Table 19.

Table 19: Population characteristics for *Rubus moluccanus*: Stem diameter at 5 cm, plant density, stems/plant, and cross-sectional area at 5 cm for the five fallow transects of ages varying from 4 to 10 years.

Age Years	Diameter[a] cm	SE	Density plants/ha	SE	Stems/plant	SE	CSA[b] m^2/ha	SE
4	1.51*	0.076	26444	2205	2.57	0.267	12.49	0.85
4	1.53	0.073	23775	1030	2.60	0.172	13.96	1.74
5	1.51	0.151	35330	4254	2.63	0.249	20.77	3.74
6	1.86	0.056	35111	2061	1.87	0.170	18.43	1.79
10	1.45	0.118	28219	2293	2.80	0.111	14.19	2.62
GM	1.59**	0.07	29776	2333	2.49	0.16	15.97	1.56

a: Stem diameter at 5cm; b: CSA: Cross sectional area at 5 cm

* Mean and SE of 5 plots; ** Mean and SE of 25 plots

The mean stem diameters varied little and were between 1.45 cm and 1.86 cm at 5 cm above ground level. Plant density varied between 23,775 and 35,330 plants/ha. The number of stems per plant was pretty uniform, with an average of 2.49. The cross-sectional area at 5 cm showed values of between 12.49 and 20.77 m^2/ha. Stem diameter seemed unrelated to basal area and stem density but showed an inverse affinity with number of stems/plant. These results indicate no age-related trends. This confirms the weak correlation of diameter with biomass that was found when looking for parameters for allometric equation establishment in Section 1 of this chapter. A more exhaustive sampling would be necessary to better understand the population dynamics of this species. It seems, however, that once a *Rubus* stand has closed its canopy, the characteristics reported here do not change much.

2.4. *Imperata cylindrica*

For *Imperata cylindrica* we counted the number of shoots in the harvested plots. The results of shoot density (shoots/ha) for the five transects is reported in Table 20. Shoot density varied between ca 237,000 and 1,168,000 shoots/ha with an average of 765,649 (SE = 154,053), figures that didn't seem to relate to age. As seen under Section 1 of this chapter, we already noted that shoot density is not well related to biomass.

Table 20: Shoot density (shoots/ha) of *Imperata cylindrica* in five fallow transects of various ages from 3 to 15 years.

Age Years	Shoot density shoots/ha	SE
3	873432	108574
6	1168020	119969
7	236794	21781
10	878106	59126
15	671892	46880
Mean	765649**	154053

* Mean and SE of 5 plots; ** Mean and SE of 25 plots

3. Root characteristics

3.1. *Trema orientalis*

The *Trema orientalis* root system is characterized by a taproot and by primary 'runner' roots that grow as long, thin root branches several meters away from the tree, close to the surface or exploring the soil to various depths. The taproots branch off at their ends into a few thin roots that continue to grow deeper into the soil. We measured taproot depth where the branching occurred as between 26 cm and 98 cm deep. In general it was very difficult with our excavation method to accurately estimate the total rooting depth or the radius that the root system explores.

3.2. *Psiadia altissima*

The *Psiadia* root system is quite distinct from *Trema*'s. It is characterized by a rootstock that thickens underneath the surface, from which primary roots grow. Most of the roots are arranged around the rootstock as dense root mass. There is no taproot but rather a dense, prolific root growth in a 20 to 40 cm radius around the rootstocks. Only a few primary or secondary roots extend as 'runners' for 2 to 4 m close to the soil surface. We counted, on average, 12.9 primary roots departing from the rootstocks (ranging between 2 and 24 roots, n=15). The primary root length varied from 71 cm for the smallest tree to 18.32 m for the largest tree. The overall mean was 10.6 meters. Root length is positively related to stem diameter and root biomass ($r^2=0.825$ and $r^2=0.815$ respectively with p=0.00). Most of the root mass extends to a depth of between 20 and 30 cm, while larger trees are as deep as 50 cm.

3.3. *Rubus moluccanus*

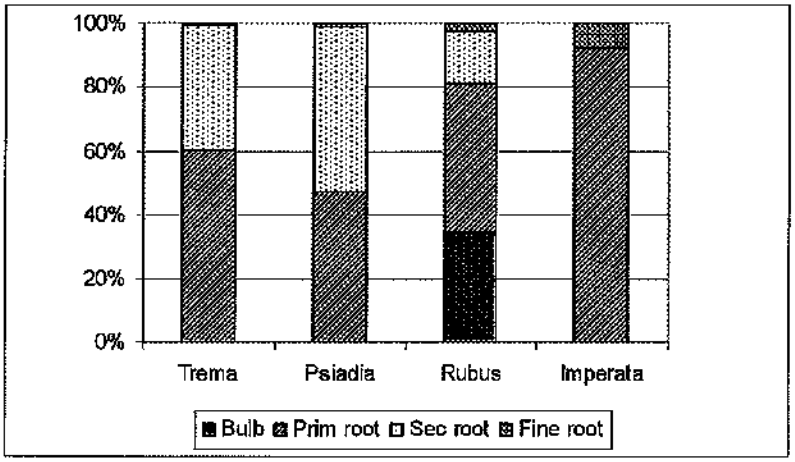
The *Rubus* root system has a root bulb that lies just underneath the surface and consists of harder wood than the stems and primary roots. The shoots depart from the bulb as well as, on average, 10 primary roots (SE=0.9, n=15), with a total length of 7.77 m (SE=0.78). Root diameter at 5 cm was 1.63 cm (SE=0.14). The root system spreads 2 to 3 meters in radius. Rooting depth is limited to the first 20 to 30 cm within the profile. We observed the root orientations on slopes for the 15 excavated root systems and noted that on the gentler slopes (< 30%) the root system was evenly spread around the root bulb, or growing slightly downhill. In contrast, on steeper slopes (35%- 45%), roots were anchored in the upper slope and only a few were growing downhill.

3.4. *Imperata cylindrica*

Imperata's roots were found within the first 20 cm of soil depth. Root diameter at 5 cm from shoot/root interface was 3.01 mm (SE=0.18, n=15). Each shoot had 4.8 rhizome branches (SE=0.31, n=15). The length of rhizomes per shoot was 111 cm (SE=9.35, n=15), which sums up to 850 km of superficial roots per hectare.

3.5. Comparison of root systems of the four species

The four species under discussion have very distinct root systems. The biomass distribution of primary roots, secondary roots (which are all other coarse roots > 2mm), fine roots, and bulb in percentages for all four species is shown in Figure 22. The biomass data are presented in the next section. Primary roots in *Trema* make up 61% of the weight, whereas in *Psiadia* the primary roots are 48% of the weight with secondary roots 51%. *Rubus*'s root weight is partitioned into 34% bulb, 47% primary roots, and 16% secondary roots. In *Imperata*, the bulk of the root mass is 92% in fleshy rhizomes. Fine roots make up a small portion of the total root biomass: for *Trema* it is 0.3%, for *Psiadia* 1%, for *Rubus* 3%, and for *Imperata*, 8%.



Figures 22: Biomass distribution of primary roots, secondary roots (all other coarse roots > 2mm diameter), fine roots (<2mm), and bulb in % for all four species.

4. Above- and belowground biomass production

Biomass is presented in reference to the following components: leaves, branches, stem, wood (that comprises stem and branch biomass), primary roots, secondary roots, fine roots, and additionally the root bulb for *Rubus*. The term 'secondary root' is used for all coarse roots that aren't primary roots and that are >2mm in diameter, to be distinguished from the fine roots (<2mm). I also report total aboveground biomass (leaf and wood), total roots (primary roots, secondary roots, fine roots), and total biomass (total root and aboveground biomass). Biomass data come from the measured biomass harvest for *Rubus* and *Imperata* and from the application of the established regressions (under Section 1 in this chapter) on measured plots for *Trema* and *Psiadia*.

4.1. *Trema orientalis*

The biomass production of *Trema orientalis* is presented in Table 21 for observed values (application of regressions on measured plots of from 1 to 8 years in age, C1 to C4) and for fitted values that derived from a regression analysis for yearly increase on the observed values. The regression equations for yearly increase are reported in Appendix 4. The best-fit regressions were of binomial form and yielded very high coefficients of determination. They were all $r^2 > 0.98$ with $p<0.0003$, except for the fine roots with $r^2=0.83$, $p=0.0043$. Because regressions average out the variability that occurred among the plots sampled, further discussion is based on fitted values.

The growth curves of *Trema* biomass components from ages 1 to 10 are still in the exponential portion of the sigmoidal growth curve; biomass increase was therefore in the first years relatively slower compared with the later years in the decade. At the age of 3 years, total aboveground biomass was 8.5t/ha, increasing to 25.2 t/ha at the age of

Table 21: Trema orientalis biomass production (kg/ha) from 1 to 10 years in age a) above ground biomass, b) below ground biomass and total biomass and c) regression output for all biomass components and root/shoot ratio

a) Above ground biomass (AGB)

Observed values

Age years	Leaves	SE	Stem	SE	Branches kg/ha	SE	Wood	SE	ABG	SE
1	175	6	593	17	135	4	782	23	1338	41
2	552	61	3776	421	583	65	4444	495	5784	644
3	776	73	7189	965	963	109	8106	1038	9579	1084
4	825	167	6187	1349	959	207	7214	1559	8852	1807
5	2082	303	19320	2811	3030	441	22157	3224	24658	3588
7	5166	568	42456	4666	9115	1002	51662	5678	56692	6231
10	9317	225	77754	1938	18355	506	96160	2440	105273	2673

b) Below ground biomass and total biomass

Observed values

Age years	Prim roots	SE	Sec roots	SE	Fine roots kg/ha	SE	Tot roots	SE	Tot biomass	SE	Leaves %	Wood %	Roots %	Root/shoot Ratio
1	257	8	55	2	2.2	0.07	483	16	1905	60	12	54	34	0.36
2	913	102	456	51	8.0	0.89	1396	155	7837	873	9	70	22	0.24
3	1243	121	708	97	10.9	1.06	1793	155	11035	1155	7	76	17	0.19
4	1345	230	691	123	9.9	1.34	2090	368	11562	1973	8	71	21	0.24
5	3012	438	1968	286	18.5	2.69	4576	666	27441	3993	7	77	16	0.19
7	5965	656	4234	485	16.6	1.83	10153	1116	56833	6247	8	77	15	0.18
10	9368	182	7305	166	21.4	0.35	16530	339	94242	2022	6	79	14	0.16

c) Regression output for all biomass components

Fitted values

Year	leaves	stem	branch	wood	agb kg/ha	prim root	sec root	fine root	tot root	tot bio	Leaves %	Wood %	Roots %	Root/shoot ratio
1	119	539	184	628	1076	148	61	5.5	277	1167	12	61	27	0.37
2	339	2447	211	2688	3656	666	321	7.5	975	5422	8	67	24	0.32
3	765	6371	794	7166	8534	1318	723	9.4	1961	11255	8	72	20	0.25
4	1397	11911	1869	13762	15710	2102	1264	11.4	3235	18666	8	75	18	0.21
5	2234	19067	3436	22476	25184	3020	1947	13.3	4797	27655	8	76	16	0.19
6	3277	27839	5495	33308	36956	4070	2769	15.3	6647	38222	8	77	15	0.18
7	4526	38227	8046	46258	51026	5254	3733	17.3	8785	60367	8	78	15	0.17
8	5981	50231	11089	61326	67394	6570	4837	19.2	11211	64090	8	78	14	0.17
9	7642	63851	14624	78512	86060	8020	6082	21.2	13925	79391	8	78	14	0.16
10	9508	79087	18651	97816	107024	9602	7467	23.1	16927	96270	8	79	14	0.16

5, to 67.4t/ha at 8 years old, and to 107 tons/ha at 10 years old. Root biomass increased at the same age increments, from 2.0 t/ha, to 4.8 t/ha, then to 11.2 t/ha, and finally to 16.9. Leaf biomass was 0.8 t/ha at age 3, increasing to 2.2 t/ha at 5 years, 6.0 t/ha at 8 years, and 9.5 t/ha at 10 years.

The percentage of leaves to total biomass was 12% in the first year, stabilizing at 8% over the remaining years. As for the roots, their share of total biomass was 27% in the first year, decreasing to 16% at age 5 and then to 14% at the age of 10. The woody component is therefore the most dominant growth, rapidly gaining in importance after starting at 61% in the first year, 76% in the fifth year, and finally 79% in year 10. Expressed as root/shoot ratio (root mass/shoot mass), the value dropped from 0.37 to 0.25 to 0.19 to 0.16 in years1, 3, 5, and 10, respectively.

4.2. *Psiadia altissima*

4.2.1. Biomass production

In Table 22, above- and belowground biomass production is shown in reference to their components for all four cycles from 1 to 8 years of age for *Psiadia altissima*. Biomass increase showed a highly linear relationship and linear regressions were established for yearly biomass increase for each of the biomass components in all four cycles. All the regressions showed coefficients of determination with $r^2 > 0.92$ and $p < 0.05$. They are reported in Appendix 6. We were unable to sample the missing years, which therefore were complemented with the fitted values from the regressions and are shown in bold in the table. In Figure 23, biomass production for all the components across the four cycles from 1 to 8 years of age are presented.

Table 22: *Psiadia altissima* biomass production (kg/ha) from 1 to 8 years in age of four cycles a) above ground biomass (AGB), b) below ground biomass and total biomass and root/shoot ratio

a) Above ground biomass

CYCLES	Age Years	Leaves		Stem		Branches		Wood		AGB	
						kg/ha					
CYCLE 1	1	205	10	1429	72	490	28	1705	93	2013	108
	2	784	49	5764	374	2607	197	8184	584	9266	646
	3	1094	55	8338	444	4557	308	13327	827	14661	877
	4	1256	46	9596	332	5300	128	15446	436	16966	507
fitted *	5	1501		11444		6206		18205		20049	
	6	1683	104	12783	793	6882	571	20243	1093	22320	1942
fitted	7	2055		15734		8692		25341		27831	
fitted	8	2332		17879		9935		28909		31722	
CYCLE 2	1	179	4	1242	31	423	11	1474	38	1743	45
	2	373	23	2692	166	1111	75	3610	236	4145	267
	3	868	68	6548	529	3389	329	10119	920	11225	993
	4	913	108	6882	836	3549	494	10608	1405	11774	1528
fitted	5	1274		9923		6074		17011		18395	
	6	1548	96	12121	752	7627	633	21164	1778	22788	1983
	7	1839	290	14534	2320	9554	1640	26115	4361	27934	4614
fitted	8	2102		16577		10694		29431		31577	
CYCLE 3	1	145	14	1003	100	335	38	1176	128	1395	147
	2	282	14	2022	101	809	45	2660	143	3069	162
	3	489	33	3624	249	1722	119	5304	367	5960	412
	4	523	33	3913	258	1928	180	5866	448	6556	484
fitted	5	905		7002		4138		11740		12759	
fitted	6	1116		8679		5263		14803		16026	
	7	1404	286	10856	1856	6396	1216	18190	3320	19782	3552
		1544	96	12209	757	8008	665	21928	1842	23465	2041
CYCLE 4	1	104	8	716	59	233	19	827	69	984	82
	2	196	50	1403	362	554	143	1830	472	2116	546
	3	289	31	2098	235	890	115	2862	352	3272	394
	4	357	23	2642	178	1238	101	3834	290	4318	316
fitted	5	439		3312		1746		5161		5708	
	6	432	27	3239	201	1646	137	4939	416	5493	478
fitted	7	607		4640		2582		7491		8218	
	8	749	50	5785	383	3402	224	9683	636	10534	692

* fitted values established trough regression application

Table 22: (Continued)

b) Below ground biomass, total biomass and root/shoot ratio

	Age	Prim root		Sec root		Fine root		Roots		Total bio		Leaf	Wood	Root	Root/shoot
	Years					kg/ha						%	%	%	ratio
CYCLE 1	1	143	8	118	6.8	12	0.50	296	17	2223	121	9.3	77.3	13.4	0.155
	2	701	51	654	50.6	33	1.80	1545	116	10605	754	7.5	77.8	14.7	0.172
	3	1156	73	1178	82.5	38	1.45	2667	178	17199	1062	6.4	78.0	15.6	0.185
	4	1341	37	1371	30.7	43	1.93	3100	77	19929	568	6.3	78.0	15.7	0.186
fitted *	**5**	**1580**		**1600**		**52**		**3633**		**23493**		**6.4**	**78.0**	**15.6**	**0.184**
	6	1754	153	1774	154.4	59	5.17	4032	351	26132	2273	6.5	78.0	15.5	0.184
fitted	**7**	**2202**		**2246**		**69**		**5083**		**32689**		**6.3**	**78.0**	**15.7**	**0.186**
fitted	**8**	**2513**		**2569**		**78**		**5808**		**37287**		**6.3**	**78.0**	**15.7**	**0.186**
CYCLE 2	1	124	3	102	2.7	10	0.24	255	7	1923	49	9.4	77.3	13.4	0.154
	2	307	20	275	18.8	17	0.94	662	45	4687	306	8.0	77.7	14.3	0.166
	3	874	80	868	86.5	32	1.96	1991	191	13074	1184	6.7	78.0	15.3	0.181
	4	917	123	909	129.2	34	3.38	2085	288	13707	1811	6.7	78.0	15.3	0.181
fitted	**5**	**1489**		**1596**		**40**		**3525**		**21901**		**5.8**	**78.0**	**16.2**	**0.193**
	6	1853	161	2014	175.3	46	4.01	4423	365	27228	2369	5.7	78.0	16.3	0.195
	7	2292	385	2538	440.6	51	7.50	5526	755	33566	5597	5.5	78.0	16.5	0.198
fitted	**8**	**2584**		**2829**		**60**		**6189**		**37849**		**5.6**	**78.0**	**16.4**	**0.196**
CYCLE 3	1	99	11	80	9.2	9	0.75	203	23	1535	164	9.5	77.2	13.3	0.153
	2	226	12	199	11.4	14	0.61	484	27	3456	185	8.2	77.7	14.1	0.164
	3	456	32	436	30.2	20	1.32	1017	71	6865	475	7.2	77.9	14.9	0.176
	4	505	39	490	42.0	20	0.97	1136	93	7587	577	7.0	77.9	15.1	0.178
fitted	**5**	**1023**		**1083**		**30**		**2407**		**15121**		**6.0**	**78.0**	**16.0**	**0.190**
fitted	**6**	**1292**		**1382**		**35**		**3067**		**19056**		**5.9**	**78.0**	**16.1**	**0.192**
	7	1585	291	1672	323.4	45	6.94	3725	703	23435	4267	6.0	78.0	16.0	0.190
		1924	167	2125	184.9	43	3.72	4634	403	28187	2452	5.5	78.0	16.5	0.197
CYCLE 4	1	69	6	56	4.6	6	0.49	141	12	1079	89	9.7	77.1	13.2	0.152
	2	155	40	136	35.1	10	2.46	331	85	2379	614	8.3	77.6	14.1	0.164
	3	244	30	221	29.2	13	1.18	530	68	3714	455	7.8	77.8	14.4	0.168
	4	329	25	312	26.4	15	0.91	732	59	4965	373	7.3	77.9	14.9	0.175
fitted	**5**	**447**		**450**		**16**		**1025**		**6666**		**6.6**	**77.9**	**15.5**	**0.183**
	6	426	37	421	36.6	16	1.43	968	84	6383	555	6.8	77.9	15.3	0.180
fitted	**7**	**651**		**670**		**21**		**1511**		**9664**		**6.3**	**78.0**	**15.7**	**0.187**
	8	844	55	889	58.6	24	1.66	1982	130	12476	819	6.0	78.0	16.0	0.190

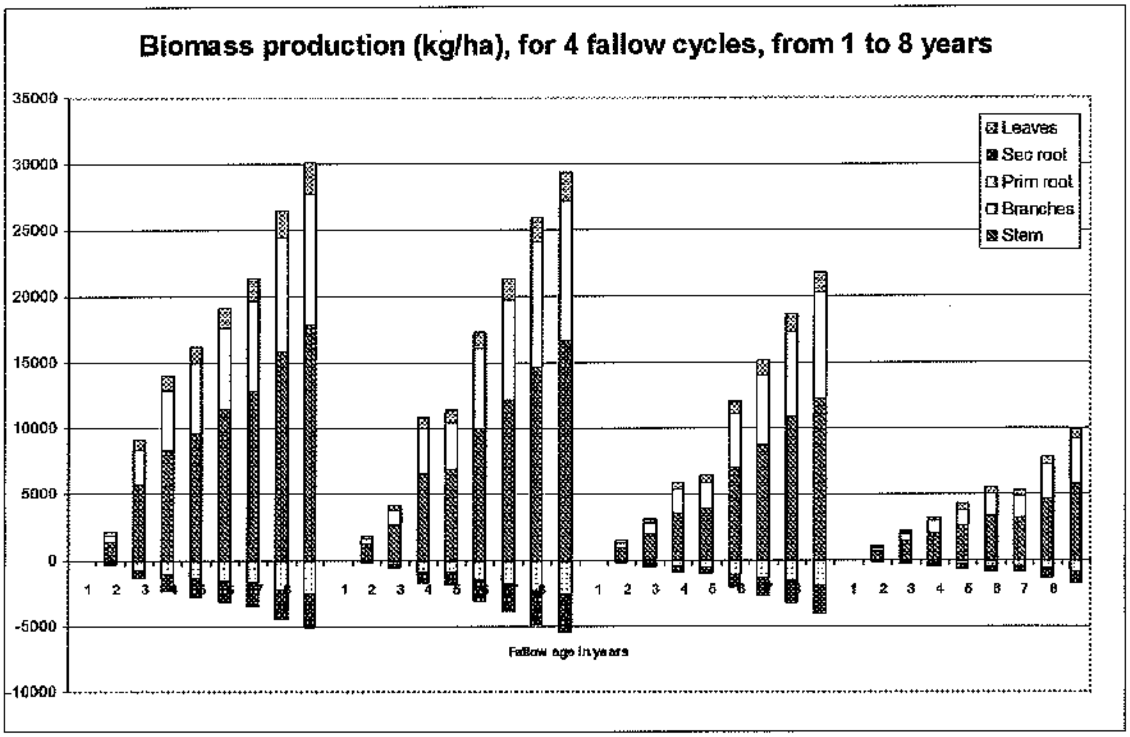


Figure 23: Biomass component production (kg/ha) for four fallow cycles, from 1 to 8 years of age

At the age of 8 years, biomass production for C1 and C2 were comparable. Their leaf production was 2.3 and 2.1 t/ha, the wood weighed 28.9 and 29.4 t/ha, and the roots were 5.8 and 6.2 t/ha, respectively. C3 produced 1.5 t/ha of leaves, 21.9 t/ha of wood, and 4.6 t/ha of roots. In C4, leaf biomass was only 0.74 t/ha with 9.6 t/ha of wood and 2.0 t/ha of roots. Total biomass in C4 represented only 44% of C3's biomass and 33% of C1's and C2's.

The increase in total above-ground biomass is also represented in Figure 24. An initial higher productivity in C1 is noticeable, as well as slower initial growth in C2 compared with C1. But after it reached 5 years of age, the total aboveground biomass was congruent for the two cycles.

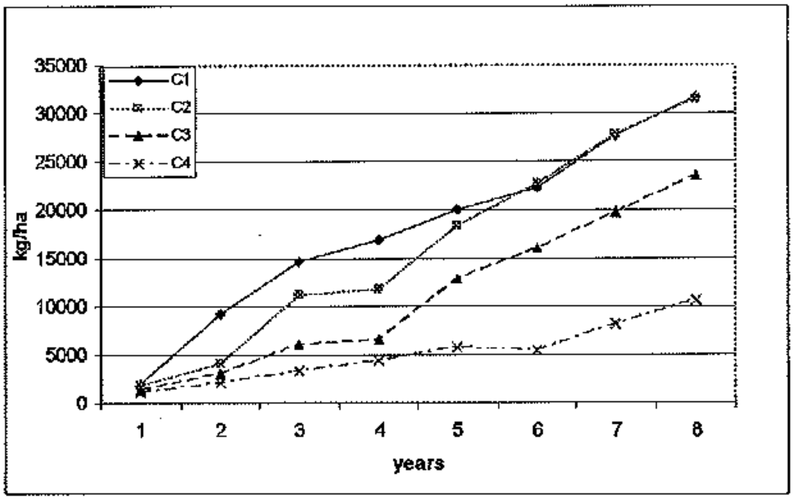


Figure 24: Aboveground biomass evolution (kg/ha) over 8 years for four cycles of *Psiadia altissima*

4.2.2. Yearly biomass increase

The yearly increases in population diameter (mm), stem density (trees/ha), and cross-sectional area (m^2/ha), as well as for all the biomass components, are shown in Table 23, and for the biomass components in Figure 25. The data are the linear regression slopes reported in Appendix 6.

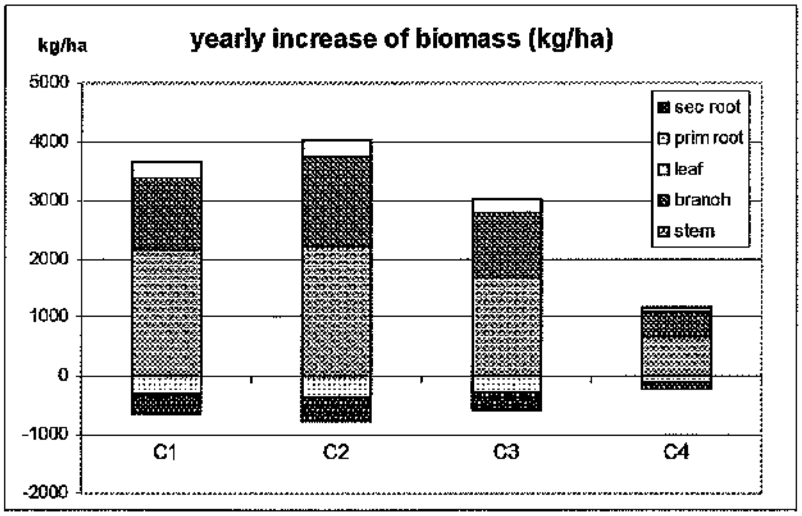


Figure 25: Yearly increase of biomass components (kg/ha) of *Psiadia altissima* for four cycles (C1-C4)

Table 23: Yearly increase of population parameters and biomass components (kg/ha) of *Psiadia altissima* for four cycles (C1-C4). Numbers are regression slopes from linear regressions reported in Appendix 6)

Parameters	C1	C2	C3	C4
Diameter (mm)	4.12	4.09	3.73	2.25
Stem density (trees/ha)	-2140	-1321	-1250	-857
Cross-sectional area (m^2/ha)	2.25	2.57	1.71	0.81
Biomass (kg/ha)				
Leaves	277	276	210	84
Stem	2145	2218	1677	664
Branches	1243	1540	1125	418
Wood (stem+branch)	3568	4140	3063	1165
Total above-ground	3891	4394	3267	1255
Primary root	311	365	269	102
Secondary root	323	411	299	110
Fine root	8.5	6.7	5.3	2.3
Total root	725	888	650	243
Total biomass	4598	5316	3935	1499

Due to slower growth in the beginning and more rapid growth later (as already seen in Figure 24), the slope of the equation was slightly steeper for Cycle 2 than for Cycle1, yielding slightly higher values, but I assume that the difference is negligible. For C1 and C2, the yearly increase in woody biomass was between 3.4 and 3.8 t/ha; for leafy biomass it was 0.28 t/ha. For C3 and C4, the increase in wood was 2.8 t/ha and 1.1t/ha per year, and for leaves it was 0.21 and 0.08 t/ha, respectively. Comparing yearly aboveground biomass productivity with C2 as 100%, C1 produced 89%, C3 74%, and C4 only 29%. Looking at biomass distribution involving leaves, wood, and roots, there is a slight decrease in leaf percentage, from 9.5% to 5.9% from year 1 to year 8, and a slight increase in root percentage, from 13.3% to 16.2%. In comparison, the share of wood stayed almost the same, with 77.2% in year 1 and 78% in year 8. The root/shoot ratio increased slightly over the years, from 0.15 to 0.19.

4.3 *Rubus moluccanus*

Biomass of *Rubus moluccanus* is presented in Table 24 from the five fallow transects, partitioned into leafy, woody biomass, and root components, including surface litter and biomass of associated species. *Rubus* leaves yielded between 1.78 t/ha and 3.42 t/ha with an average of 2.54 t/ha, whereas for wood it was between 9.44 and 18.02 t/ha with a mean of 13.38 t/ha. Total root biomass was between 4.36 t/ha and 13.88 t/ha with an average of 8.48 t/ha. The *Rubus* root system contains a root bulb. The weight distribution within the root system was 47% attributed to primary roots, 34% to the root bulb, 16% to all coarse roots that aren't primary roots, and 3% to fine roots. Leaves make up on average 11% of the total biomass, wood 56%, and the root system 34%. The root/shoot ratio was high, 0.53. No relationship between biomass yields and age could be detected.

The biomass contribution of the associated species was, on average, 2,111 kg/ha with a high portion, 78% or 1,643kg/ha, being leaves, representing two-thirds of the *Rubus* leafy biomass. The species that constituted the bulk biomass were *Aframomum angustifolium* (Zingiberaceae, vernacular name *Longoza*) and *Lantana camara* (Verbenaceae, *Radriaka),* found in four of the five transects; *Clidemia hirta* (Melastomataceae, *Mazambody*) and *Psidium guajava* (Myrtaceae, *Gavobe*) occurred in two of five transects; *Dioscorea bulbifera* (Dioscoreaceae, *Hofika*) and *Mellinis munitiflora* (Poaceae, *Milinesy*) were encountered in one of the five transects.

Table 24: Biomass production of *Rubus moluccanus* and *Imperata cylindrica* a) *Rubus* above and below ground biomass b) *Rubus* litter and biomass of associated species c) root/shoot ratio of Rubus d)*Imperata* biomass and root/shoot ratio

a) *Rubus moluccanus* above ground and below ground biomass

Age	Leaves	SE	Wood	SE	AGB	SE	Bulb	SE	PrimRoot	SE	SecRoot	SE	FineRoot	SE	Total Root	SE	Total Bio	SE
Years									kg/ha									
4	1786	158	9437	712	11225	847	2405	129	3176	511	1342	544	167	49	7090	1145	17945	1431
4	2134	260	13429	1075	15563	1147	1813	787	1802	808	636	83	106	10	4359	1656	20896	2057
5	3417	317	13591	2948	17008	3152	3893	1818	4987	2820	1781	929	507	162	11168	5716	23826	7810
6	2496	639	18023	4866	20519	5013	4311	934	7323	3234	2121	784	121	20	13876	4829	31462	7241
10	2864	436	12442	1190	15306	1592	2121	777	2670	942	937	420	181	63	5909	2129	20377	600
GM	2540	199	13384	1224	15924	1302	2909	476	3992	924	1363	277	217	50	8480	1652	22901	2336

b) *Rubus moluccanus* litter and biomass of associated species

	Rubus		Other species		Other species		Other species	
Age	Litter	SE	Wood	SE	Leaves	SE	AGB	SE
Years				kg/ha				
4	5058.0	340.0	114	95	992	148	1106	147
4	4759.2	782.4	1250	278	787	129	2037	255
5	6096.4	724.3	530	280	0	443	530	443
6	6906.9	742.0	0	0	1607	210	1607	222
10	6412.2	636.3	444	210	4830	443	5274	415
GM	5847	318	468	197	1643	503	2111	296

c) Leaf, wood and root %, root/shoot ration of *Rubus*

Age Years	Leaves %	Wood %	Root %	Root/shoot ratio
4	10	52	39	0.63
4	11	67	22	0.28
5	12	48	40	0.66
6	7	52	40	0.68
10	13	59	28	0.39
GM	11	56	34	0.53

d) *Imperata cylindrica* biomass production and root/shoot ratio

Imperata cylindrica											Fern		*Imperata* and fern				
Years	Leaves	SE	Tot roots	SE	Coarse roots	SE	Fine roots	SE	Tot bio	SE	leaves	SE	leaves	SE	Leaves	Roots	Root/shoot
Age							kg/ha								%	%	ratio
3	6027	749	3784	470	3522	496	262	33	9811	1220	0	0	6027	749	61	39	0.63
6	5408	555	3074	316	2918	300	156	16	8482	871	1913	663	7321	1096	64	36	0.57
7	4655	428	2368	218	2170	200	197	18	7023	646	1076	333	5731	409	66	34	0.51
10	6849	461	3337	225	3044	205	293	20	10186	686	921	298	7770	422	67	33	0.49
15	4770	333	2553	178	2307	161	246	17	7324	511	67	42	4838	294	65	35	0.54
AV	5542	409	3023	268	2792	248	231	24	8565	637	796	354	6338	535	65	35	0.55

As litter was very important in the *Rubus* fallows, surface litter was weighed, which was on average 5847kg/ha. Litter contribution is underestimated, as only the superficial layer of material that was easily removable from the floor and that was not contaminated with soil was collected. I estimate that a third of the litter stayed behind. The total aboveground biomass, including the surface litter and the associated species, resulted in 23.9 t/ha, of which the living *Rubus* plants contributed 66% or 15.9 t/ha.

4.4 *Imperata cylindrica*

Imperata's leaf biomass was on average 5.54 t/ha and its total root biomass was 3.02 t/ha. The fine root weight was only 7.8% of the total root biomass with 231 kg/ha. The leaves contributed 65% to the total biomass and the roots therefore made up 35%. The root/shoot ratio was 0.55. The total *Imperata* above- and belowground biomass was between 7.02 t/ha and 10.19 t/ha with an average of 8.57 t/ha. The data is presented in Table 24d. The age range in the transects was between 3 and 15 years. No biomass increase with age could be detected. The height of *Imperata* stands was roughly estimated at between 50 and 125 cm.

In four of the five transects, the two most dominant fern species in the region, *Pteridium aquilinum* (Dennstaedtiaceae) and *Sticherus flagellaris* (Gleicheniaceae), were associated with *Imperata* and contributed between 0.07 t/ha and 1.91 t/ha (for an average of 0.8 t/ha) to the leafy biomass. There were no good correlations between fern biomass and the age of the fallow or *Imperata* biomass. It seems that once *Imperata* is established, biomass and height no longer increase noticeably, and that the observed variations may be due to other factors, such as soil.

4.5 Biomass production comparison of the four species

Biomass production for all four species under discussion and for *Psiadia* for the four cycles at the ages of 3 years, 5 years and 8 years is presented in Figure 26. Leaf, wood, and root biomass are reported. The scale of the y-axis was maintained for all three graphs to better reflect the dynamics over the years. The choice of fallow ages is based on the average fallow periods that are representative in the fallow zone of Beforona today—3 years—and in the forest region of Ambavaniasy—5 years. An 8-year fallow period today represents an exceptionally long fallow period that farmers would like to respect but rarely are able to. More information on this topic was presented in Chapters 2 and 3.

Aboveground biomass production (leaf and wood) for *Psiadia* was most productive at the age of 3 years in C1 with 14.4t/ha, followed by *Rubus* and C2 *Psiadia* with 10-11t/ha. *Trema* produced 7.9t/ha AGB, followed by C3 *Psiadia* with 5.8 t/ha. Lowest production was obtained by C4 *Psiadia* and *Imperata* with 3.2 - 3.3 t/ha. At the age of 5 years, the tree fallow was becoming more productive than the shrub species, attaining 24.7 t/ha. C1 and C2 *Psiadia* as well as *Rubus* were similarly productive with 19.7 t/ha, 18.3 t/ha, and 16.8t/ha respectively. C3 *Psiadia* generated 12.6t/ha and C4 *Psiadia* and *Imperata* were lowest in production with 5.5 t/ha. At this age, *Rubus* and *Imperata* stop accumulating additional biomass, with new growth merely replacing shed leaves. At the age of 8 years, the tree fallow shows a clear advantage over the shrubby fallows and reaches 67 t/ha of AGB, whereas C1 and C2 *Psiadia* produce less than half that, with 31.5 t/ha. C3 *Psiadia* becomes more productive, with 23.5 t/ha, than *Rubus* with 16.8t/ha. C4 *Psiadia* remains a slow accumulator with 10 t/ha and *Imperata* remains as low as at the age of 5 with 5.5 t/ha. The degradation gradient begins to show clearly as well as the potential for species to accumulate biomass over time.

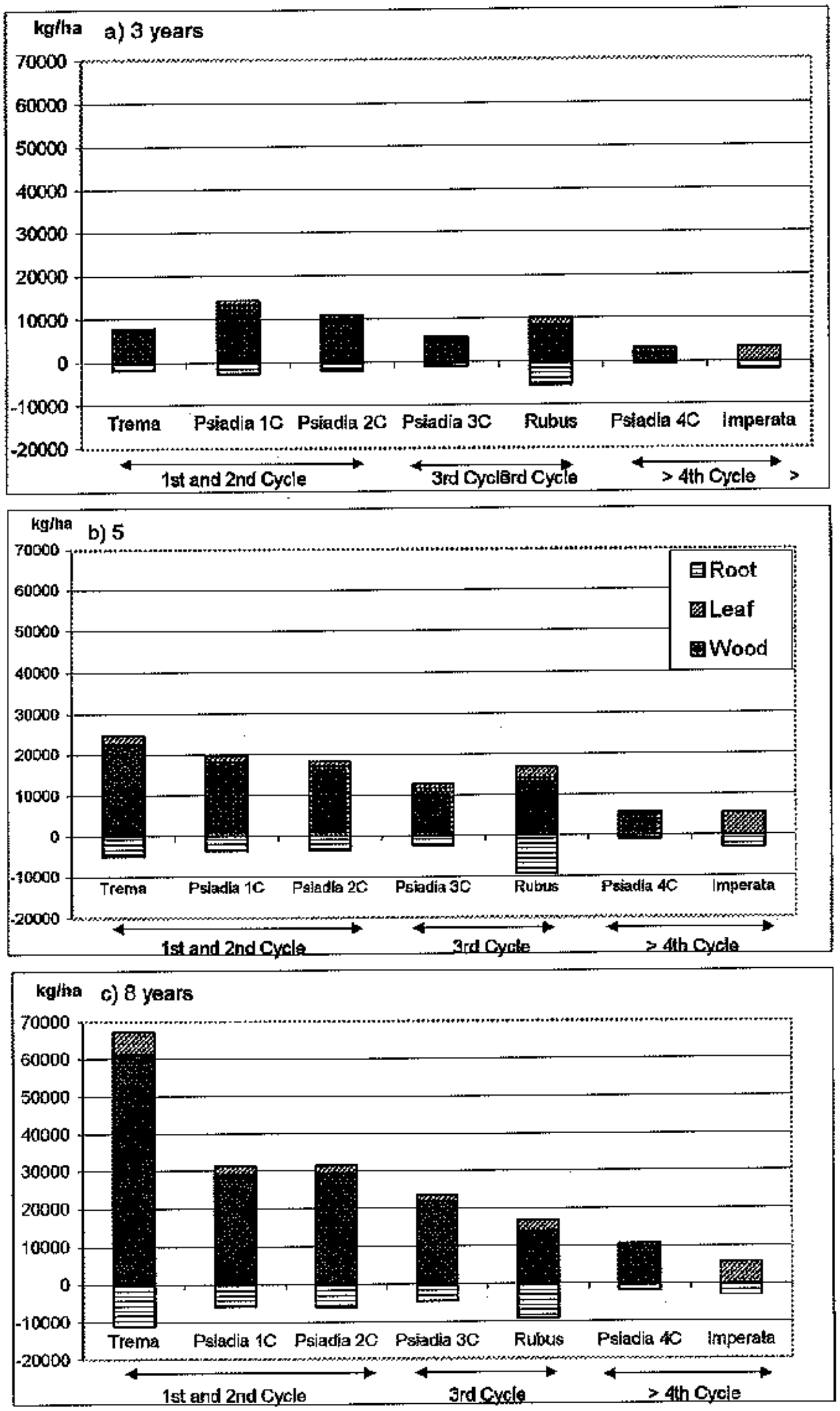


Figure 26: Biomass production (kg/ha) for four species, and four cycles for *Psiadia* at ages of a) 3 years, b) 5 years, c) 8 years

5. Plant nutrient concentrations

Nutrient concentration of leaves, wood, and roots are reported in Appendix 8 and shown in Figure 27. The fern species *Pteridium aquilinum* as a major fallow species has been included in the leaf analysis, which is also reported in Appendix 8. Nutrient concentrations decreased in general with an increasing degradation gradient for N, P, K, Mg, and Ca. The more specific results are summarized forthwith. *Trema* had significantly higher values compared with the other species for N, P in leaves, wood, and roots. This was also the case for K, Mg in wood, and roots and for Ca in leaves and wood. *Psiadia* accumulated potassium and sulfur but had low Mg levels in its leaves. *Rubus* on the other hand accumulated Mg in its leaves, but showed low concentrations of potassium. It had the highest P levels in wood and roots compared with the other species and it also showed the highest values for N, Mg, and Ca in its roots. *Imperata* maintained the lowest ranking for all the macronutrients in the leaves in comparison with the other species. It was, however, a good accumulator of P, K, S, and Al in its roots. The Ca concentration was extremely low in the leaves (20 times lower than in *Trema* leaves) as well as in the roots (27 times lower than in *Rubus* roots).

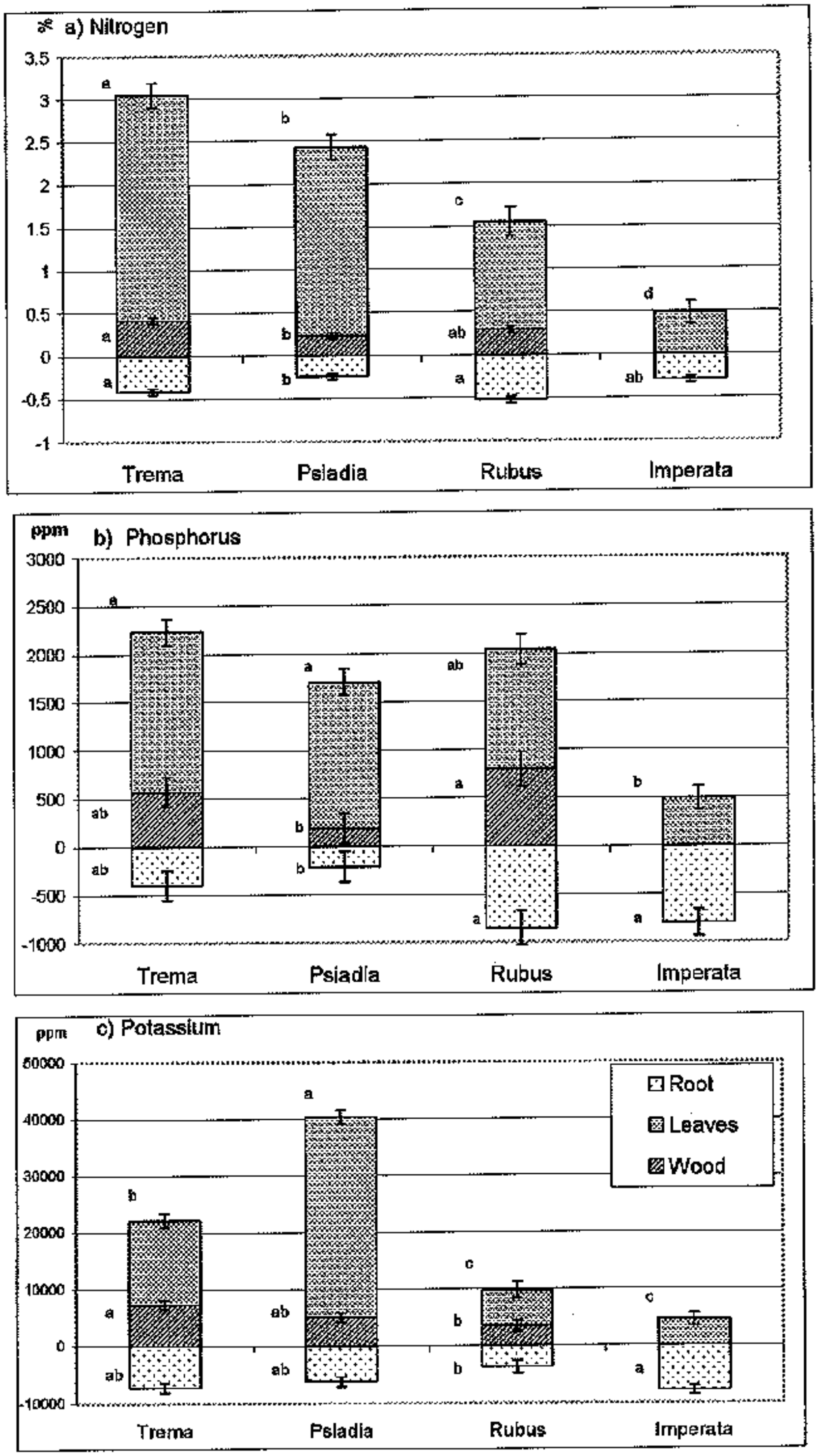
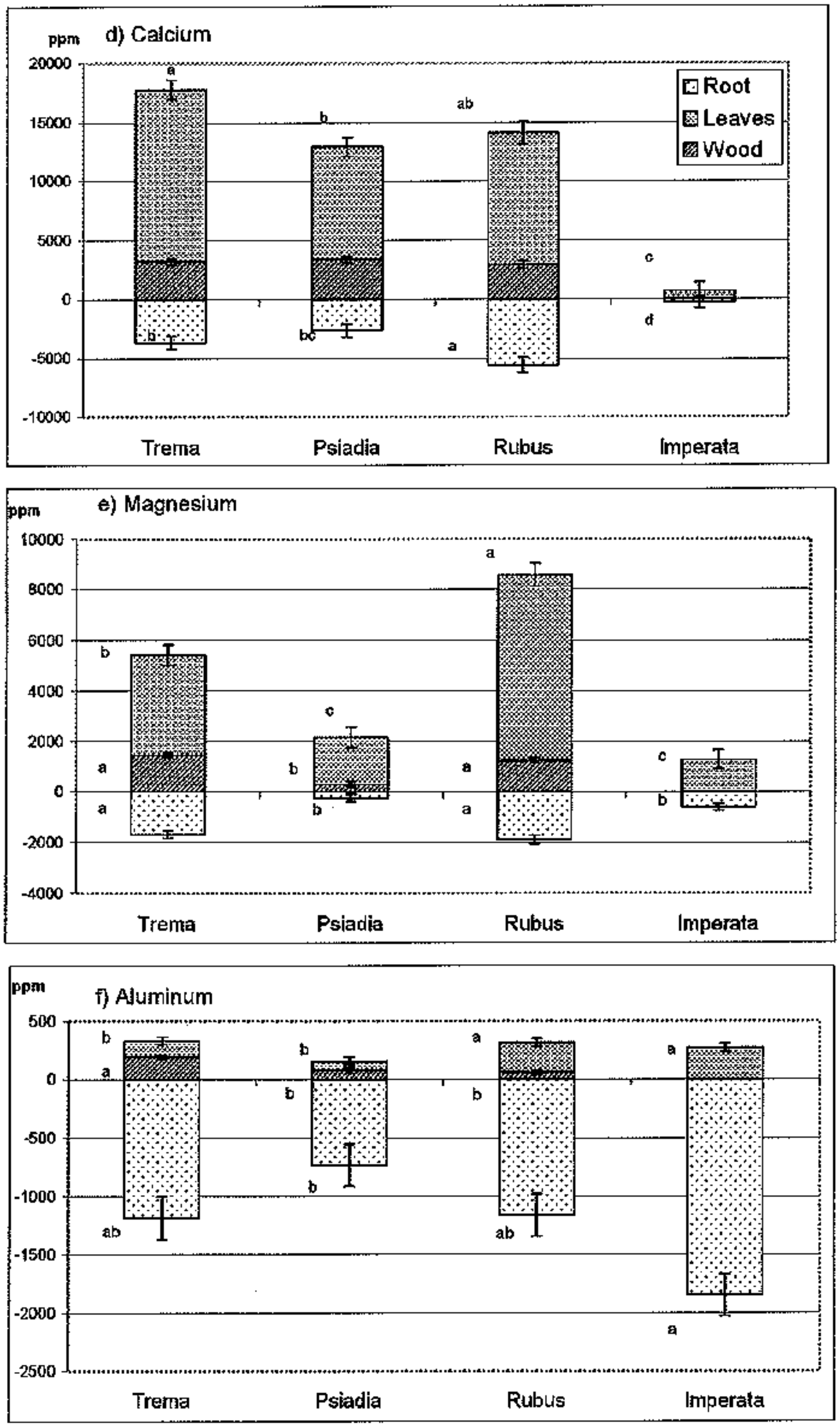


Figure 27: Nutrient concentration of biomass components (leaves, wood and roots) for four species in % for a) nitrogen and in mg/kg for b) phosphorus, c) potassium, d) calcium, e) magnesium, and f) aluminum

Figure 27: (Continued)



6. Nutrient stocks of biomass components for four species

Nutrient stocks were calculated for all the biomass components for the macronutrients N, P, K, Ca, Mg, and S, as well as for C for the four species. All the data is presented for *Trema* aged from 1 to 10 years in Appendix 9, and for *Psiadia* aged from 1 to 8 years in Appendix 10. For *Imperata* and *Rubus*, the transect data and their averages are reported in Appendices 11 and 12. An excerpt of the data is shown in Table 25, representing the total macronutrient stocks (above- and belowground stocks) for the ages of 3, 5, and 8 years. The same data is presented in Figure 28, but without carbon and sulfur. The averages of the transects for *Rubus* and *Imperata* were taken as stocks at the age of 5 years, which remained the same stocks through the age of 8 years. The 3-year stocks were calculated from the 5-year stocks by assuming linear growth.

6.1. Total nutrient stock accumulation at 3, 5, and 8 years of fallow growth for *Trema, Psiadia* (C1-C4), *Rubus*, and *Imperata*

At the age of 3 years *Rubus* accumulated the highest concentrations of nutrients compared with the other species for N, P, Mg, Ca, and S with 68, 13, 29, 72, and 10kg/ha, respectively. In the case of K only, its stocks of 57 kg/ha were inferior to *Trema* and C1 and C2 *Psiadia* with 78kg/ha – 101 kg/ha. *Trema* and C1 and C2 *Psiadia* follow *Rubus* in its position, followed in turn by C3 *Psiadia*. Interestingly, *Imperata* has higher nutrient stocks than C4 *Psiadia*, except for calcium.

At 5 years, *Trema* was the top-ranking species for N and K, with 173 and 233 kg/ha respectively, followed by *Rubus* and C1 and C2 *Psiadia*. The stocks of Mg and Ca were equal for *Rubus* and *Trema*, with 50 and 121kg/ha respectively. *Rubus* still exceeded all other species in P and S with 21 and 17kg/ha. *Imperata* still had greater nutrient stocks than C4 *Psiadia*.

It is only at the <u>age of 8 years</u> that *Trema* produced the highest nutrient stocks for all the macro-elements. C1 and C2 *Psiadia* obtained higher stocks than *Rubus* of the elements N, K, Ca, and S, but not of P and Mg. *Rubus* remained superior to C3 *Psiadia* in all the elements. C4 *Psiadia* became competitive with *Imperata* and achieved higher values of N, K, and Ca, but *Imperata* still had higher stocks of P, Mg, and S.

Table 25: Nutrient stocks (kg/ha) for total biomass (above ground and below ground) for four species in four cycles, at a) 3 years, b) 5 years and c) 8 years

3 YEARS	Yields	C	N	P	K	Mg	Ca	S
	kg/ha							
Trema	9980	4934	59	6.2	78	16.9	41.3	3.6
Psiadia C1	14004	7203	51	3.9	101	5.5	51.9	7.6
Psiadia C2	10952	5631	40	3.0	78	4.2	40.4	5.9
Psiadia C3	7128	3667	26	2.0	51	2.8	26.4	3.9
Rubus	14513	6863	68	12.6	57	29.4	72.4	10.1
Psiadia C4	3703	1907	14	1.0	27	1.5	13.9	2.1
Imperata	5139	2380	21	3.0	30	5.4	2.8	4.9

5 YEARS	Yields	C	N	P	K	Mg	Ca	S
Trema	29717	14725	173	18.5	233	49.9	121.9	10.8
Psiadia C1	22784	11714	82	6.2	163	8.8	84.1	12.3
Psiadia C2	20796	10681	73	5.6	146	7.9	76.0	11.1
Psiadia C3	14452	7425	51	3.9	102	5.5	53.0	7.7
Rubus	24188	11438	113	21.0	94	49.0	120.7	16.8
Psiadia C4	6522	3354	24	1.8	47	2.5	24.1	3.6
Imperata	8565	3966	35	5.0	49	9.0	4.7	8.1

8 YEARS	Yields	C	N	P	K	Mg	Ca	S
Trema	78728	39054	461	49.3	619	131.9	322.9	28.7
Psiadia C1	35954	18482	129	9.8	256	13.9	132.5	19.4
Psiadia C2	35562	18255	124	9.4	248	13.4	129.4	18.8
Psiadia C3	25438	13062	89	6.8	178	9.6	92.8	13.5
Rubus	24188	11438	113	21.0	94	49.0	120.7	16.8
Psiadia C4	10750	5525	39	2.9	76	4.1	39.6	5.8
Imperata	8565	3966	35	5.0	49	9.0	4.7	8.1

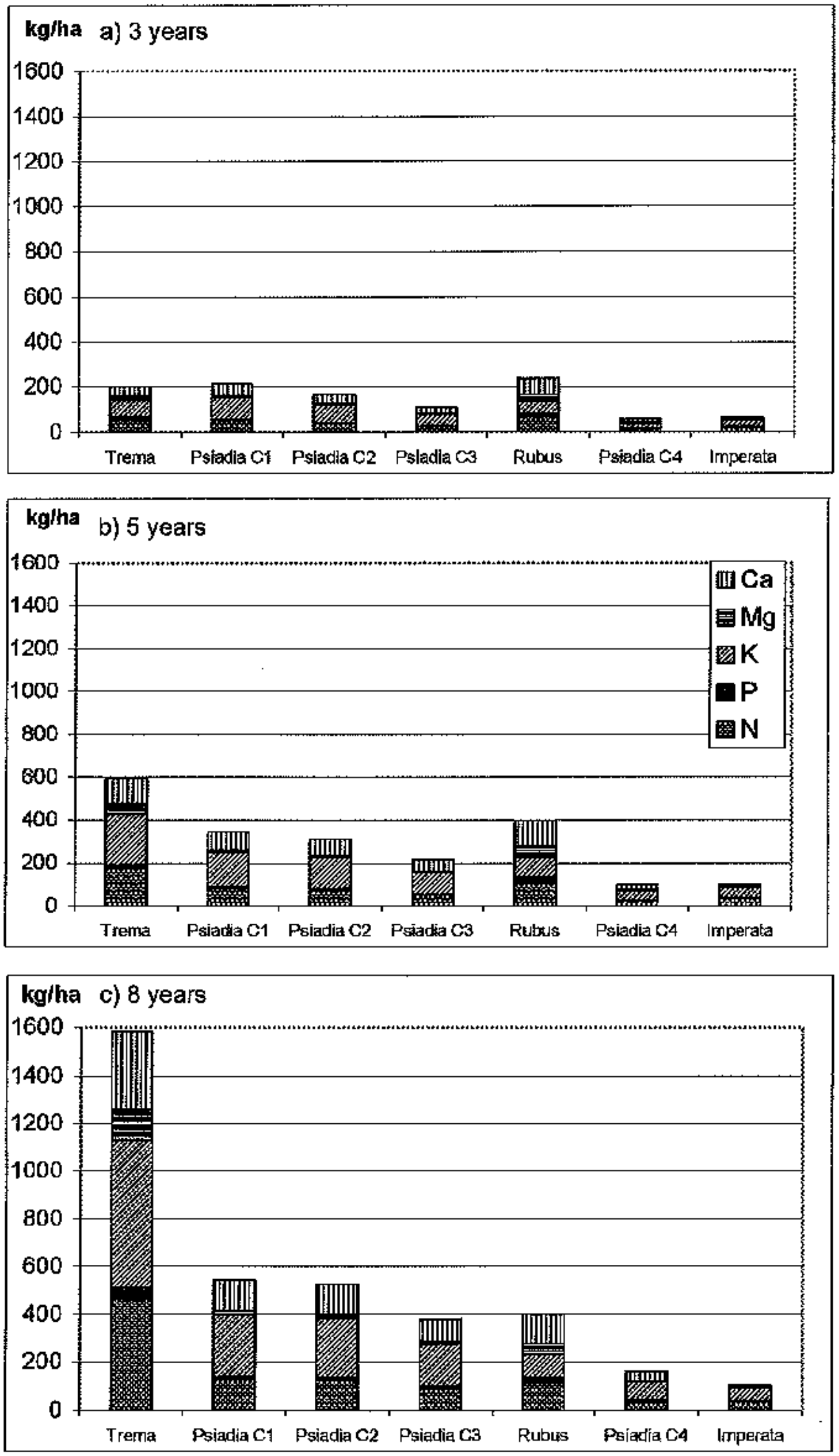


Figure 28: Nutrient stocks (kg/ha) for total biomass (Above and below ground) for four species and four cycles for *Psiadia*, at a) 3 years, b) 5 years, and c) 8 years

6.2. Nutrient stocks with mulching techniques

In order to propose a technical improvement in the farming system, the question raises how much nutrients can a fallow contribute to a subsequent crop if its biomass is mulched instead of burned. A highly plausible scenario, involving minimal labor input from farmers, would be the removal of the large wood stems and branches and the mulching of the smaller sized woody biomass. I calculated therefore how much nutrient stocks would be applied if mulched by subtracting from the total biomass the stem component and one-half of the branches for *Trema* and *Psiadia* and one-half of the stem biomass for *Rubus*. There is no biomass removal of *Imperata*. The roots remain in the soil and are assumed to decompose and release their nutrients. Total biomass and

Table 26: Nutrient stocks (kg/ha)for agricultural mulching: For *Trema* and *Psiadia*: Leaves, 1/2 branches and roots (without stem and 1/2 branches); For *Rubus*: Leaves, 1/2 wood and roots; For *Imperata*: Total biomass: leaves and roots

3 YEARS	Yields	C	N	P	K	Mg	Ca	S
	kg/ha							
Trema	3211	1533	30	2.3	29	7.1	19.9	1.71
Psiadia C1	4990	2450	31	2.2	58	2.9	21.2	4.35
Psiadia C2	3968	1949	24	1.7	44	2.2	16.6	3.39
Psiadia C3	2536	1245	16	1.1	29	1.5	10.8	2.22
Rubus	10497	4902	56	9.4	43	24.5	60.7	8.00
Psiadia C4	1264	621	8	0.6	15	0.8	5.6	1.17
Imperata	5139	2380	21	3.0	30	5.4	2.8	4.87
5 YEARS	Yields	C	N	P	K	Mg	Ca	S
Trema	8931	4280	87	6.7	82	19.8	56.2	4.92
Psiadia C1	8237	4044	49	3.6	91	4.7	34.6	7.04
Psiadia C2	7836	3847	44	3.2	82	4.2	31.9	6.37
Psiadia C3	5381	2642	31	2.2	57	2.9	22.1	4.44
Rubus	17496	8169	94	15.7	71	40.9	101.2	13.3
Psiadia C4	2337	1147	14	1.0	26	1.3	9.9	2.03
Imperata	8565	3966	35	5.0	49	9.0	4.7	8.11
8 YEARS	Yields	C	N	P	K	Mg	Ca	S
Trema	22952	11025	228	17.7	212	51.1	146.5	13.03
Psiadia C1	13107	6436	77	5.6	143	7.3	54.6	11.09
Psiadia C2	13638	6696	74	5.4	139	7.1	54.7	10.84
Psiadia C3	9649	4737	53	3.9	100	5.1	39.0	7.77
Rubus	17496	8169	94	15.7	71	40.9	101.2	13.3
Psiadia C4	3946	1937	23	1.7	43	2.2	18.4	3.32
Imperata	8565	3966	35	5.0	49	9.0	4.7	8.11

nutrient stocks for this mulching material are presented in Table 26 and in Figure 29. *Rubus's* advantage in accumulating nutrient stocks until the age of 5 years becomes even more pronounced than under total nutrient stocks.

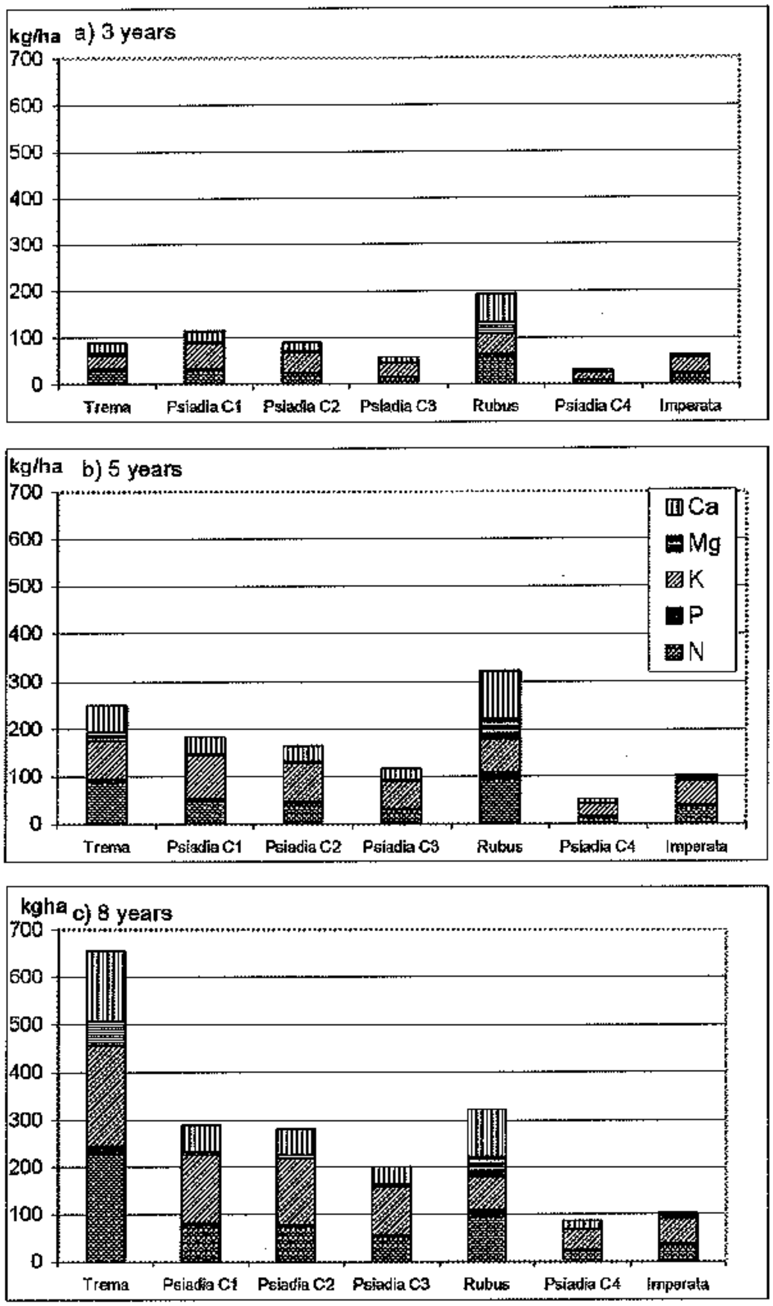


Figure 29: Nutrient stocks (kg/ha) for agricultural mulching four species and four cycles for *Psiadia* at a) 3 years, b) 5 years, and c) 8 years. For *Trema* and *Psiadia*: Leaves, 1/2 branches and roots (without stem and 1/2 branches); For *Rubus*: Leaves, 1/2 wood and roots; For *Imperata*: Total biomass: leaves and roots

7. Exchangeable soil nutrients, carbon concentrations, and stocks

7.1. Exchangeable soil nutrients and pH

Exchangeable soil nutrients (concentrations in mg/kg) as well as exchangeable soil nutrient stocks (in kg/ha at 0-20 cm depth) are shown in Tables 27 and 28 and Figure 30. The highest nutrient stocks of phosphorus, potassium, and magnesium were found in the forest and declined with increasing soil use. Calcium increased with cultivation up to 163% of forest values, but then dropped to 43% in the *Imperata* fallow. pH was lowest in the forest at 4.3 and highest in the first fallow after deforestation at 5.5, slowly decreasing thereafter to 5.1 in *Imperata*. Aluminum contents increased steadily with increased soil use and were 237% in *Imperata* compared with initial forest values. Iron contents decreased following deforestation and increased again with *Imperata cylindrica*.

Table 27: Exchangeable soil nutrient concentration (mg/kg), 0-20cm depth

Vegetation	**P**		**SE**	**K**	**SE**	**Mg**		**SE**	**Ca**	**SE**	**Fe**	**SE**
Forest	3.112	a	0.75	120.0	19.0	144	a	24	256	80	11.54	2.18
Trema	0.693	ab	0.75	90.8	19.0	149	a	24	414	80	5.04	2.18
Psiadia	0.000	b	0.75	64.7	19.0	58	b	24	315	80	4.20	2.18
Rubus	0.096	b	0.84	63.7	21.2	103	ab	27	260	89	3.41	2.44
Imperata	0.108	b	0.75	65.1	19.0	63	b	24	101	80	7.38	2.18
p-value	0.043			0.203		0.034			0.133		0.113	

Vegetation	**Al**		**SE**	**Mn**	**SE**	**Zn**	**SE**	**Cu**	**SE**	**pH**		**SE**
Forest	104	b	30.21	19.68	4.89	0.868	0.209	0.216	0.1457	4.35	b	0.20
Trema	115	ab	30.21	13.01	4.89	0.465	0.209	0.337	0.1457	5.48	a	0.20
Psiadia	144	ab	30.21	5.84	4.89	0.839	0.209	0.293	0.1457	5.31	a	0.20
Rubus	147	ab	33.77	19.92	5.47	0.542	0.233	0.157	0.1629	5.27	a	0.23
Imperata	224	a	30.21	4.91	4.89	0.283	0.209	0.154	0.1457	5.15	a	0.20
p-value	0.086			0.126		0.260		0.873		0.008		

(n = 5 transects, adjusted Tuokey-Kramer test $p<0.05$, Standard error of means, different letters that follow numbers are signficantly different at a level $p<0.05$)

Table 28: Exchangeable soil nutrient stocks (kg/ha), 0-20 cm depth

Vegetation	P		SE	K	SE	Mg		SE	Ca	SE	Fe	SE
Forest	5.104	a	1.24	196.8	32.9	237	ab	40	419	141	18.92	3.65
Trema	1.161	ab	1.24	152.0	32.9	245	a	40	681	141	8.47	3.65
Psiadia	0.000	b	0.00	117.2	32.9	104	b	40	570	141	7.53	3.65
Rubus	0.181	b	1.38	115.7	36.8	188	ab	45	479	157	6.21	4.08
Imperata	0.207	b	1.24	117.4	32.9	114	b	40	181	141	13.39	3.65
p-value	0.044			0.375		0.060			0.177		0.139	

Vegetation	Al		SE	Mn	SE	Zn	SE	Cu	SE
Forest	171	b	50.97	32.28	8.53	1.424	0.372	0.353	0.2479
Trema	189	b	50.97	21.64	8.53	0.781	0.372	0.550	0.2479
Psiadia	255	ab	50.97	10.63	8.53	1.527	0.372	0.538	0.2479
Rubus	267	ab	56.99	36.64	9.53	1.006	0.416	0.288	0.2772
Imperata	405	a	50.97	8.92	8.53	0.505	0.372	0.272	0.2479
p-value	0.033			0.138		0.293		0.884	

(n = 5 transects, adjusted Tuokey-Kramer test $p<0.05$, Standard error of means, different letters that follow numbers are signficantly different at a level $p<0.05$)

7.2. Total carbon and nitrogen concentrations and stocks

Total carbon and nitrogen concentrations (percentages) and stocks (kg/ha) to 20 cm in depth are shown in Table 29. Nitrogen and carbon soil concentration and stocks decreased considerably with increasing soil use. From forest soil to *Trema* soil, the values decreased ca one-half and the shrubby and herbaceous fallow reached only ca one-quarter of the forest values.

Table 29: Bulk density, total soil carbon, and nitrogen (%) concentrations and stocks (kg/ha), C/N and organic matter content (%) for rainforest soil and four fallow soils (0-20cm depth)

	Bulk density g/cm3	C %	N %	C/N	OM %**	C stock t/ha x 20cm depth	N stock t/ha x 20cm depth
Forest	0.82*	13.32	0.997	13.36	22.90	218.4	16.35
Trema	0.83	5.57	0.519	10.73	9.57	91.9	8.58
Psiadia	0.90	2.99	0.209	14.31	5.16	53.7	3.75
Rubus	0.92	3.10	0.246	12.60	5.34	56.8	4.49
Imperata	0.90	3.87	0.230	16.83	6.66	70.0	4.62

* (Brand et al., 1997), ** %OM = C% * 1.72

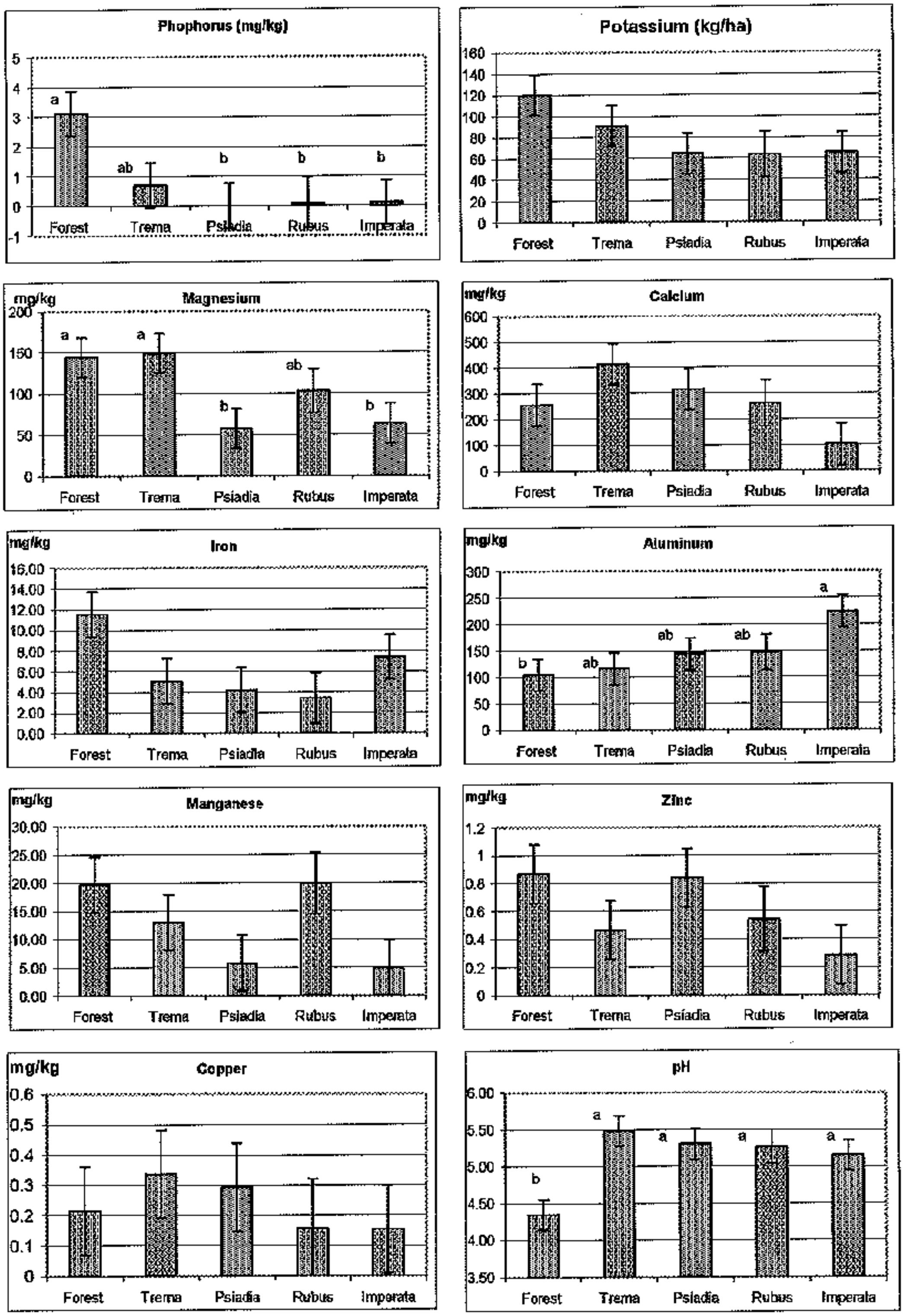


Figure 30: Exchangeable soil nutrients (mg/kg) and pH (water) for rainforest and four fallow soils (means of 5 transects and 2 SE)

DISCUSSION

1. Regression model accuracy

The established regression models achieved a high level of predictability for most biomass components through diameter size $r^2>0.79$, p=0.0 for *Trema orientalis* and $r^{2>}0.89$, p=0.0 for *Psiadia altissima,* except for leaves and fine roots, which were slightly more difficult to predict. These findings are similar to Haase and Haase's (1995), who found that woody and total biomass regressions had a higher level of predictability than regressions for leafy biomass. Nevertheless, unsatisfactory predictability levels for leaves and fine roots were obtained only for the small diameters in *Trema,* where heterogeneity in growth is expected to be more likely. For *Rubus,* diameter was not strongly related to biomass, but the easily harvestable root bulb is a good predictor for most biomass components at $r^2 > 0.71$, $p < 0.001$, except for leaves ($r^2 = 0.56$, p=0.001) and fine roots ($r^2 = 0.41$, p=0.1). A high level of accuracy was achieved for fresh and dry leafy *Imperata* biomass in estimating root and total biomass ($r^2 > 0.83$, $p = 0.0$).

2. Above- and belowground biomass

The 1-to-10-year growth curves for biomass production and population characteristics differed across the four species. *__Trema__* showed exponential growth in biomass for the dbh range of 0-200mm. No extrapolation beyond this diameter range is possible. Mean population diameter increased exponentially as well, whereas tree density decreased exponentially, yielding a linear increase in basal area. On the other hand, *__Psiadia__* demonstrated linear growth in biomass and population characteristics (mean population diameter, stem density, and cross-sectional area) over 1 to 8 years in all four cycles. We measured *__Rubus__* populations only where canopy closure had occurred. For transect ages from 4 to10 years, we detected no relationship between age and biomass. According to farmers, *Rubus* accumulates no additional biomass after 5 years. The same principle applied to *Imperata*. No relationship was detected between biomass and age for transects between 3 and 15 years old, and farmers estimated that after the age of 4 years, total biomass remains the same. This should be verified because, in the literature, biomass accumulation has been reported as stopping after 1 year (Hashimoto et al., 2000; Hartemink, 2001). Although the standing biomass for these two species remains the same after 4 or 5 years, new growth still occurs but is compensated by the shedding of leaves that turn into litter. Because the turnover of litter is important in returning nutrients to the soil (Brown and Lugo, 1990), litter turnover rates and changes in soil properties would be important to monitor to provide more insight into the soil-improving potential of a particular species.

3. Biomass production comparison of the four species

Biomass production comparison of the four species showed that, at the age of 3 years, C1 and C2 *Psiadia* and *Rubus* are the most productive species. *Trema* reaches higher biomass productivity only after the age of 5 years and with its rapid increase in growth during the next 5 years is clearly superior in biomass accumulation compared with the shrubby species. At the age of 8 years, C1 and C2 *Psiadia* produced only 47% of *Trema*'s aboveground biomass (AGB). C3 *Psiadia, Rubus,* C4 *Psiadia*, and *Imperata* generated only 35%, 25%, 15%, and 8% of *Trema*'s AGB, respectively. In summary, the degradation gradient reflected in biomass production from tree to shrub to herbaceous fallows, and from C1 to C4 for the *Psiadia* fallow, becomes increasingly distinct with advancing age.

Nevertheless, it is unlikely that farmers can depend on *Trema* as a major fallow species, because *Trema* is able to persist only during the first fallow cycle following deforestation and disappears from the second cycle onward. As shown by Cao et al.

(1997) from Xishuangbanna, China, *Trema*'s seed density was highest in the first 2 cm of soil. Seed density was drastically reduced after a slash-and-burn event. The fact that *Trema* disappears as a dominant species so soon after the first cycle following deforestation, as well as the weak establishment of pioneer tree species after disturbance, calls for more scientific attention. Vegetation in Madagascar seems to show less resistance to growing back than pioneer species in other parts of the world. In Thailand, for instance, farmers depend on the regrowth of the pioneer species *Macaranga denticulata* in 7-year fallow/cropping cycles and are able to maintain a productive system for upland rice production (Yimyam et al., 2003).

The resilience of the agricultural system depends therefore on the shrubby species. Best production is obtained with C1 and C2 *Psiadia*, but *Rubus* obtains a similar productivity on even more degraded soils and is superior to C3 and C4 *Psiadia*. Thus *Rubus* is an effective species for accumulating biomass on intermediate soils. The drawback with *Rubus* is that its very dense growth habit inhibits indigenous tree regeneration and because of its sharp spines it is difficult to handle in applying mulching techniques. Unfortunately, it therefore lends itself most easily to burning. C4 *Psiadia* shows very slow biomass accumulation and is as evenly productive as *Imperata* until the age of 5. *Imperata* has a very low potential as a biomass producer for a fallow in comparison with woody species.

Comparing the productivity of the studied fallows, we note that, while the average fallow period of 5 years for C1 and C2 *Psiadia* produces 20t/ha AGB, it takes 17 years in C4 to produce the same amount of biomass. This result is congruent with what farmers were indicating about optimal fallow periods (see Figure 6 in Chapter 3). While farmers maintain 5 years of fallowing during the first cycles, they insisted that on the more degraded soils the optimal periods are between 15 and 20 years.

4. Comparison of fallow biomass productivity with other findings from tropical rainforest regions in the literature

Secondary regrowth data for the four measured fallows and from the literature are summarized in Table 30.

Table 30: Above ground biomass production (t/ha)for four fallows, four cycles for *Psiadia* for 3, 5, 8 and 10 years and literature values

	3 years	5 years	8 years	10 years	15 years	
Fallow data						
Trema	8.5	25.2	67.2	107		
Psiadia C1, C2	13.0	19.3	31.7	(ca 40)		
Rubus	9.6	15.9	15.9	15.9		
Psiadia C3	5.9	12.8	23.5	(ca 30)		
Psiadia C4	3.3	5.7	10.5	(ca 13)		
Imperata	3.3	5.5	5.5	5.5		
Literature Reference:						**Location**
Brand and Pfund (1998)	14	24				Beforona, Madagascar
Snedaker (1980)	23	37-77	66-121			Literature review
Brown and Lugo (1990)					100	Amazonia
Sanchez (1976) citing Snedaker, 1970)	27	45	72	90		Guatemala
Scott, 1987	52			89		San Carlos, Venezuela
Ramakrishnan (1992)		23.3		57.5	103	Burnihat, Meghalaya, India
Uhl (1987)	19.9	33.9				Rio, Negro, Amazonia
Uhl and Jordan (1984)		40				Rio, Negro, Amazonia

(Snedaker, 1980).(Brand and Pfund, 1998) (Scott, 1987) Brown and Lugo (1990) (Ramakrishnan, 1992) (Uhl and Jordan, 1984; Uhl, 1987)

Until the age of 5 years, all biomass production in our fallows is inferior to what is reported on secondary regrowth in the literature. Only the *Trema* biomass is comparable to Ramakrishnan's (1992) and Brand and Pfund's (1998) data for periods of between 5 and 10 years and comparable to other reports for periods of 10 years. Various studies show that early fallow biomass increase follows a logarithmic or linear curve and therefore it grows especially quickly during the first 5 years and subsequently slows. (Sanchez, 1976, citing Bartholomew et al, 1953; Nye and Greenland, 1960). Although this pattern of growth behavior is widely reported in the literature, we could not confirm it in our findings. *Trema*, the only tree fallow, exhibits a much slower initial growth for the first 5 years than what is reported in the literature. Other secondary forest species become established only after 5 to 10 years, and contribute substantially to biomass after 20 years. In conclusion, fallow productivity in eastern Madagascar is at 5 years ca one-half what is reported on average in the literature, indicating the low natural productivity of the eastern Malagasy ecosystem. At 10 years only *Trema* can compare to other tropical fallows, whereas the gap for the shrubby fallows widens to ca one-third of their productivity. Still lower productivity is observed for the herbaceous fallows. *Imperata* biomass stagnates at 5.5 t/ha after the age of 4 years. These results are comparable to the findings of Hashimoto et al (2000), who found that *Imperata* biomass was between 2.0 and 5.1t/ha in the tropical lowlands of Borneo, but are inferior to the results of Hartemink (2001), who found a maximum biomass of 23t/ha in the humid lowlands of Papua New Guinea on fertile soils.

5. Above- and belowground biomass contribution to total biomass

The root/shoot ratio decreased for *Trema* from 0.37 to 0.16 from ages 1 to 10, whereas it increased slightly for *Psiadia* from 0.15 to 0.19. *Rubus*'s ratio was considerably higher at 0.53, as was *Imperata*'s at 0.55. It is difficult to generalize the findings on root contribution to total biomass, as it can vary widely. Brown and Lugo (1992) reviewed the literature and found that the root/shoot ratio ranged between 0.03 and 0.81 for moist tropical forests. The average ratio was 0.25. Deans et al. (1996) found an increase in root/shoot ratio with increasing tree size in regenerating secondary forests in the tropical forest zone of Cameroon. This would be congruent with *Psiadia* but not with *Trema*. Tropical forest root biomass data compiled by Canell (1982; cited by Deans et al., 1996) ranged between 10% and 25% of the aboveground biomass, which is consistent with the results of this study.

The remarkably higher root/shoot ratio for *Rubus* and *Imperata* indicates most likely their better adaptation to a more degraded environment as well as to frequent disturbances compared with the early cycle species *Trema* and *Psiadia*. Uhl (1987) notes that successional species that exhibit a higher root/shoot ratio appear to be better adapted to nutrient uptake and nutrient retention under low nutrient concentrations. Several authors found that root/shoot ratios increase with decreasing soil fertility (Jordan, 1985; Vitousek and Sanford, 1986; George and Marschner, 1996, citing Keyes and Grier, 1981). Furthermore species that are able to resprout from roots and thus propagate vegetatively—which is the case for *Rubus* and *Imperata*—are more successful in surviving and recovering from frequent fire incidences than species that depend on seeds for reproduction (Hoffmann, 1998).

6. Plant nutrient concentration

In general, plant nutrient concentrations were best in the early cycle fallows and decreased with advancing soil use. *Trema* and *Psiadia* had the highest values in their leaves, but had considerably lower concentrations in roots and wood, a finding confirmed by other authors (Uhl, 1987; Andriesse and Schelhaas, 1987a). *Rubus*'s leaf concentrations were inferior to those of the other woody species in N, P, and K, but it obtained relatively higher values in wood and roots. *Imperata* had very low nutrient values, especially for Ca, but was able to accumulate P and K in its roots.

7. Plant nutrient stocks

Rubus was the most effective species in accumulating nutrients in short-term fallows. As *Trema* is a slow starter, it exhibits its advantage as a tree species only after the age of 5 years. Until the age of 8 years, *Psiadia* is a slower nutrient accumulator than *Rubus*. The advantage of *Rubus* is it larger root system including the root bulb, and higher concentrations of the macronutrients in its wood and roots, whereas *Psiadia* shows in general low concentrations in the root and wood components. It is surprising that the *Psiadia* fallow in the fourth cycle produces lower nutrient concentrations up to the age of 5 years than the *Imperata* fallow, which is limited to a certain production level and exhibits low nutrient concentrations for most elements. But still, higher concentrations of P and K in *Imperata* roots make this species competitive with C4 *Psiadia* in the initial fallow years.

8. Nutrient stocks for mulching techniques

The same trends as described under total nutrient stocks prevail, except that the advantage of *Rubus* becomes more distinct. The gap between *Rubus* and the other species is larger at the age of 3 and *Rubus* remains superior over *Trema* in all the elements except for K at age 5. At the age of 8 years, when *Trema* becomes the top-ranked species, *Rubus* still performs better than C1 and C2 *Psiadia* in terms of N, P, Mg, and Ca but not in K. *Imperata* remained superior to C4 *Psiadia* at 8 years for all the elements except for Ca. Theoretically, *Rubus* is the species with the highest potential for mulching techniques that could replace burning for short-term fallows. The problem, as already mentioned in connection with other locations, is the spiny appearance, which makes it very unpleasant to handle. Another disadvantage of *Rubus* is the low level of potassium stocks, which, at the age of five, were only 43% of *Trema*'s and 67% of C1 and C2 *Psiadia*'s stocks. *Psiadia* had very high foliar K concentrations (2.3, 5.6, and 7.7 times higher then in *Trema*, *Rubus* and *Imperata* leaves respectively). Toky and Ramakrishnan (1983) stress the importance of potassium in early successions, when this element is highly susceptible to leaching and runoff losses. Selectively rapid uptake through the fallow vegetation is therefore very important in retaining this element within the system.

9. Exchangeable soil nutrient concentrations and stocks

The highest nutrient stocks of phosphorus, potassium, and magnesium were found in the forest and declined with increasing soil use. This contradicts Brand and Pfund (1998), in part, who noticed an increase in P (23%), K (60%), and Mg (30%) stocks with shrubby and mixed fallows compared with rainforests. An initial increase in soil nutrient stocks can be expected after the burning of forest biomass, which we detected only for soil pH and Ca.

The carbon concentration of 13.3% in the topsoil in primary forest was very high, but was confirmed by Johnson's (1992) soil survey data from the Ranomafana area. He reported contents of 12.1% and 13% under primary forest. Nitrogen concentration in rainforest soil in the region under study was 0.997%, which was also congruent with Johnson's findings of 0.77% to 0.98%. Carbon stocks (0-20 cm depth) declined from 218t/ha under primary forest to 54 t/ha under *Psiadia* and 70t/ha under *Imperata*, showing a ca two-thirds decline of carbon in the topsoil. Although Brand and Pfund (1998) reported similar stocks for degraded fallows and grasslands in the Beforona area at between 70 and 85t/ha, their accounting of carbon stocks under rainforest were only 107t/ha, which is half that of our findings. Soil nitrogen stocks were 16.4t/ha under rainforest compared with the 9.6 t/ha finding reported by Brand and Pfund (1998). On the shrubby and *Imperata* fallow soils, we found 3.8-4.8t/ha of N soil stocks, while Brand and Pfund reported 5.7-7.6t /ha for mixed, degraded fallows and grasslands.

CONCLUSIONS

1) Established regression models for the prediction of biomass components obtained high levels of accuracy for all four species. Whereas for *Trema* and *Psiadia*, diameter was used as a predictor variable, the easily harvestable root bulb was used for *Rubus* and either fresh or dry weight leaf biomass for *Imperata*.

2) The hypothesis that the tree fallows will produce superior biomass to shrubs and herbaceous species could be confirmed only after the age of 5 years. This was also the case with nutrient stocks, where *Rubus* showed the highest nutrient accumulation potential at the age of 3 years and partially at 5 years, followed by *Trema* and C1 and C2 *Psiadia*.

3) As the tree fallows disappear after the first cycle, the resilience of the agro-ecosystem depends on shrubby fallows. The biomass accumulation potential of shrubby fallows in the eastern region was only one-third to one-half of what was reported in the literature on regenerating secondary vegetation in other rainforest regions, providing a direct indication of relatively low eco-system productivity in general.

4) Nutrient concentrations in plant tissues decreased with increasing fallow degradation, which confirmed the initial hypothesis. The exception was *Rubus*, which demonstrated a robust ability to accumulate nutrients in its roots and wood. With a high shoot/root ratio, it gained the advantage of better accumulating nutrients, especially in the early years. Considering nutrient stocks under mulching, *Rubus*'s advantage increased even further compared with the other species. Although *Rubus* is an exotic weedy species that is difficult to handle, it thrives on intermediate soils and is the last species in the sequence before the herbaceous species takeover (see Chapter 3). Its position, especially

in advanced degraded landscapes, is therefore of critical importance as it acts as a nutrient 'sponge' on the landscape.

5) Considering the management application of mulching instead of burning, the drawback of *Rubus* is that it has a spiny habit, which makes handling difficult. It also suppresses the natural regeneration of indigenous species and is a low potassium accumulator. *Psiadia*, on the other hand, was able to store high concentrations of potassium in its leaves, a critical element during the early succession phase. *Imperata* has a limited biomass accumulation potential and has low nutrient concentrations resulting in low nutrient stocks. With its very high C/N leaf level of 98, N immobilization is induced when mulched. But despite its low productivity, *Imperata* maintained higher nutrient stocks than C4 *Psiadia* up to the age of 5 years.

6) The hypothesis concerning decreasing soil nutrient availability with increasing fallow degradation was confirmed. Under current farming practices, a rapid decline of exchangeable soil nutrients from rainforest to *Imperata* was noted. Carbon and nitrogen stocks were depleted to levels of one-fourth to one-third of the primary forest stocks. The highest soil nutrient stocks of P, K, and Mg were found in forest soils and declined with increasing soil use. Available P was diminished to nondetectable levels and K, Ca, and Mg levels were reduced to 40% to 50% of their original levels.

Chapter 5

Fire-less alternatives to slash-and-burn agriculture or *tavy* in eastern Madagascar

INTRODUCTION

To meet household needs for staple foods, farmers converted 111,000ha/yr of the eastern Malagasy rainforest to cropland between 1950 and 1985 (Green and Sussman, 1990). With an annual population growth rate of 3% in the Beforona region (Barck and Moor, 1998) and the absence of reinforced forest protection, deforestation continues unabated. Fallow periods have declined from periods of 8 to 15 years in the 70s to periods of 3 to 5 years today, resulting in a rapid decline in crop yields. Trapped in poverty and without alternative upland farming options, farmers either overexploit the land and farm it to complete exhaustion or engage in further deforestation.

Although degradation processes from forest to man-made savannas have been described by looking at soil characteristics and vegetation change based on botanical description (Razafintsalama, 1996; Projet Terre-Tany / BEMA, 1997; Pfund, 2000), and by describing various aspects of the farming systems (Projet Terre-Tany / BEMA, 1998), there are no published empirical data available today on the productivity of these upland soils, nor on alternative farming techniques to replace the current slashing and burning.

As we have seen in Chapter 2, the entire annual upland agricultural system is based on vegetation burning for land clearing and fertilization via the ash of staple foods such as rice, manioc, and sweet potato—and also of ginger, the most important cash crop in the region. The ashes provide a substantial amount of exchangeable cations, especially P, K, Ca, and Mg, that are transferred from the ashes to the soil and contribute in raising the soil pH and decreasing Al saturation (Nye and Greenland, 1960). This is especially important because the soils of eastern Madagascar are characterized by extremely low nutrient contents, low CEC, P deficiencies, low pH, high Al saturation levels, and no significant reserves of weatherable minerals (Johnson, 1992; Brand and Rakotovao, 1997). Further advantages identified by farmers during the field studies were that the effects of burning can contribute to a more friable surface soil, provide a weed-free seed bed, and reduce pests.

The most prominent disadvantage of the slash-and-burn practice is the extensive loss of nutrients that escape from the system via several processes, including volatilization, convection (C, N, S), wind and water erosion of the ashes and surface soil (P, K, Ca, Mg), and leaching (K). The nutrients remain also bound in recalcitrant ash complexes (Goulding, 1990; Mackensen et al., 1996; Giardina et al., 2000; Menzies and Gillman, 2003). Total element losses from burning and leaching have been reported by Mackensen et al. (1996): C, 94-98%; N, 95-98%; S, 69-76%; K, 42-52%; P, 30-47%; Mg, 22-44%; and Ca, 13-35%. Giardina et al (2000) concluded from a literature review that nutrient losses from slashing and burning were, for N, P, Ca, and K ca 97%, 59%, 50%, and 43%, respectively. Besides nutrient losses, surface organic matter is removed, leaving behind bare soil, where surface sealing and crusting occurs as well as desiccation, development of water repellency, and the alteration of soil texture and structure (Sanchez, 1994). Soil and air temperatures rise; surface soil moisture can diminish but at the same time increase in the B-horizon, as water is no longer taken up by the plants. This increases the danger of landslides. Additional processes that take place include alterations or loss of microbial species and populations, loss of invertebrates, and partial elimination of plant roots (Nye and Greenland, 1960; Brand and Rakotondranaly, 1997; Neary et al., 1999; Grist and Menz, 2000; Castellanos et al., 2001). As already seen in Chapters 3 and 4, burning also induces changes in vegetation composition, where regenerating woody plants are weakened or killed, thus creating favorable conditions for invasive pyrophilic and herbaceous species. This phenomenon has been reported in reference to various other tropical locations (Uhl et al., 1981; Dupuy et al., 1997; Hoffmann, 1998).

As seen in previous chapters, the negative consequences of current farming practices, amplified by the shortening of the fallow periods and increasing fire frequencies, are leading to the collapse of the system and the abandonment of agriculture in the uplands. This research was designed with the goal of developing fire-less upland management practices that intensify, improve, and sustain agricultural production and are likely to be adopted by smallholders. The development of fire-less agricultural intensification techniques faces several challenges: how to minimize nutrient losses from the vegetation and soil pool, how to make up for lost or limited nutrients for improved production, and how to preserve and increase newly restored nutrients and cycle them optimally.

Because external inputs are very costly and difficult to obtain, modest applications of locally available guano-phosphate were proposed, providing the system with the most limited nutrients, P and Ca. At the same time the approach selected was intended to improve and build on the biological potential of fallows through slash-and-mulch techniques. In addition to retaining nutrients within the vegetation and surface soil pools, mulching helps prevent erosion and allows for protecting and improving soil organic matter, which plays an important role in creating good soil structure and providing substrates for soil-borne biological communities. In addition, the planting of leguminous fallow species instead of relying on natural fallow regeneration was proposed with the anticipation of speeding up the nutrient stock accumulation within the restricted and current fallow periods. By working with these components the question rises how best to create and manage synergies between the external inputs and the biological components and processes within the existing system.

The main objective was therefore to test intensification techniques that build upon the traditional fallow agriculture and that are based on the efficient use of available biological resources in combination with modest nutrient inputs that are locally available in order to increase and sustain nutrient levels in smallholder farms.

More specifically, the objectives were to:

1) Characterize and quantify agricultural productivity and exchangeable soil nutrients in four fallow types along an increasing gradient of land degradation.
2) Quantify crop productivity and exchangeable soil nutrients in slash-and-mulch systems in an intensified crop rotation and with modest application of guano-phosphate relative to the current slash-and-burn techniques.
3) Quantify the productivity and nutrient accumulation capacity of a planted leguminous fallow relative to natural fallows.

Hypotheses

1. Agricultural productivity decreases from *Trema* to *Psiadia* and *Rubus* to *Imperata* fallow and from the first to fourth fallow cycle following deforestation for the *Psiadia* fallow.
2. Treatment responses will be:
    - 2.1. *Tavy* practice will result in high initial yields and an increase in available soil nutrients in the beginning of the experimental period, but this will be followed by a rapid decline in crop productivity and available soil nutrients.
    - 2.2. Mulching alone will not significantly improve crop yields relative to *tavy*.

2.3. Guano-phosphate in combination with mulching will produce equal yields for the first crop and higher yields for subsequent crops relative to *tavy*. The differences between the treatments with guano and mulch alone will decline towards the end of the rotation due to declining residual effects.

3. Leguminous fallow will accumulate higher nutrient stocks, resulting in higher fallow productivity than the natural fallows.

MATERIALS AND METHODS

1. Site description

The study was conducted in the eastern region of Madagascar in proximity to the Mantadia-Zahamena rainforest corridor. Three research locations were selected for the presence of certain types of natural fallow. Some characteristics of the sites are shown in Table 31. *Trema* and *Psiadia* fallows were found only next to the rainforest border, whereas *Rubus* and *Imperata* fallows with longer cultivation histories are located further away from the rainforest. The locations of the sites relative to the major vegetation zones in the region were shown in Figures 12 and 13 in Chapter 3.

Table 31: Research site characteristics

	Marolafa	Ambavaniasy	Berano
Experimental location	CDIA Farmer Center	Farmers' field	Farmers' field
GPS S	18° 57' 52"	18° 56' 49"	18° 50' 55"
GPS E	48° 35' 14"	48° 30' 38"	48° 19' 55"
Altitude (m)	550 m	715 m	932 m
Mean annual temperature	21.5 °C	20.2 °C	16.9 °C
Mean annual rainfall	2563 mm	3331 mm	1331 mm
Fallow type	*Rubus, Imperata*	*Psiadia*	*Trema*

Rainfall and temperature

Average monthly temperature and rainfall data were presented in Chapter 4 (Figure 14 and Table 13). The monthly rainfall during the experimental period, from November 1999 to June 2001, is presented for all three sites in Figure 31.

During the first cropping season (1999/2000), dry weather marked the first 2½ months of the rainy season. Rainfall was only 30 to 55% of the average rainfall. Several dry spells exceeding seven days were observed, slowing down crop development and resulting in increased rice plant mortality, especially on less fertile soils. Regular rain did not begin until February, instead of the more typical December onset. Cyclone *Leon Eline* passed through the region on February 17/18, 2000 (a category three Hurricane on the Saffir-Simpson scale, with strong winds of 115 miles per hour). Rainfall in Marolafa was 151 mm within two days. Cyclone *Gloria* occurred on March 1 and 2, 2000 (a category one Hurricane with lower wind speeds, between 74 and 95 miles per hour, but

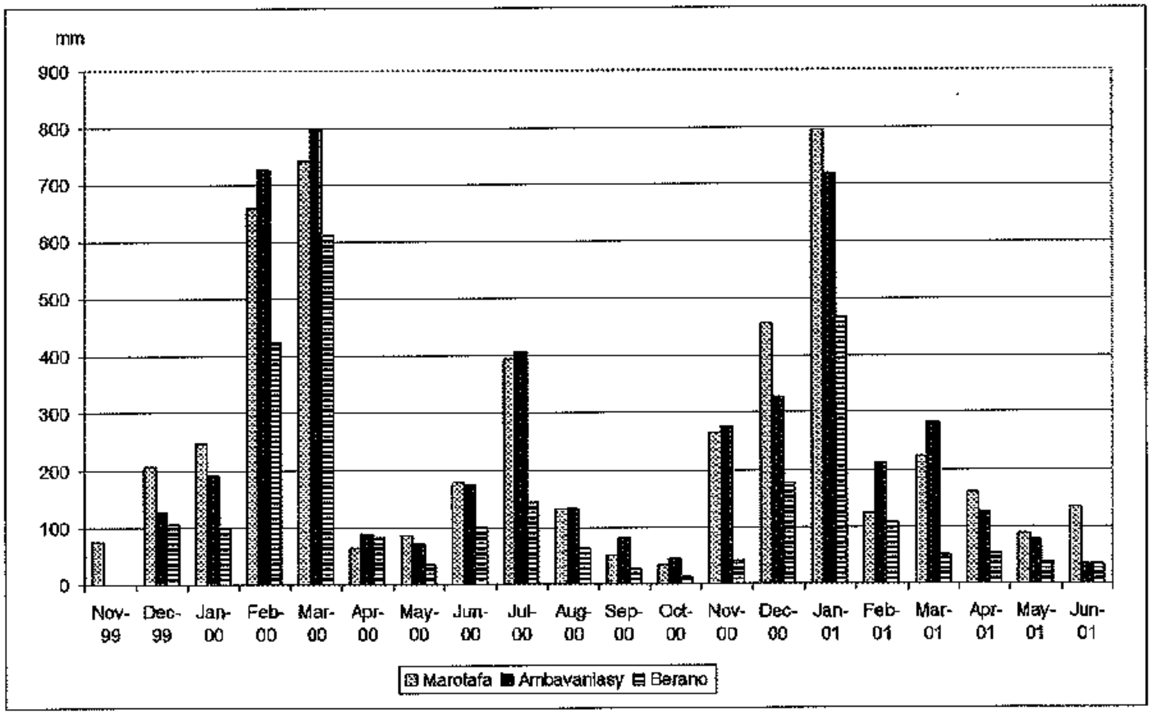


Figure 31: Monthly rainfall during experimental period from Nov 1999 to June 2001 for Marolafa, Ambavaniasy, and Berano

with higher precipitation) (Pacific Disaster Center, 2002). A total of 415 mm of rain fell within two days, 570 mm within 6 days, in Marolafa. Many landslides were associated with this cyclone and we lost one of our experimental plots. The rainy season (2000/2001) was characterized on the other hand by average rainfall and no cyclone events

Geology, pedology, primary vegetation characteristics, and fallow selection were described in Chapter 4.

2. Experimental design and statistical analysis

Experimental design

The experiment followed a randomized block design for three locations and a non-randomized bloc design for *Psiadia altissima*. Blocking was done along the contour lines not only in order to eliminate the slope effect within the blocks, but also to integrate it as block effects. More details on the experimental design are provided in Table 32. For *Rubus* and *Imperata*, the experiments were installed on-station on the land of the CDIA farmer center and consisted of four treatments and five replicates arranged in blocs. For *Trema*, the experiment was established on-farm on one field that was offered by a farmer. Due to restricted field size, only three treatments with four blocs as replicates could be installed. The experiment on *Psiadia* fallow was also done under on-farm conditions. As *Psiadia* offered the opportunity to study the degradation sequence with cycles following deforestation, blocking was done within the landscape on fields in different cycles. In each cycle three replicates were applied. For the multi-location or fallow analysis, cycle was equal to bloc and was analyzed as a random factor, whereas in the cycle analysis cycle was taken as a fixed factor and the replicates served as random factors (see SAS models). The non-randomization in the *Psiadia* experiment was due to field arrangements, as the experiments were embedded in larger farmer fields under cultivation. Thus the *tavy* plots were spatially separated from the mulching plots, while the soil and relief conditions were judged to be similar and thus analyzed as bloc. Given these restricting field conditions, the PROC MIXED statistical procedure with the SAS program (SAS, 2001) was used to account for the unbalanced design.

Table 32: Experimental design

Fallow	Location	Setting	Design (blocs, treatments
Trema orientalis	Berano	On-farm	RCB* (4 blocs, T1-T3)
Psiadia altissima	Ambavaniasy	On-farm	NRB (4 blocs, T1-T3, R3)
Rubus moluccanus	Marolafa	On-station	RCB (5 blocs, T1-T4)
Imperata cylindrica	Marolafa	On-station	RCB (5 blocs, T1-T4)

* RCBD: randomized complete bloc design, NRBD: non-randomized bloc design
T: Treatment, R: Repetitions

Elementary plot

The elementary plot was 5 m x 5 m with a minimal distance of 1 m between the plots. Total number of plots was 88. Two crop rows were planted around the plots as boundary plants, allowing the harvest of the entire elementary plot.

Treatments:

T1: Slash-and-Burn: ***Tavy***

T2: Slash-and-mulch without guano amendment: **M0**

T3: Slash-and-mulch + 600kg/ha of guano-phosphate: 40kg/ha P, 225kg/ha Ca: **M40**

T4: Slash-and-mulch + 1200kg/ha of guano-phosphate: 80kg/ha P, 450kg/ha Ca: **M80**

Tavy: burning of slashed natural fallow at the beginning of the experiment, removal of weeds and crop residues. Ginger leaves were retained in fields, as the plants shed before harvest time. These practices were consistent with farmers' practices. Slash and Mulch: mulching of natural fallow, (except for removal of woody stems), recycling of weeds and crop residues. Guano-phosphate application: Single application of guano-phosphate during rice planting: half of the dose into the planting hole, half between the crop lines.

Crop rotation

Traditional crop rotation was slightly intensified, by integrating beans as a winter crop after rice. It was followed by ginger, which is traditionally planted on a separate field from the rice. After the ginger harvest, a leguminous fallow, *Crotalaria grahamiana*, was planted, a practice not yet pursued in eastern Madagascar. *Crotalaria grahaminana* and *Tephrosia vogelii* were the two best known species in the region and both produced among the highest biomass yields in a biomass productivity trial by Rakotonarivo (2000). *Crotalaria* was selected because it was found growing spontaneously in the region. It is likely that native *Rhizobium* strains are adapted to this species. *Crotalaria* was also among the best performing species in an extensive species screening trial for improved fallows in western Kenya (Niang et al., 2002)

The applied rotation was:

- Upland rice: 1999/2000 rainy season (5 months)
- Beans: 2000 winter season (3 months)
- Ginger: 2000/2001 rainy season (10 months)
- *Crotalaria grahamiana* fallow since July 2001

Statistical analysis

Statistical analysis was done with the SAS procedure PROC MIXED (SAS, 2001) to facilitate multi-location comparisons and to analyze the treatment, fallow, and cycle effects. PROC MIXED is a mixed model procedure that allows the analysis of data sets with fixed and random factors. It is also able to account for unbalanced designs and missing values because its computations are based on likelihood. Many of the statistical computations are the same as those obtained from analysis of variance methods for a balanced data set (Littell et al., 1996; DiIorio, 1997). Estimation of least square means was used and the adjusted Tukey-Kramer test was applied for pair-wise comparison of means. The adjustment of the p-values corrected for the family wise errors that occur when many comparisons are undertaken. Test of significance was done at $P < 0.05$, unless otherwise stated.

SAS Model for treatment and fallow comparisons:

```
proc mixed data=mylib.filename;
class fallow bloc trt rep;
model Variable= fallow trt;
random bloc(fallow) trt*bloc(fallow);
lsmeans trt fallow/pdiff adj=tukey;
run;
```

SAS Model for cycle comparisons:

```
proc mixed data=mylib.filename;
class cycle trt rep;
model Variable= cycle trt cycle*trt;
random rep;
lsmeans cycle trt /pdiff adj=tukey;
run;
```

Statistical time analysis for soil nutrients

In addition to separate analyses for treatment, fallow, and cycle, soils were also analyzed in a time analysis to evaluate if significant changes in soil nutrient levels occurred over time. This was done by developing models including the interactions time*treatment, time*fallow and time*cycle. Because of a number of borderline significance levels that were slightly above $p = 0.05$, a level of significance of $p < 0.1$ was adopted.

*SAS model for soil time*treatment and time*fallow analysis*

```
proc mixed data=mylib.filename;
class fallow trt time bloc plot rep;
model Variable = fallow trt time fallow*time trt*time/ddfm=kr;
random bloc rep*bloc plot*rep*bloc;
lsmeans time fallow trt fallow*time trt*time/pdiff adj=tukey;
run;
```

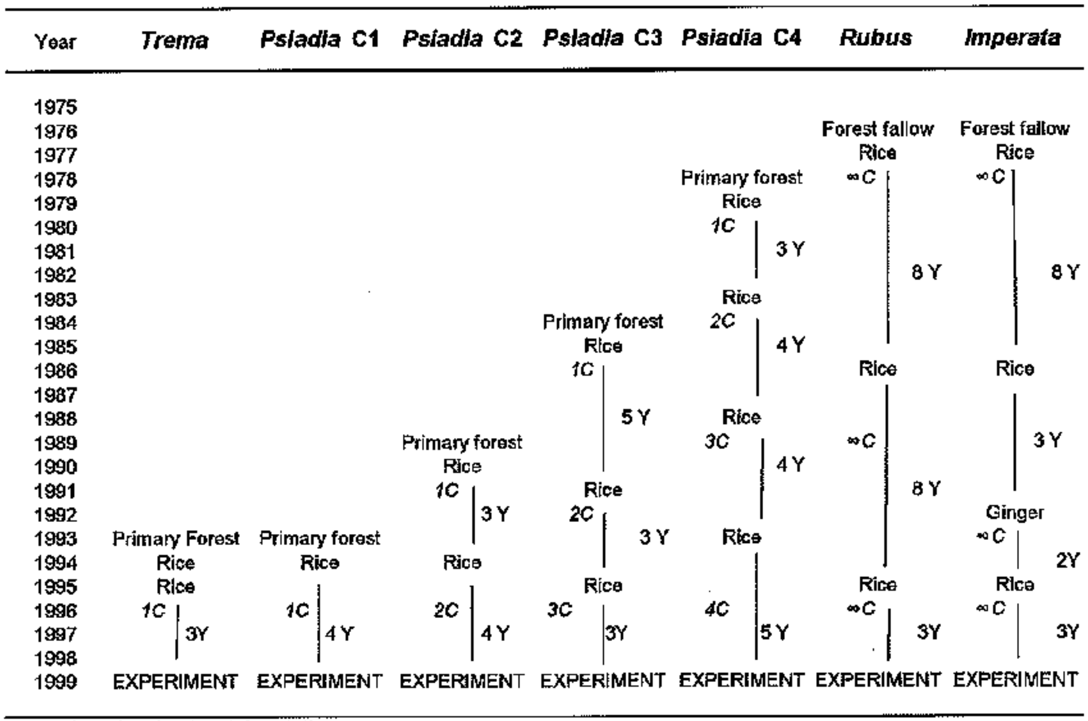
*SAS model for soil time*cycle analysis*

```
proc mixed data=mylib.filename;
class cycle time plot rep;
model Variable = cycle time cycle*time /ddfm=kr;
random plot*rep;
lsmeans time cycle cycle*time /pdiff adj=tukey;
run;
```

3. Experiment management and treatment application

Cropping history of experiment plots

Figure 32 summarizes the cropping history of the experimental plots since the time of deforestation for *Trema* and *Psiadia*, and since the cutting of a forest fallow (*Savoka Mody*) for *Rubus* and *Imperata*. In 1999, when the experiments were established, the fallows were aged between 3 and 5 years, which is the average fallow period in the region.



C: number of cycle after deforestation
Y: fallow period in years

Figure 32: Cropping and fallowing history of experiment plots

Crop management and itinerary

Cropping techniques and management were made similar to traditional practices in order to achieve results comparable to those of the farmers' production system. One major difference was that a line planting technique was used in the experiment instead of the scatter planting that is traditionally employed by farmers. This made it easier to monitor and apply measurements to the plot population. The dates of experimental interventions are recapitulated in Table 33.

Land preparation, mulch, residue and weed management

The natural fallow was cut with the machete (*Antsy*) just above ground level. The fallow biomass was left for several days to dry off. This was enough time to obtain a good burn because of hot and dry weather conditions. For the mulch treatments in the *Trema*, *Psiadia*, and *Rubus* fallows, the woody stems and thick branches were removed from the mulch plots just before planting. The leafy biomass, small twigs, and branches remained on the plot as part of the mulch. The mulch was cut with the machete into pieces of 50 cm to 1 m in length, and was evenly distributed on the plot. Burning of the *tavy* plots was done in the late afternoon the day before planting. Rice was planted through the mulch. In places where the mulch layer was too thick, some of the biomass was deposited on the upper border of the plot and redistributed within the plot once the rice plants were established. In the *tavy* treatments, crop residues and weeds were removed according to traditional practices, whereas in the mulch treatments they were recycled within the plot. Ginger leaves were recycled in all the treatments, because the ginger plants shed their leaves naturally ca 1 month before harvest. For the rice crop, no soil preparation was done, but before the bean and ginger crop a superficial tillage with an *angady* (a shovel with a small, square, flat metal blade) was applied according to farmers' practices.

Guano-phosphate application

The guano-phosphate originated from bird guano that accumulated on the coral limestone of the Barren Islands. These islands are located off the coast of Maintirano in the Mozambique Channel between coordinates 18°25' S – 18°37' S and 43°48 E – 43°57' E. In 1999 the guano (brand name *Hyperbarren)* was extracted and processed by

Table 33: Dates of experimental management interventions

Rice	Plot Identific.	Fallow Slashing	Soil Samples	Burning	Planting	Hyp Dose1	Hyp Dose 2	Reseeding	1st Bird Watch	Weeding1	Weeding2	Weeding3	Weeding4	Weeding5
Imperata	1999 1,3 Nov	3-10 Nov	10,11 Nov	15-Nov	16,17 Nov	16,17 Nov	11-Dec	14-Dec	17nov-15dec	7-16 dec	21-Dec-25	3-9 jan	27-30 jan	15-18 feb
Rubus	3-Nov	4-11 Nov	11-Nov	16-Nov	17,18 Nov	17,18 Nov	10-Dec	15-Dec	18nov-15dec	17-21 dec	10-12 jan	9-14 feb	x	x
Psiadia	19-21,30 Nov	22-25 Nov	26-30Nov	-	26Nov-2Dec	26Nov-2Dec	26Nov-2Dec	20-22 dec	3-19 dec	20-22 dec	10-16 jan	25feb-3mars	x	x
Trema	21,23 Oct 8-Nov	25-29 Nov	23-Nov	23-Nov	24-Nov	24-Nov	19-Jan	22-Dec	nov24-dec16	19 -21 jan	x	x	x	x

Rice (continued)	2nd Bird watch	Harvest 1. Time	2nd time	Cropping period days	Beans	Soil Preparation	Planting	Soil Samples	No Weeding	Harvesting	Cropping period days
Imperata	ca 1 month 20mars-4 may	19-Apr	4-May	170		May5-10	26,27 May	20-Jun	samples 28-Aug	28-Aug	94
Rubus	20mars-8 may	20-Apr	4,8 May	173		May11-15	24,25 May	21-Jun	29-Aug	29-Aug	97
Psiadia	10April -3- ma	9,10 May	30-May	183		1-6 June	6,8,9 June	22,23 June	18-Sep	18-Sep	107
Trema	8 may -7 june	7-Jun		196		8-12 june	13-Jun	28-Jun	6-Oct	6-Oct	118

Ginger	Soil preparation	Planting	Weeding1	Weeding2	Weeding3	Leaf Harvest	Soil Samples	Root Harvest	Cropping period days	Crotalaria fallow Planting 1. Part	Planting 2. Part	Biomass harvest
Imperata	1-3 sept	1,2 Oct	29-Nov	23-Jan	14 Mars	5-Apr	1-3 June	5-Jun	246	7-9 June		
Rubus	3-5 sept	3-Oct	28-Nov	22-Jan	14 Mars	6-Apr	1-3 June	4-Jun	244	11-13 june		
Psiadia	19-22 sept	4,5 Oct	21-Nov	17-Jan	8 Mars	7-Apr	6,7 June	8,9 June	246	18 june C4	3/14sep rest	
Trema	7-9 oct	11-Oct	12-Dec	22-Feb	13-Apr	13-Apr	12-Jun	13-Jun	245	11-Sep		

the company Prochimad from Antananarivo. *Hyperbarren* is sold in powder form with a particle size of 130 µm (Prochimad, 1999), which is fine enough, since the material should be < 150µm in order to be agronomically effective (Hedley et al., 1995). The nutrient contents of *Hyperbarren* are presented in Table 34 (analyses from Prochimad (1999) and CALS Nutrient Analysis Laboratories at Cornell University, acid digestion with HNO_3 for total elemental analysis, CALS analysis number 2020). In addition, exchangeable nutrient concentration and total and exchangeable nutrient stocks for the application rates of 600 kg/ha and 1200kg/ha are reported. The Cornell analysis yielded slightly lower P and higher Ca concentrations compared with Prochimad's analysis.

Data analysis was done based on the results of the Cornell laboratory. Some testing on the Malagasy guano was done by Truong et al. (1981). They concluded that this guano has very high solubility (15.84% citrate AOAC solubility) and can be recommended for direct application in agriculture. Its efficiency is equivalent to Triple-Super Phosphate (Truong et al., 1981; van Straaten, 2002).

Table 34: Total and available nutrient concentrations (in % and mg/kg) and nutrient stocks (kg/ha) of two used application rates of *Hyperbarren* guano-phosphate

	Total Nutrients					Available Nutrients		
	Concentration			Nutrient stocks		Concentration	Nutrient stocks	
	Prochimad Analysis * %	Cornell Analysis %	Cornell Analysis mg/kg	Application I 600kg/ha kg/ha	Application II 1200kg/ha kg/ha	Cornell Analysis mg/kg	Application I 600kg/ha kg/ha	Application II 1200kg/ha kg/ha
P	8.74	6.53	65299	39.18	78.36	42.2	0.025	0.051
K	trace	0.02	204	0.12	0.25	10.4	0.006	0.012
Mg	1.2	0.53	5258	3.15	6.31	609	0.365	0.73
Ca	28.4	37.4	374144	224	449	22768	13.7	27.3
FE		0.09	870	0.52	1.04	0	0	0
Al		0.09	901	0.54	1.08	8.48	0.005	0.01
Mn		0	0	0.02	0.04	0.36	0	0
Zn		0.03	0	0.16	0.31	0.64	0	0.001
Cu		0.05	0	0.28	0.56	9.49	0.006	0.011
S		0.42	4205	2.52	5.05			

* Prochimad, 1999

4. Crop management

Planting:

Planting for all three crops—rice, beans and ginger—was performed with a dibbling stick. The stick, preferably from a hardwood tree, was 3 to 4 cm in diameter and was trimmed at the end into a cone shape that made holes of 3 to 5 cm in depth.

Crop variety and plant spacing

Characteristics of crop varieties and spacing (following farmers' practices) are summarized in Table 35. Selected varieties were among the most preferred traditional varieties in all three locations. There were no improved crop varieties present in the region. Only one ginger variety exists in the region that did not have a specific name. To prepare the ginger seed, the ginger roots were cut into pieces with at least two to three buds. The pieces were kept in a cool dry place for one week before planting to let the cut surfaces seal.

Table 35: Characteristics of crop varieties and plant spacing

	Rice	Beans	Ginger
Variety	*Vary Somotra*	*Tsaramenankavy*	local variety
Growth period	4 months	3 months	>10 months
Between line spacing	30 cm	30 cm	25 cm
Within line spacing	20 cm	20 cm	25 cm
Number seeds/pocket	3 to 4	2	1

Weeds

Weeding was performed by hand. Frequency of weeding depended on the developmental stages of the weed and the crop. Weeding was completed before flowering, preferably, to prevent reseeding. Weeding was applied to all the plots in a location at the same time. Weeding frequency differed among the fallows. Weeding on the *Imperata* fallow for the rice crop was the most intense, with a total of five weedings. Weeding frequency and dates of weeding are shown in Table 33. Before the weeding, species names were inventoried and weed biomass was determined from three randomly selected subplots of 50 cm x 50 cm within one elementary plot. A composite sample was taken for dry weight determination and nutritional analysis.

Additional crop management

For the first three weeks after planting and one month before harvest the rice crop had to be guarded against the bird *Foudia madagascariensis* (*fody*). This bird is able to devastate entire rice fields when descending on them in large flocks. The *fodys* are most active in the early morning, the late afternoon, and on rainy days.

Crop observations

Every two weeks, all field plots were visited and qualitative observations taken on crop development, climate influence, pest occurrence, etc.

Rice harvest

Harvesting was done by line and by planting pockets. Number of pockets/line, stems/pocket, and panicles/pocket were counted. Number of grains per panicle and 1000-grain weight was determined. Panicles were cut individually with a small knife, following traditional harvesting techniques. The straw was cut above ground level with a machete, fresh weight was determined in the field, and a composite sample taken. Panicles were air-dried in a cool and dry place for two weeks, then threshed, after which their dry weight was determined. A composite sample from grain and straw was taken from each elementary plot for dry weight determination and nutrient analysis.

Bean harvest

Measurements taken were the number or planting pockets/line, plants/pocket, and pods/pocket. Fresh straw, pod, and grain weight was determined in the field. Bean grain was air dried in an open dry place for two weeks and samples of straw and pods (without grain) were taken for dry weight determination. Empty pods and straw were recycled in the field for the mulch treatments.

Ginger harvest

Ginger leaves were sampled for biomass calculation two months prior to root harvest and one month prior to the shedding of the leaves. Ten plant stems were randomly harvested along a diagonal line through the plot. Fresh and dry weight was determined. Number of plants and stems/plant were counted for each plot. Leaf biomass was calculated from these parameters. Ginger roots were harvested starting from the lower part of the plot and working up the slope. The roots were dug up with sticks and by hand. Root number/plot was counted and fresh weight was determined in the field.

5. *Crotalaria grahamiana* planting and harvesting

Crotalaria was planted with the dibbling stick in a scattered arrangement analogously to traditional rice planting (ca 25cm x 25 cm spacing), with two seeds/planting hole. One year after planting, subplots were harvested for biomass determination. Three plots of 1 m x 1 m were randomly selected within an elementary plot. Height of plants and stem diameter at 10 cm was measured. The plants were cut at ground level and biomass was separated into woody, leafy, and seed biomass. Fresh weight was determined and a sub-sample taken for dry weight determination and nutrient analysis. Harvested plants were returned to the plot.

6. Plant and soil sampling and analysis

Plant sampling

Throughout the sampling procedures we adhered, as far as possible, to the principle that it is preferable to include less tissue from more plants rather than more tissue from fewer plants (Mills and Jones, 1996). Plant tissues were air dried in brown paper bags in a well-ventilated dry area and, if necessary, oven-dried at 50° C to constant weight.

Plant sample preparation

Initial grinding was done in Madagascar with a coffee grinder. A well-mixed sample of 10 to 20 grams was exported to the CALS Nutrient Analysis Laboratories at Cornell University. At Cornell, plant samples were ground with a blade mill with a mesh size of 2 mm and oven-dried over night at 60° C before plant nutrient analysis.

Plant macro- and micronutrient analysis

The samples were digested in the *Mars 5 Microwave digestion system* with 5 ml HNO_3 diluted to 50 ml and then analyzed with the *Spectro Ciros CCD ICP Spectrometer* for the micro- and macronutrients P, K, Mg, Ca, S, Mn, Fe, B, Ni, Cu, Zn, Mo, Al, Na, Co, Cd, Pb, and V. Nitrogen and carbon were analyzed with stable isotope analysis and mass spectrometry.

Soil sampling

Three soil samples were taken at different times over the course of the agricultural experimentation at 0 month of the experiment or before the rice crop was planted (October 1999), at 8 months after experiment establishment or at bean planting (June 2000), and at 19 months after experiment establishment or at ginger harvest (June 2001). Sampling was done with a soil augur to a depth of 0-20 cm. This depth covered the main rooting zone within the A-horizon. In a few cases where the B-horizon (distinct orange color) started at < 20 cm, sampling depth was reduced to that of the A-horizon. Eight augur samples were taken randomly within an elementary plot. The samples were combined in a bucket and mixed well. Organic and rock debris was removed and a composite sample was taken.

Soil sample preparation

Samples were air-dried in paper bags in a dry, well-ventilated place. When dry, they were mixed again and sieved through a 2 mm sieve and a sub-sample of 80 grams was exported to the CALS Nutrient Analysis Laboratories at Cornell University (Tan, 1996).

Soil analysis

At the lab, the samples were oven-dried overnight at 50°C. Plant available nutrients were analyzed with Morgan's solutions extraction, Cornell Lab Analysis Number 1030. This was done for the elements P, K, Mg, Ca, Al, Mn, Fe, Zn, and Cu. Total nitrogen and carbon were analyzed with stable isotope analysis and mass spectrometry.

Bulk density determination

A graduated 100 mL cylinder was 'forced' into soil. After cylinder removal from the soil, its surfaces were cut with a sharp knife. Samples were oven-dried and dry weight was determined. Samples from three random locations within an experimental plot were combined. Bulk density determination was done for 0-5 cm and 5-10 cm soil depths. (Tan, 1996)

RESULTS

1. Rice, bean, and ginger yields

Results are presented by looking separately at treatment, fallow, and cycle effects in Appendices 13-15 and Figure 33.

1.1. Treatment effect

Rice: *Tavy* achieved the highest yields at 1140kg/ha rice grain followed by M80 at 707kg/ha. The difference between the two wasn't significant, but the difference between the *tavy* yield and the other treatments was significant, with M40 and M0 yielding 642kg/ha and 356kg/ha, respectively. The same patterns were observed for straw, where *tavy* produced 1962 kg/ha and M80, M40, and M0 achieved only 57%, 54%, and 30%, respectively, of the *tavy* rice straw yield.

Beans: Best yields were obtained in M80 (563 kg/ha), which was significantly higher than in M40 (384 kg/ha). *Tavy* and M0 produced very low yields, with 174 kg/ha and 167kg/ha, respectively, which was ca 30% of M80's production and 44% of M40's yield. Bean straw and bean pod dry weight followed the same pattern, as did the number of pods per plant, the number of grains per pod, and the 100-grain weight. The harvest index was 0.5 for the low yields and 0.53 for the treatments with guano-phosphate (GP).

Ginger: Highest yields were obtained in M80 at 8.33 t/ha fresh root weight followed by M40, M0, and *Tavy* at 6.64 t/ha, 5.35 t/ha, and 4.26 t/ha, respectively, which for *tavy* is 51% of M80's yield. The differences among the treatments were significant. The same clear differences were obtained with straw yield, following the same order: 813 kg/ha,

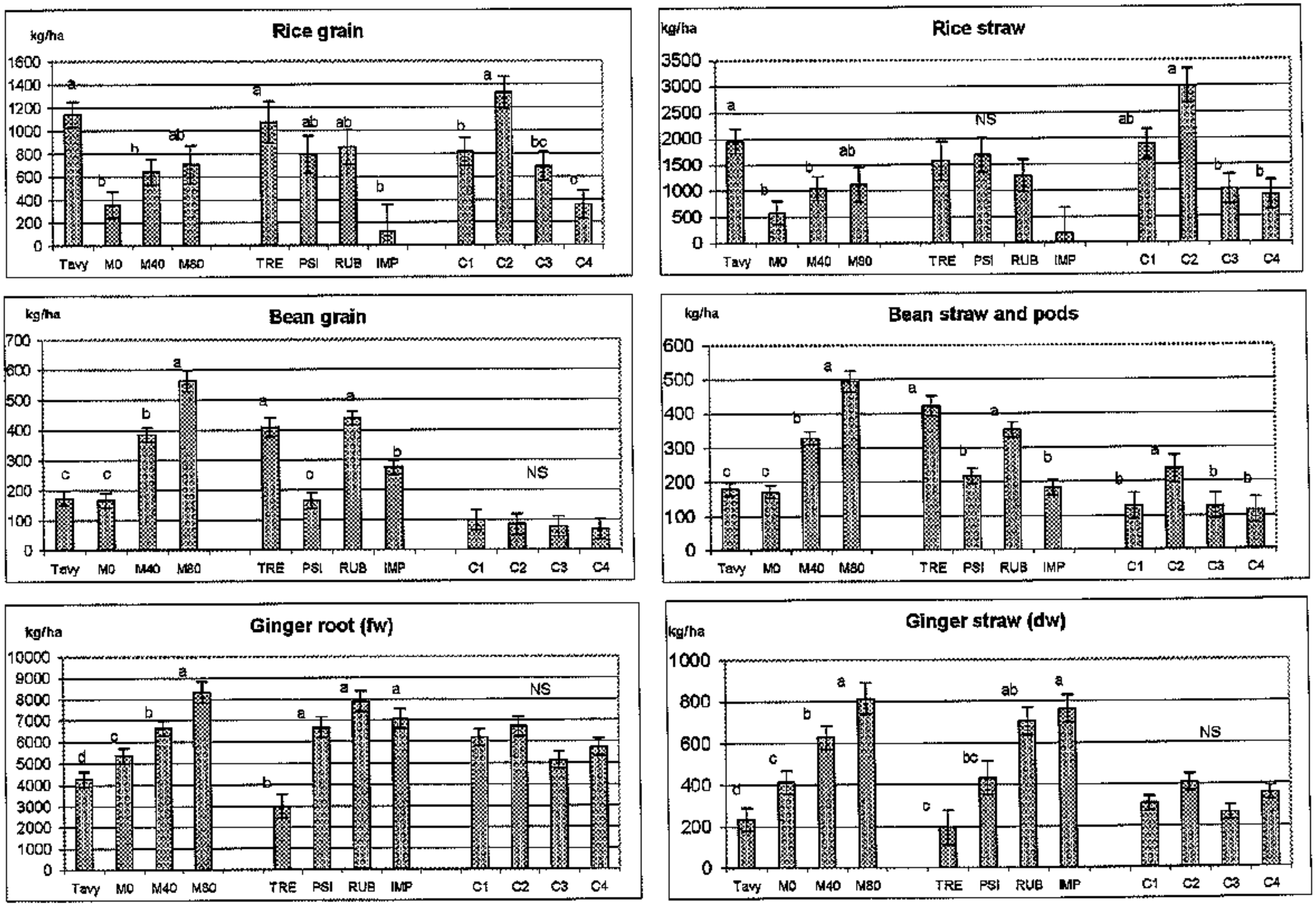


Figure 33: Rice and bean grain and straw yield, ginger root and straw yield (all in kg/ha dw, except ginger root in fw)

628 kg/ha, 413 kg/ha, and 234 kg/ha dry weight, respectively. The number of leaves/plant and the weight per root followed the same patterns.

1.2. Fallow effect

Rice: Highest rice yield was obtained with the *Trema* fallow, at 1073kg/ha of paddy, although the difference wasn't significant relative to *Rubus* (857 kg/ha) and *Psiadia* (795kg/ha). Very low yields were obtained on *Imperata* plots, at 121kg/ha. The reported *Trema* yield is an expected yield calculated with the average harvest index of 0.4 and straw biomass because the fertilization process was interrupted during the cyclone events by heavy rainfall and winds. Grain formation could not occur despite the otherwise normal crop development. The rice straw yields were similar for *Psiadia*, *Trema*, and *Rubus* at 1678 kg/ha, 1572 kg/ha, and 1291kg/ha, respectively. *Imperata*'s straw yield was also very low, 179 kg/ha.

Beans: *Rubus* and *Trema* fallow had similar yields of 437kg/ha and 408 kg/ha, respectively. The difference from *Imperata*, at 276 kg/ha, was significant. Lowest yields were obtained by *Psiadia*, at 165 kg/ha. Combined straw and pod yields showed the same pattern and yielded between 73 kg/ha and 166 kg/ha. Looking at straw alone without pods, *Psiadia* had the second-best yields, indicating relatively good vegetative growth. The number of pods per plant, the grains/pod, and 100-grain weight followed the same pattern as the grain yield. Bean yields were considerably lower for *Psiadia*, but straw yields were comparable to those of *Rubus*. Possible reasons for *Psiadia*'s low productivity included high mortality due to rat damage and, in part. Also the overcast weather conditions during the winter months seemed to be more pronounced in Ambavaniasy than at the other sites and may have had a negative impact on productivity.

Ginger: Root fresh weight was highest in *Rubus* at 7.88 t/ha, followed by *Imperata* at 7.06 t/ha and *Psiadia* at 6.65 t/ha, with *Trema* trailing with lowest yields at 3.0 t/ha. Differences between the first three fallows were not significant, but compared with those of *Trema*, they were. Highest straw yield was produced on *Imperata* (763 kg/ha dry weight) and *Rubus* (704 kg/ha), followed by *Psiadia* (432 kg/ha) and *Trema* (192 kg/ha). Survival was best on the *Imperata* fallow at 83%, which was significantly higher than for the two shrubby fallows *Rubus* and *Psiadia*, at 76% and 75 %, respectively. *Trema* was lowest at 57%. Mortality was not related to pest attack but was due to non-germination of the planting stock, for which we found no explanation. In order to eliminate altitudinal, climatic, and across-site effects, yields were studied for four different cycles in *Psiadia altissima*.

1.3. Cycle effect

Rice: Rice yield was significantly highest in C2 at 1326 kg/ha, followed by C1 at 816kg and C3 at 687 kg/ha. Lowest yields were realized in C4 at 353 kg/ha. The straw yield followed the same pattern, with totals of 2998 kg/ha, 1886 kg/ha, 1025 kg/ha, and 902 kg/ha, respectively. Whereas C2 had the highest percentage of fertile tillers, C1 obtained best results for grain/panicles and 1000-grain weight.

Beans: The yields were best in C1 and decreased with increasing cycle numbers, although there was no significant difference and yields were very low, at 68-99 kg/ha. Possible reasons for these low yields were discussed under the *Psiadia* fallow effect. A significantly higher production of bean straw could be observed for C2 at 237 kg/ha compared with the other cycles that produced between 114 and 128 kg/ha of straw. The other parameters showed no significant differences.

Ginger: The yields in the various cycles were not significantly different. Highest yield was obtained in the second cycle at 6.7 t/ha, followed by the first cycle at 6.19 t/ha, and the fourth and third cycles at 5.72 t/ha and 5.11 t/ha, respectively.

1.4. Pests

The beetle *Heteronynchus* sp. (*Behatoka*) attacked all rice fields during the seedling stage. At first the larvae fed on roots and tender stems in December, followed by the adult beetle, which damaged stems and leaves in late December and January. Rice plants were safe from the beetles once they outgrew the seedling stage. The drought conditions in the beginning of the rainy season slowed down germination and seedling development considerably, leaving the plants vulnerable to pest attack. According to farmers, attacks are worse on more depleted soils. This was confirmed in our experiment, where rice on *Imperata* experienced the highest plant mortality. The farmers' only strategy to avoid *Heteronynchus* attacks is to plant as early as mid-October, allowing the plants to become established before the insect develops.

1.5 Length of cropping period for the three crops

Optimal growth period and actual cropping period for the three crops on the four fallows is shown in Table 36. Rice and beans were harvested at maturity and ginger roots at eight months, for all locations. These results show that the growing season for the rice crop was extended remarkably compared with its usual cropping period. This was due to drought conditions at the beginning of the season, which slowed plant development for several weeks (see also the rainfall report in the M&M section). The results also demonstrate that prolonged growth periods occurred at higher altitudes, which we did not expect at the beginning of the experimentation period.

Table 36: Optimal and actual cropping period for 3 crops on 4 fallows

	Rice Number of days	Bean Number of days	Ginger Number of days
Optimum growth period	120	90	At least 8 months
Beforona			
Imperata	170 (+ 50)	94 (+ 4)	246
Rubus	173 (+ 53)	97 (+ 7)	244
Ambavaniasy			
Psiadia	183 (+ 63)	107 (+ 17)	246
Berano			
Trema	196 (+ 76)	118 (+ 28)	245

1.6. Relative yield comparison

Relative yields for the four treatments in all four fallows are shown in Table 37a.

Table 37a: Relative yields for four treatments in four fallows for rice, beans, and ginger with *tavy* = 100%

		Trema	*Psiadia*	*Rubus*	*Imperata*	Average all fallows*
Rice						
	Tavy	100	100	100	100	100
	M0	53	21	53	34	31
	M40	87	47	63	81	56
	M80			74	33	62
Beans						
	Tavy	100	100	100	100	100
	M0	128	56	86	91	96
	M40	177	196	265	275	221
	M80			349	299	324
Ginger						
	Tavy	100	100	100	100	100
	M0	155	108	161	117	126
	M40	119	127	226	152	156
	M80			254	159	195

*SAS analysis

Rubus and *Imperata* benefited most from GP application, with highest yield increase responses for beans and ginger, followed by *Psiadia* and *Trema*. For *Psiadia* and *Trema*, the GP residual effect was fairly low with respect to ginger. In *Trema* we observed the highest yields of ginger with mulching alone. The proportional yield-improving effects of GP were highest with beans, but looking at it in terms of returns, the ginger crop benefited the most from the GP in economic terms.

2. Exchangeable soil nutrients

Exchangeable macro- and micronutrients in the surface soil at 0-20 cm were analyzed three times during the experimentation: before the rice crop (Time 1 or at 0 months of experiment establishment), before the beans (Time 2 or at 8 months after experiment establishment), and after the ginger crop (Time 3 or at 19 months). Two types of statistical analysis were applied to the data: the first, examining the treatment, fallow, and cycle effects separately; the second, studying the time effect within the treatment, fallow, and cycle from Time 1 to Time 3. Statistical analysis was done with the PROC MIXED procedure in SAS. Results will be presented for both types of analysis. The data are reported in Appendices 16-17 and shown in Figure 34 for each of the measured elements and separately for treatments, fallow, and cycle.

2.1. Treatment effect

Phosphorus: Available phosphorus showed no significant differences either among the treatments or in the time analysis. A peaking in M80 could be noticed, rising from 0.22 to 2.0 mg/kg from Time 1 to Time 2, and in M0 and M40 to ca 1mg/kg, whereas *tavy* showed almost no reaction (0.5mg/kg). At the end of the experiment, the values were as low as in the beginning, at ca 0.3 mg/kg for all treatments.

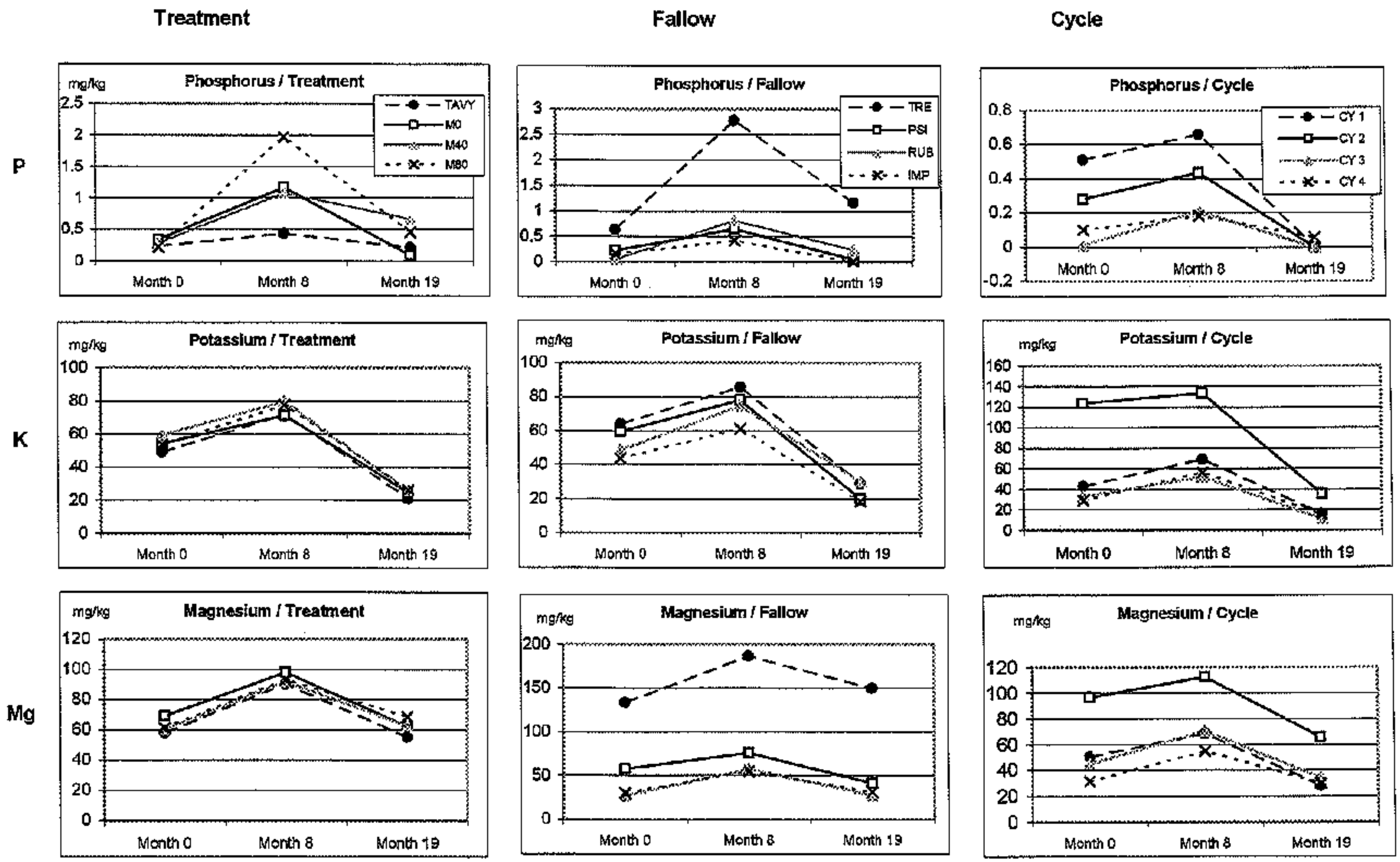


Figure 34: Exchangeable soil nutrients (mg/kg) for four treatments, four fallows and four cycles

Figure 34: (Continued)

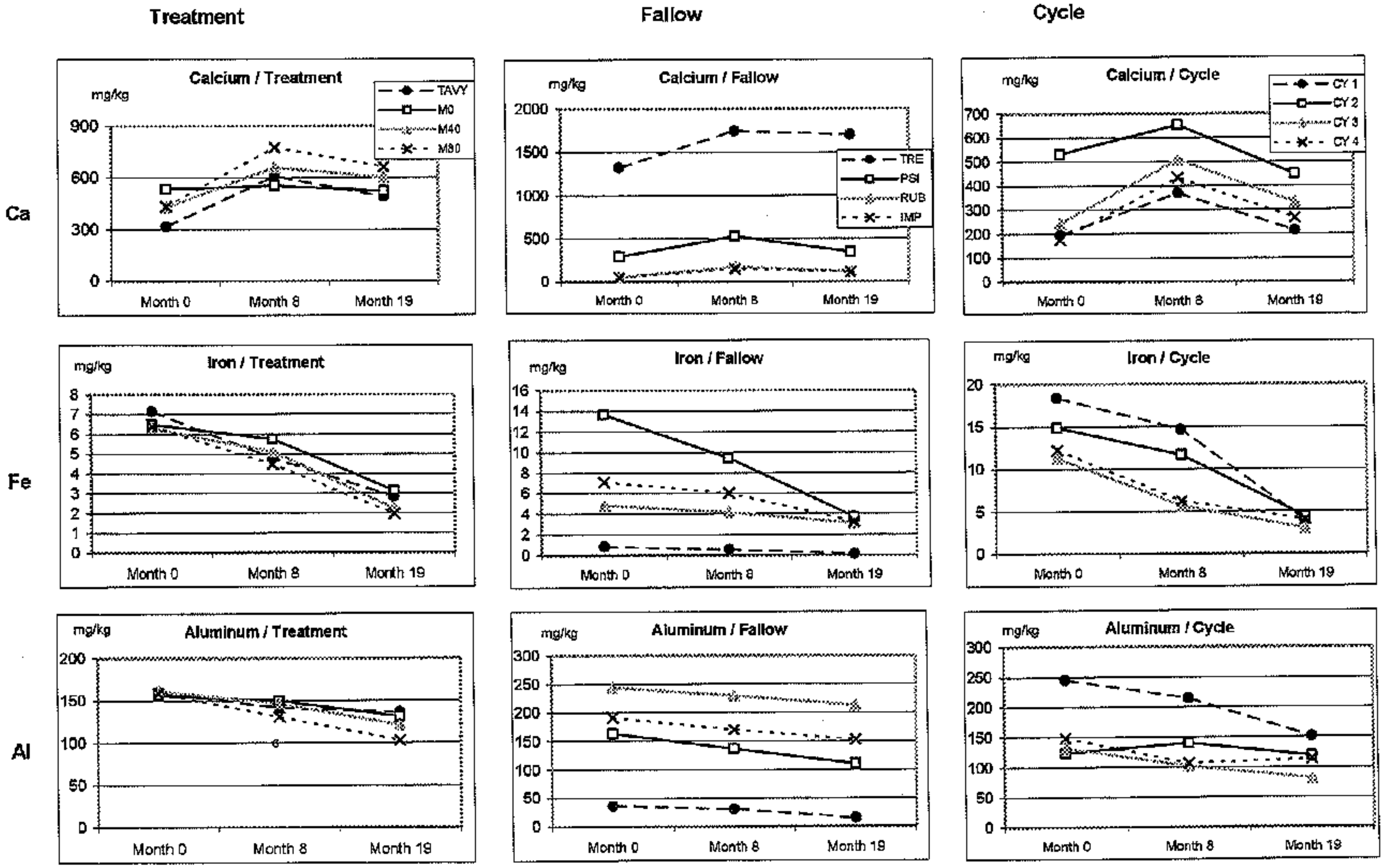


Figure 34: (Continued)

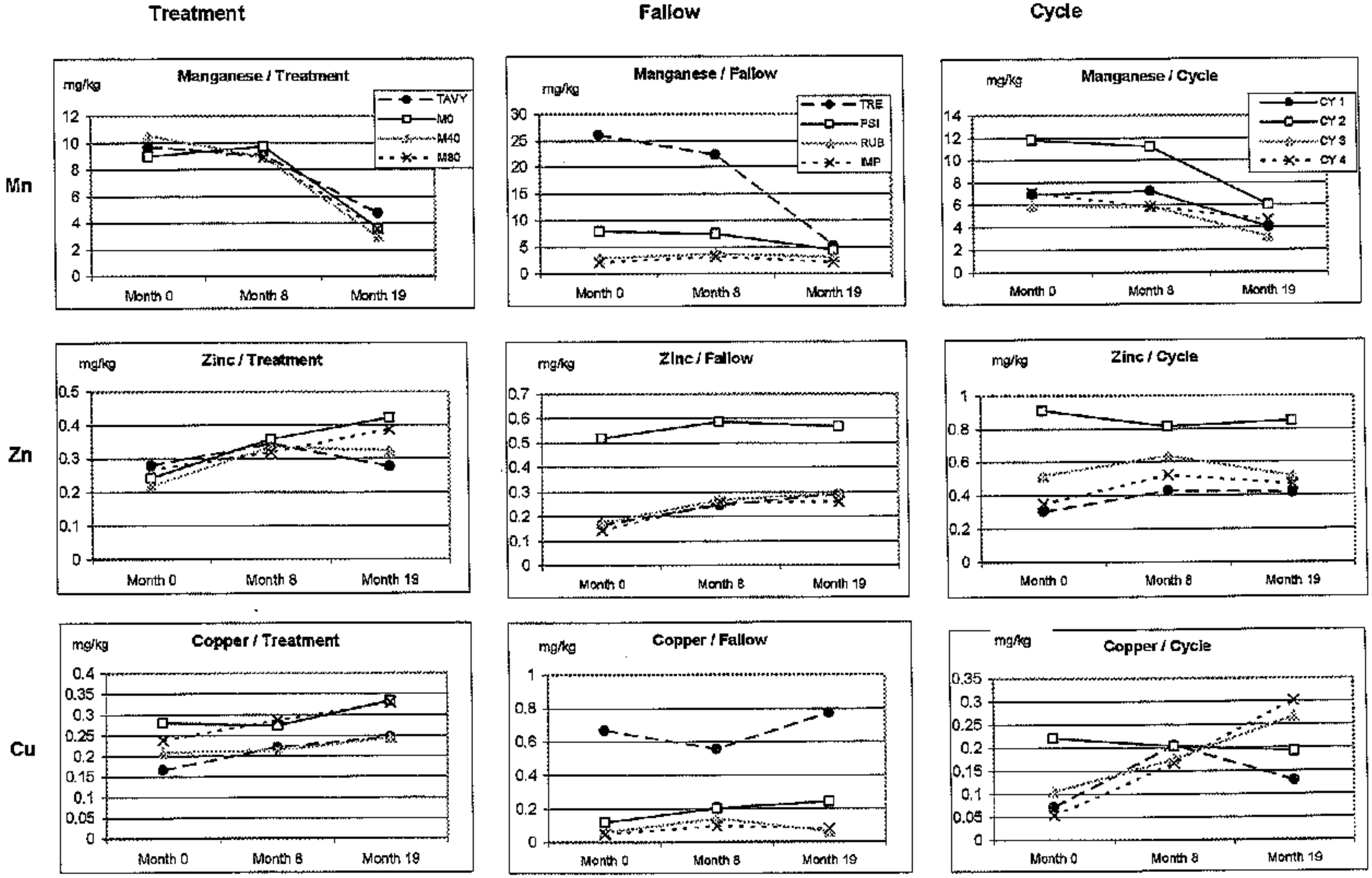
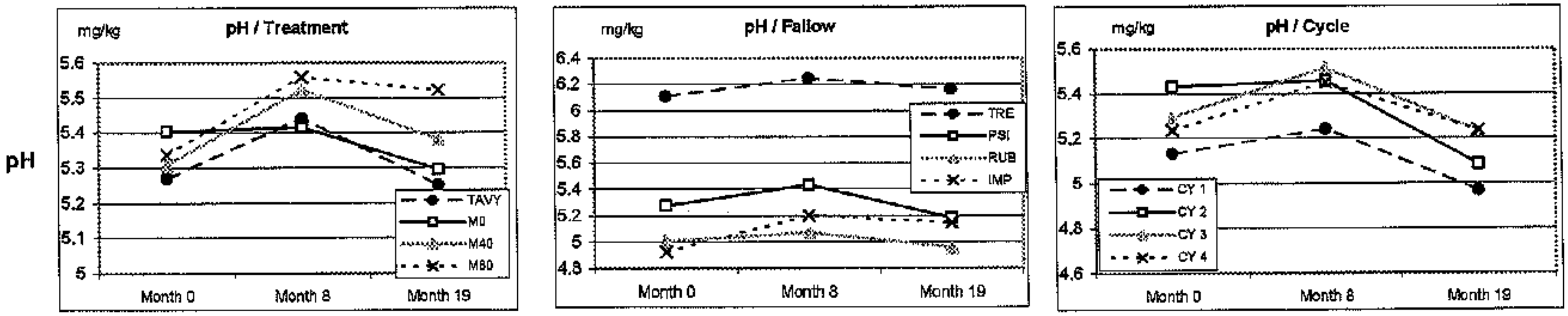


Figure 34: (Continued)



Treatment

Fallow

Cycle

Potassium: The potassium did not show significant differences between treatments, but only for the main factor time, which averages out all treatments. It showed that potassium increased significantly from Time 1 to Time 2 and decreased significantly from Time 2 to Time 3 across treatments from 54 mg/kg to 75 mg/kg to 25 mg/kg, respectively.

Magnesium: Magnesium performed similarly to potassium, with no significant differences between the treatments except for at Time 3, where the *tavy* treatment had significantly lower values (55mg/kg) than the mulch treatments (62-69 mg/kg). Looking at the time effect across treatments, we notice a significant rise in available nutrients, from 62 mg/kg at Time 1 to 94 mg/kg at Time 2, a figure that had dropped to the initial value (63mg/kg) by the end of the experiment.

Calcium: Calcium showed no significant differences between treatments but did so in the time analysis within each treatment, excepting M0. For this treatment the calcium level remained almost equal throughout the experimentation at 518 mg/kg, 559 mg/kg, and 527 mg/kg, for Times 1, 2, and 3, respectively. The values for M40 and M80 rose significantly from Time 1 to Time 2 and remained significantly higher at Time 3 compared with the value at Time 1. M40 concentrations evolved over time, from 431 mg/kg to 660 mg/kg to 596 mg/kg, while for M80 this was 434mg/kg, 775mg/kg, and 663 mg/kg, respectively. The *tavy* treatment rose significantly, from 328 mg/kg to 608 mg/kg, but then dropped significantly, back to 497 mg/kg after the ginger crop.

Aluminum: Exchangeable aluminum decreased in all the treatments during experimentation. It dropped the furthest for GP treatments while M80 showed a significant difference from *tavy* at Time 3. Values at the beginning were between 155 and 161 mg/kg for all treatments. In the end, M80 had the lowest concentrations at 103 mg/kg. They were higher for M40, M0, and *tavy*, at 122 mg/kg, 131 mg/kg, and 136 mg/kg, respectively.

Iron: Iron concentration dropped significantly for all treatments, from 6.6 mg/kg to 5.0 mg/kg to 2.5 mg/kg over the experimental period, looking at the time effect only. Differences weren't significant between the treatments. The exception occurred in Time 3, when M0 had higher values at 3.12 mg/kg, compared with those of M40 and M80 at 2.22 and 1.95 mg/kg, respectively. *Tavy* occupied an intermediary position at 2.8mg/kg.

Manganese: Exchangeable Mn in the soil solution diminished significantly for all treatments from Time 1 to Time 3, from 9.7 mg/kg to 3.8 mg/kg across all treatments. At Time 3, *tavy* had the highest concentrations at 4.7 mg/kg, followed by M0 and M80, both at 3.6 mg/kg, and finally M40 at 2.9 mg/kg.

Zinc: Zinc increased significantly for all mulch treatments over the course of the experimentation period, reaching between 0.32 to 0.43 mg/kg, whereas it remained at the same level in *tavy* (0.26mg/kg). In *tavy*, the change from Time 1 to Time 3 produced a 4% decrease, whereas in M80, M40, and M0 it was a 45%, 50%, and 70% rise, respectively.

Copper: Copper concentrations in the soil solution increased over the period of the experiment, but the differences were not significant between the treatments and between the time periods within a treatment, except for the main factor time. There, a significant increase could be observed, rising from 0.224 mg/kg at Time 1 to 0.290 mg/kg at Time 3.

pH: Soil pH showed little variation between treatments for all three times, but was different for the change over time within the four treatments. For all treatments, pH increased significantly at Time 2, but dropped to the initial values at Time 3 (which was between pH 5.24 and 5.39) except for M80, which maintained the raised level at Time 3 with a pH of 5.52.

2.2 Fallow and cycle effect

Fallow and cycle studies can be considered complementary, as both are representative of the degradation sequence. This sequence parallels the fallows transition from tree to shrubby to herbaceous fallows. And with each additional cycle, soil fertility level is assumed to decrease. Both fallow and cycle, however, exhibit variability. The fallows exist at different sites/locations while the cycles involve varying topographical influences. Results for fallow and cycle are presented together in summarized form.

Fallow/cycle effect

For P, K, Mg, and Ca as well as pH, higher values were found under *Trema* fallow than under either shrubby or *Imperata* fallows. Aluminum showed the inverse pattern, with lowest concentrations in *Trema* and highest in *Imperata*.

C2 had the highest values in K, Mg, Ca, Mn, Zn, and pH, whereas C1 obtained the highest P values and in K, Mg, and Ca, it was on a level that was similar to C3 and C4. A lower pH and the highest Al values were also noted for C1, which may have been caused by the shortness of the time span since deforestation, indicating that the soil is still in the transition from a forest to an agricultural soil. Moreover, C1 was located on the upper part of the hill; it might have already suffered severe erosion during its first cultivation cycle.

Time effect

The change in soil nutrient concentration over time can be summarized as follows: For all the macronutrients, the early succession soils had higher values in the beginning of the experimentation compared with the soils with a longer cropping history. At the end of the experimentation, phosphorus values had dropped to almost 0, independently of initial soil fertility status. Also independently of initial values, K concentrations ended at similar low concentration levels (between 20 and 25mg/kg) for all fallows and cycles. Mg levels settled at similar or slightly lower values than in Time 1, whereas Ca levels increased slightly over time, except in C2. The pH under fallow was similar at Time 3 to its value at Time 1, whereas for the cycles the pH had dropped slightly by the end. A definite decline over the cropping period could be seen for Fe, Al, and Mn for all the fallows and cycles. The within-cycle time effect comparison shows similar trends to fallow for all the major macronutrients. But in the cycle comparison, the proportional drop in nutrient concentrations from Time 1 to Time 3 becomes more pronounced for the earlier cycles compared with that of the more advanced cycles. This is most obvious with P and K, but is also remarkable for Mg and Ca and pH. This shows the vulnerability of these soils to nutrient depletion in the early cycles, and implies that careful nutrient management should be in effect from the second cycle onward.

3. Nutrient concentrations in crops

Nutrient concentration for tree crops, upland rice, beans, and ginger was analyzed for grain and root and for straw. Analysis was done by looking at the treatment, fallow, and cycle effects separately. The results are reported in Figures 35-37 for the macronutrients and in Appendices 18-20 for the elements N, P, K, Mg, Ca, S, Al, Mn, Zn, Fe, B, Ni, Cu, Na, Co, V, and C.

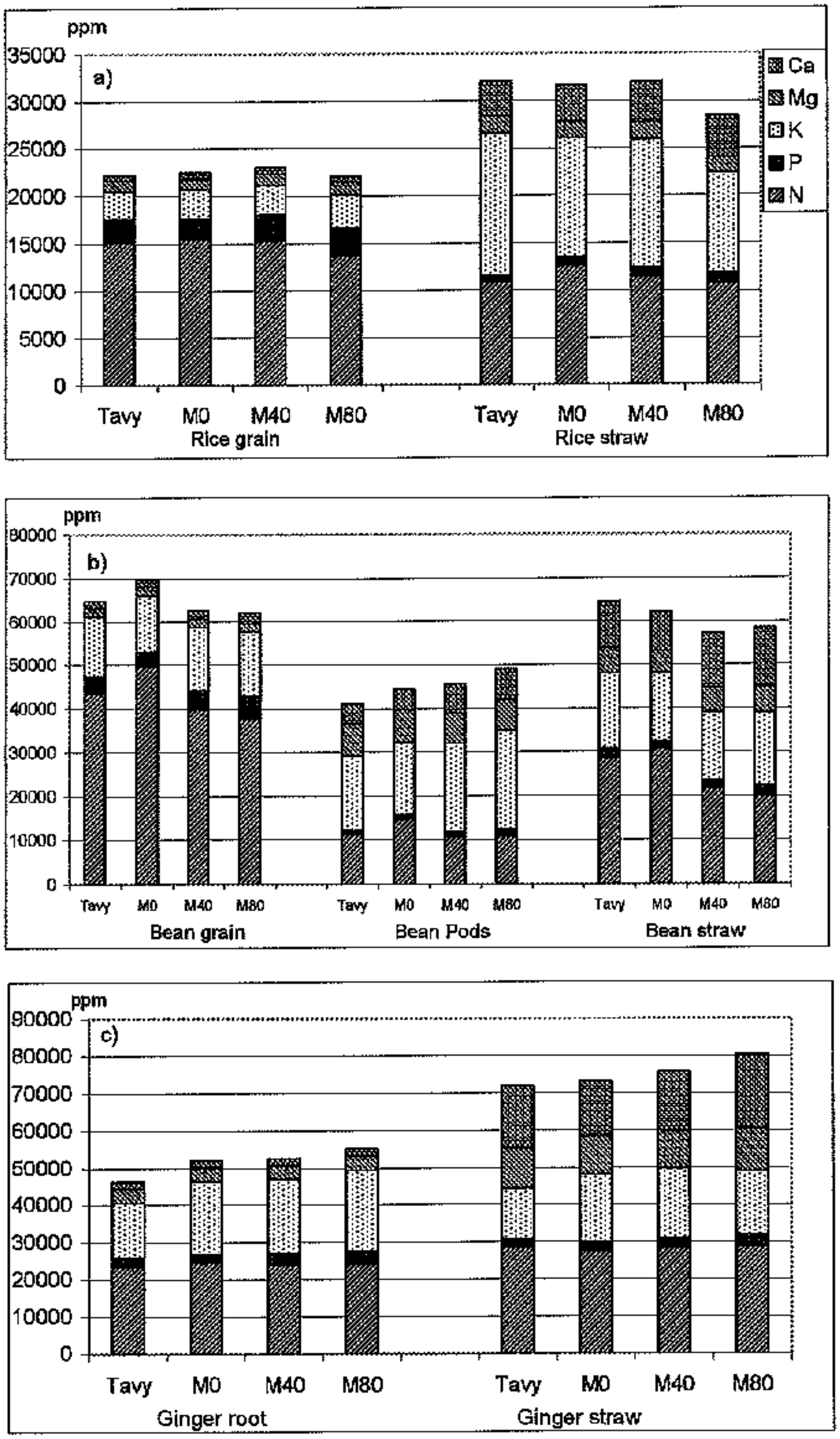


Figure 35: Nutrient concentrations for a) rice grain and straw, b) bean grain, pods, straw, c) ginger root and straw for four treatments

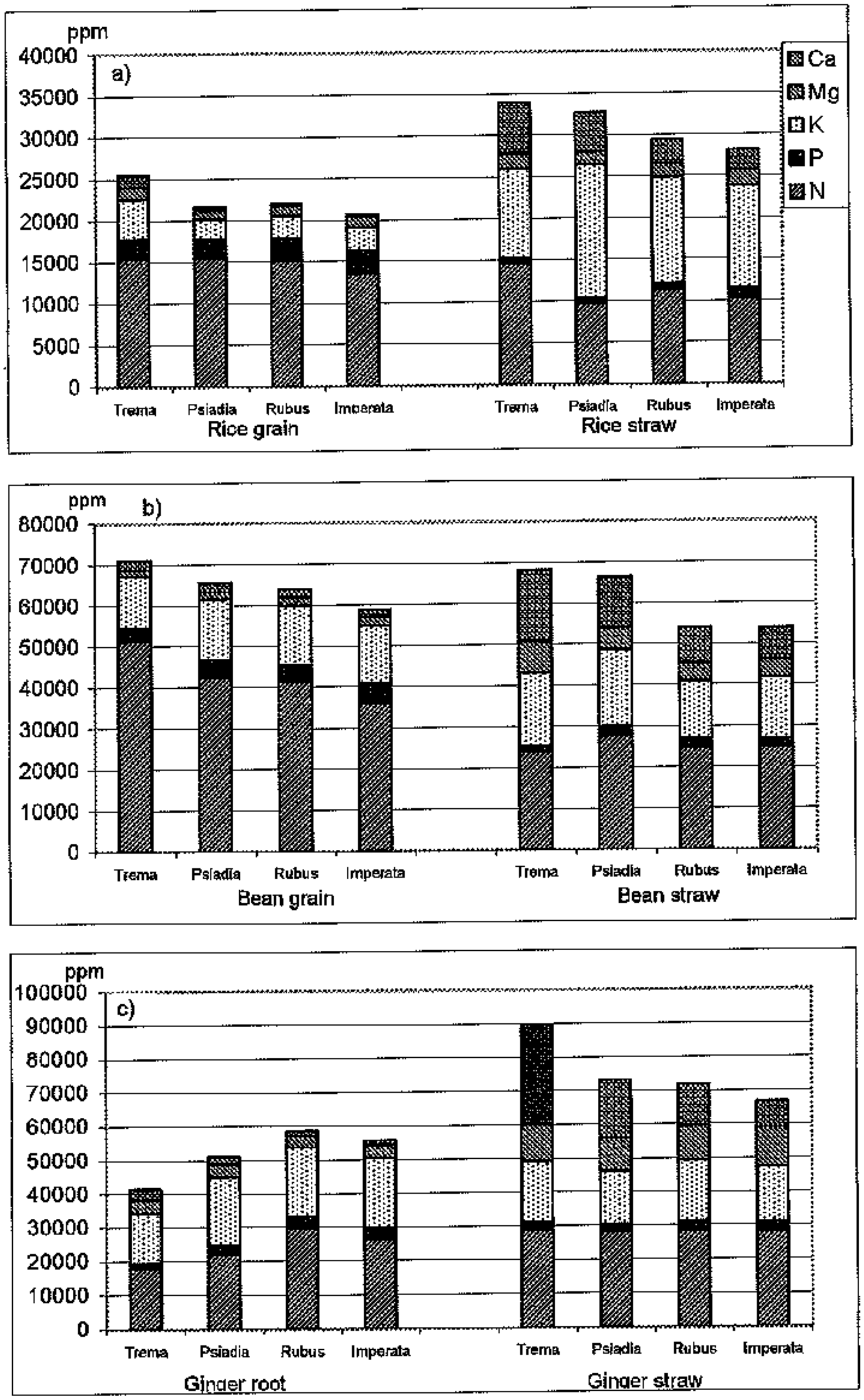


Figure 36: Nutrient concentrations for a) rice grain and straw, b) bean grain, pods, straw, c) ginger root and straw for four fallows

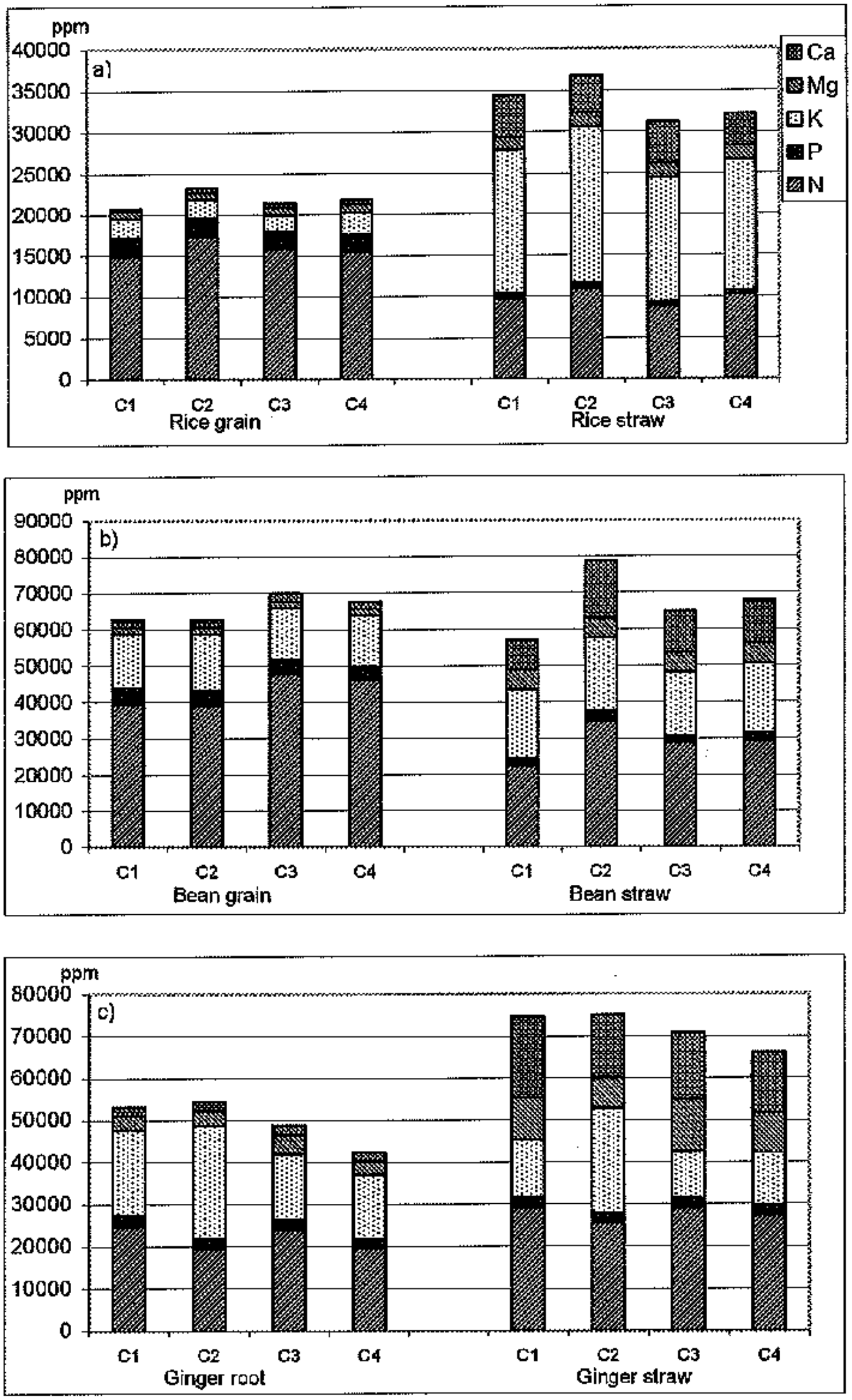


Figure 37: Nutrient concentrations for a) rice grain and straw, b) bean grain, pods, straw, c) ginger root and straw for four cycles

3.1. Treatment effects

Phosphorus was the only element that showed increases in all crops of 30-50% for harvested products and straw in the GP treatments as compared with *tavy* and M0. The increases were higher for M80 than for M40. *Tavy* and M0 had similar low values, showing no distinct effects of burning for *tavy* or of mulching for M0. Calcium uptake increased with guano applications, which added 225kg/ha of Ca in M40 and 450kg/ha of Ca in M80. Higher concentrations could be observed in grain/root and straw, especially for the beans and ginger, but there was no significant difference in the rice crop. *Tavy* and M0 had similar lower values. Zinc was another element that increased with guano application in rice and bean grain, although the differences weren't significant. Given the nutritional importance of this element, this effect should be further studied in relationship to management practices that could optimize the expression of this trend. Nitrogen showed no differences in the rice and ginger crop. Significantly lower values were observed with the GP treatments in bean grain and straw, indicating a possible dilution effect as yields in these treatments were 2.2 (M40) and 3.3 (M80) times higher than in *Tavy*. Potassium levels were initially similar between the treatments in rice and beans but showed a significantly lower value with the third crop in the *tavy* treatment. This may indicate K depletion from the system in the *tavy* treatment, whereas under mulching K was retained. The available K in soil after the ginger crop was, in the *tavy* treatment, significantly lower at 20 mg/kg than under GP treatments at 25 and 26 mg/kg. Magnesium concentration was not significantly different in straw and harvested products for the three crops. It seems thus that the concentration of this element was affected neither by treatments nor by the cropping period of the three crops, and may not be a limiting element in the system. Iron, another important micronutrient in human nutrition, showed no tendencies in rice grain, but a slight increase in beans in M80 was noted. Aluminum showed high accumulations in ginger root and bean straw. In both cases, *tavy* and M0 had the highest values, while M80 lowered concentrations considerably, although the differences weren't significant.

3.2. Fallow and cycle effects

Nitrogen concentration in rice and bean plant tissues increased with increasing soil fertility, but showed a decrease in ginger root on the *Trema* soil, where the crop exhibited very low productivity. There was no difference for the cycles. Phosphorus concentration decreased for bean grain and ginger root with advancing cycles, but on the other hand, it increased significantly in all crops from *Trema* to *Imperata*, an unexpected result. This might be explained by a dilution effect or concentration increase with declining yields. It might also be due to more efficient soil microbial associations in the more highly degraded soils involving, for example, mycorrhizal species. Mycorrhiza play an important role in taking up P, especially in P-deficient soils. Also possibly supporting this assumption was the higher P concentrations in *Imperata* and *Rubus* root that we found in the fallow study (see Chapter 4). While potassium concentrations showed no clear tendencies, it showed some increase with increasing soil fertility for fallow and cycle. We observed lower values in bean grain and ginger root in the *Trema* fallow. Calcium's response to fallow and cycle was the most consistent and clearest among the elements. It showed significant concentration increases in all crops with increasing soil fertility. Mg, S, and Zn showed no persistent trends. Higher aluminum tissue concentrations were found on the more highly degraded soils.

3.3. Ginger leaf deficiencies

Many ginger leaves exhibited deficiency symptoms with a lighter coloring and welting of the leaf tips. Samples were taken of leaves showing the typical symptoms and leaves that were seemingly healthy, presenting a dark green color. The results of the analysis are reported in Table 37b. N, P, and K were the elements that showed the most pronounced decline in concentrations for the deficient-looking leaves. The deficient leaves reached only 32% in K, 67% in P, and 75% in N of healthy leaf concentrations. On the other hand, the deficient leaves exhibited higher levels of Mg (130%) and Ca (157%) compared with those of healthy leaves. For S and Zn, levels were lower in deficient leaves at 80% and 77%, respectively, whereas for boron and sodium they slightly exceeded the healthy leaves with 110% and 111%. Most dramatic were the higher levels of Al, Fe, and Mn in deficient leaves, representing 380%, 256%, and 224% of the concentrations found in green leaves.

Table 37b: Nutrient concentration of ginger leaves with and without deficiency symptoms (Averages with SE, n=8, in % for N and in mg/kg for all other nutrients)

	N	SE	P	SE	K	SE
Deficient	3.10	0.0511	2142	78.0	4976	488.9
Non deficient	4.12	0.0511	3210	78.0	15782	488.9
def/non def %	75		67		32	
	MG		CA		S	
Deficient	13645	317.3	13865	538	3515.07	221.6
Non deficient	10470	317.3	8828	538	4371.19	221.6
def/non def %	130		157		80	
	AL		MN		FE	
Deficient	859.93	133.1	1239.59	54.38	365.87	36.11
Non deficient	226.12	133.1	552.99	54.38	143.02	36.11
def/non def %	380		224		256	
	NA		ZN		B	
Deficient	101.37	10.43	17.2889	0.398	51.8823	1.78
Non deficient	91.5139	10.43	22.4382	0.398	46.9672	1.78
def/non def %	111		77		110	

4. Nutrient uptake (kg/ha), nutrient harvest index, recycled nutrients and exported nutrients

4.1. Nutrient uptake in the four treatments

Nutrient uptake for all three crops for macro- and micronutrients are reported in Appendix 21 and also in Figure 38.

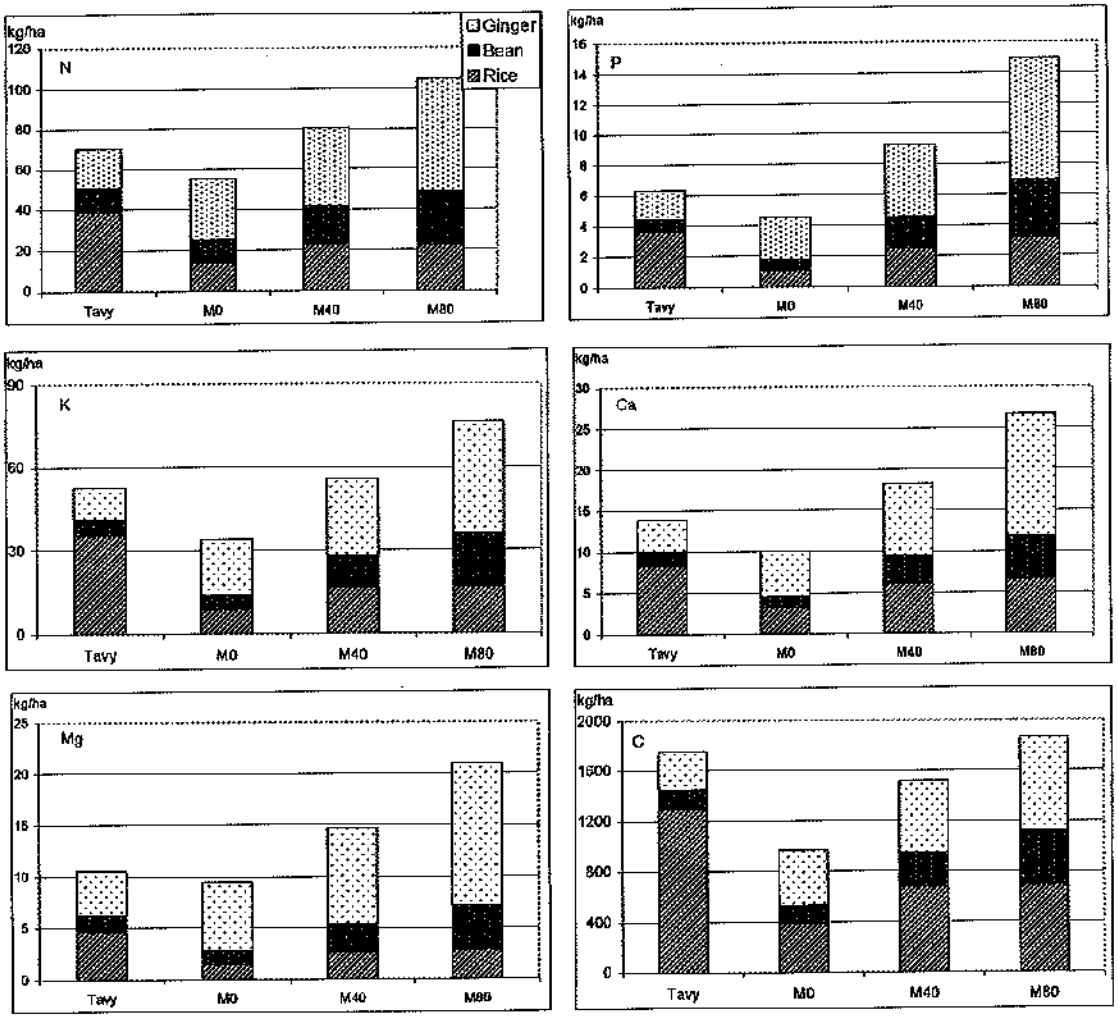


Figure 38: Macronutrient uptake and carbon sequestration (kg/ha) for three crops in four treatments

4.1.1. Total nutrient uptake over entire rotation of three crops

Macronutrients

For all the macronutrients N, P, K, Ca, Mg, and S, M80 had the highest uptake of nutrients over a period of three crops, followed by M40, *Tavy*, and finally M0. The uptake in kg/ha for M80 of N, P, K, Ca, and Mg was 105, 14.9, 76, 26.8, and 14.7, respectively. The uptake for M40 was between 62% and 76% of that in M80. In the *tavy* treatment the crops took up between 42%and 70% of M80's, with P having the lowest and K the highest percentage. M0 took up the least nutrients of all the treatments, only 30-52% of what M80 took up. The largest differences in uptake were of P, followed by Ca and Mg, and smaller differences were observed involving N and K.

Other nutrients

For the other nutrients, the highest uptakes happened in M80 for Fe, B, Ni, Co, Zn, Al, and Na. *Tavy* had the highest Mn uptake. M0 again obtained the lowest values. Rice accumulated most of the Mn, Co, and Ni whereas it had very low uptake of Al. Ginger accumulated Fe, B, Al, and Na and beans accumulated Fe, Al, and B.

4.1.2. Nutrient uptake for each of the three crops

The rice crop took up the most nutrients with the *tavy* treatment, while the bean and ginger crops took up the most nutrients with the guano treatment. Looking at the distribution of nutrient uptake among the three crops for each treatment, two groups can be distinguished, namely the *tavy* and mulch treatments (see Table 38).

In the *tavy* treatment, between 55 and 67% of the macronutrients N, P, K, Ca, and S were taken up in the rice crop, while for Mg it was 44%. The bean crop received 11 - 17% of all the nutrients while for ginger the uptake ranged between 23 and 29%, except for Mg, which was at 41%. In the mulch treatments, on the other hand, between 24 and

Table 38: Percentage of nutrient uptake between three crops for four treatments

	N				P				K			
	Rice	Bean	Ginger	total	Rice	Bean	Ginger	total	Rice	Bean	Ginger	total
M0	25	21	54	100	25	16	59	100	26	15	59	100
M40	29	23	48	100	27	22	51	100	30	20	50	100
M80	21	25	54	100	21	25	54	100	22	25	53	100
Tavy	55	17	28	100	57	14	29	100	67	11	23	101

	Mg				Ca				S			
	Rice	Bean	Ginger	total	Rice	Bean	Ginger	total	Rice	Bean	Ginger	total
M0	15	15	70	100	32	14	54	100	30	14	56	100
M40	18	19	63	100	33	19	48	100	33	20	47	100
M80	14	21	66	101	25	19	56	100	27	24	49	100
Tavy	44	15	41	100	60	13	28	101	60	11	29	100

30% of the macronutrients were taken up by rice, except for Mg with an uptake of 16%. The uptake for beans was 18-23%, and for ginger it was 51-55%, except for Mg at 66%. The nutrient distribution between the three crops stayed proportionally similar for the various nutrients except for Mg. A higher allocation of Mg went into ginger and less into rice, whereas the proportion allocated for beans was similar to allocations of other nutrients. This may lead to the assumption that ginger may be an especially Mg-needy crop. These results show that nutrients in the *tavy* treatments were taken up at the beginning of the rotation and declined rapidly with the second crop, whereas nutrients in the mulch treatments weren't optimally available in the beginning, but had a residual effect in the later stages of rotation.

4.1.3. Nutrient uptake distribution within a crop

The distribution of nutrients within a crop can be expressed by the nutrient harvest index or NHI. NHI is the ratio obtained when the nutrients allocated in the harvested product are divided by the total nutrients in the crop (harvested product and straw). Differences among treatments were not significant and there were no clear trends to detect. I thus limit the discussion to the differences between crops. The average nutrient harvest indices from all the plots (n=88) are reported in Table 39.

Table 39: Nutrient harvest index (average of all plots: n=88)

	N	P	K	Mg	Ca	S
Rice	0.43	0.68	0.14	0.30	0.10	0.31
Beans	0.73	0.75	0.44	0.24	0.21	0.53
Ginger	0.60	0.65	0.67	0.34	0.19	0.54

A high nutrient harvest index indicates a preferential allocation of nutrients to the harvested product. This can translate into some benefits for human nutrition. At the same time, it implies higher nutrient exports from the system. A low nutrient harvest index is preferable in cases where crop residues return to the field, which assures that nutrients are retained and recycled within the system. Looking at the latter aspect, it can be concluded that phosphorus is rapidly exported from the system with a high NHI for all crops (0.65-0.75), whereas most of the Ca is allocated in the straw (0.10-0.21). Comparing the three crops, rice has the lowest NHI overall, so nutrients are therefore better preserved if residues are recycled, whereas for ginger, a larger portion of the nutrients accumulated in the roots and were thus exported. Beans tended also to export a higher percentage of nutrients, especially of N, P, and S. The biggest difference among the crops was detected for K, where 67% of the nutrients were exported in ginger, whereas only 14% were exported in rice.

4.1.4. Recycled and exported nutrients

The recycled nutrients were contained in the crop residues, which for the mulch treatments were rice straw, bean pods and straw, and ginger straw. In the *tavy* treatment, rice and bean residues were removed from the field according to traditional practices. Ginger leaves were the only recycled residues, as they shed naturally one month before the harvest. The amount of the major macronutrients recycled is presented in Table 40. Exported nutrients for the mulching treatment comprised only the harvested crop components, whereas for *tavy* it included in addition rice and bean straw and pods. The amount of all exported macronutrients for all three crops is reported in Table 41.

For N, K, and S the recycled nutrients were similar in M80 and M40, but they were significantly higher then in M0 and *Tavy*. For P, Ca, and Mg, the differences were significant in each of the treatments, with the highest amounts observed in M80, followed by M40, M0, and *tavy*.

Highest nutrient exports of K, Mg, Ca, and S occurred in the *tavy* treatment, although the differences from M80 in the second position weren't significant. N and P experienced the highest exports in M80, which was especially pronounced for P, where 10.5 kg/ha were exported in M80 followed by M40 with 6.1 kg/ha, *Tavy* with 5.6 kg/ha, and finally M0, with a significantly inferior 3.1 kg/ha. Most nutrients in *tavy* were exported with the rice crop, whereas most nutrients in GP were lost through ginger root export.

An overview of total nutrient uptake, nutrients recycled, and nutrients exported in kg/ha over the cultivation period of three crops for each of the four treatments is presented in Table 42.

Table 40: Recycled nutrients (kg/ha) for rice, beans and ginger and the sum of all three crops for 4 treatments

	C		SE	N		SE	P		SE	K		SE	Mg		SE	Ca		SE	S		SE
Rice																					
TAVY	-			-			-			-			-			-			-		
M0	289		65.52	9.1		2.65	0.43	b	0.155	9.4		3.83	1.15		0.366	3.02	b	1.056	1.37		0.433
M40	473		65.52	13.6		2.65	0.85	a	0.155	16.3		3.83	2.01		0.366	5.75	a	1.056	2.12		0.433
M80	424		106.10	12.6		3.79	0.78	a	0.227	13.8		5.60	1.84		0.548	5.48	a	1.565	1.85		0.636
p-value	0.080			0.184			0.025			0.176			0.070			0.039			0.208		
Beans																					
TAVY	-			-			-			-			-			-			-		
M0	70	c	7.91	3.5	c	0.41	0.18	c	0.045	3.0	c	0.46	1.13	c	0.124	1.20	c	0.246	0.39	c	0.069
M40	134	b	7.91	4.8	b	0.41	0.47	b	0.045	6.2	b	0.46	2.13	b	0.124	2.88	b	0.246	0.85	b	0.069
M80	196	a	12.45	6.6	a	0.65	0.88	a	0.072	10.5	a	0.77	3.15	a	0.210	3.99	a	0.378	1.16	a	0.113
p-value	<.0001			0.001			<.0001			<.0001			<.0001			<.0001			<.0001		
Ginger																					
TAVY	111	b	26.28	6.7	d	1.57	0.53	c	0.180	2.9	c	1.12	2.52	d	0.604	2.79	c	0.693	0.87	c	0.191
M0	182	b	26.30	12.1	c	1.57	0.97	c	0.180	6.9	b	1.12	4.39	c	0.605	4.37	c	0.695	1.52	b	0.192
M40	289	a	26.30	17.7	b	1.57	1.94	b	0.180	11.7	a	1.12	6.58	b	0.605	7.65	b	0.695	2.13	a	0.192
M80	369	a	36.63	23.9	a	2.18	2.99	a	0.254	12.8	a	1.58	9.74	a	0.840	12.94	a	1.000	2.62	a	0.267
p-value	<.0001			<.0001			<.0001			<.0001			<.0001			<.0001			<.0001		
Total 3 crops recycled																					
TAVY	96	c	72.38	7.0	c	2.77	0.59	d	0.231	1.3	c	3.80	2.78	d	0.654	2.74	d	1.160	0.76	c	0.432
M0	552	b	73.12	25.0	b	2.79	1.66	c	0.232	20.0	b	3.83	6.85	c	0.657	8.75	c	1.171	3.37	b	0.436
M40	869	a	73.12	35.4	a	2.79	3.13	b	0.232	33.9	a	3.83	10.40	b	0.657	15.75	b	1.171	5.06	a	0.436
M80	1007	a	119.89	42.6	a	4.45	4.70	a	0.366	38.0	a	5.99	14.93	a	1.050	22.18	a	1.897	5.53	a	0.699
p-value	<.0001			<.0001			<.0001			<.0001			0.008			<.0001			<.0001		

* Means that are followed by the same letter are not signficantly different at $p<0.05$

Table 41: Nutrients exported (kg/ha) by rice, bean and ginger and sum of all three crops for 4 treatments

	C		SE	N		SE	P		SE	K		SE	MG		SE	CA		SE	S		SE
Rice																					
Tavy	1248		12595	38.2	a*	3.45	3.54	a	0.371	34.00	a	3.163	4.61	a	0.388	8.29	a	1.024	4.92	a	0.442
M0	138		12595	5.3	b	3.45	0.70	c	0.371	0.05	b	3.169	0.33	b	0.389	0.17	b	1.025	0.45	b	0.442
M40	241		12595	9.9	b	3.45	1.65	bc	0.371	0.94	b	3.169	0.70	b	0.389	0.33	b	1.025	0.78	b	0.442
M80	265		19637	10.8	b	5.11	2.37	ab	0.538	4.43	b	5.074	1.20	b	0.599	1.94	b	1.613	1.22	b	0.691
p-value	1.000			<.0001			<.0001			<.0001			<.0001			<.0001			<.0001		
Bean																					
Tavy	137	b	11.0	11.1	c	0.96	0.81	c	0.121	5.16	b	0.413	1.41	a	0.094	1.53	a	0.124	0.89	b	0.071
M0	72	c	11.1	8.3	c	0.98	0.54	c	0.123	2.23	c	0.421	0.33	c	0.095	0.29	c	0.126	0.44	c	0.072
M40	154	b	11.1	14.8	b	0.97	1.76	b	0.122	5.63	b	0.417	0.77	b	0.094	0.77	b	0.125	0.96	b	0.072
M80	237	a	16.5	19.9	a	1.39	2.94	a	0.184	8.79	a	0.636	1.24	a	0.143	1.49	a	0.191	1.46	a	0.108
p-value	<.0001			<.0001			<.0001			<.0001			<.0001			<.0001			<.0001		
Ginger																					
Tavy	199	c	17.4	12.1	c	1.61	1.23	c	0.225	7.64	c	1.482	1.77	c	0.169	0.91	c	0.082	1.36	c	0.128
M0	273	b	16.7	18.4	b	1.61	1.76	c	0.226	14.00	b	1.484	2.28	c	0.170	1.15	c	0.082	1.85	b	0.129
M40	316	b	17.2	22.3	b	1.61	2.93	b	0.226	18.58	b	1.484	2.89	b	0.170	1.46	b	0.082	2.05	b	0.129
M80	434	a	25.5	33.1	a	2.21	5.06	a	0.312	28.06	a	2.046	4.06	a	0.247	2.16	a	0.127	2.63	a	0.179
p-value	0.001			<.0001			<.0001			<.0001			<.0001			<.0001			<.0001		
Total nutrients exported by three crops																					
Tavy	1629		14819	61.1	a	4.10	5.59	b	0.501	46.38	a	3.876	7.81	a	0.458	10.73	a	1.090	7.12	a	0.497
M0	501		13867	32.2	b	4.12	3.05	c	0.504	16.04	b	3.907	2.94	c	0.461	1.62	b	1.093	2.74	c	0.500
M40	709		14353	46.0	b	4.11	6.11	b	0.502	24.14	b	3.890	4.16	bc	0.459	2.48	b	1.091	3.70	bc	0.499
M80	939		23128	65.6	a	6.27	10.48	a	0.770	42.73	a	5.930	6.44	ab	0.726	5.64	a	1.715	5.43	ab	0.777
p-value	1.000			<.0001			<.0001			<.0001			<.0001			<.0001			<.0001		

* Means that are followed by the same letter are not signficantly different at p<0.05

Table 42: Total nutrient uptake, total nutrients recycled, and total nutrients exported (kg/ha) over the cultivation period for three crops and percentage of total nutrients recycled, for four treatments

	N				P				K			
	Total	RYC*	EXP*	ryc	Total	RYC	EXP	% recy	Total	RYC	EXP	ryc
	kg/ha			%	kg/ha			%	kg/ha			%
TAVY	68	7	61	10	6.2	0.6	5.6	10	48	1	46	3
M0	57	25	32	44	4.7	1.7	3.1	35	36	20	16	56
M40	81	35	46	43	9.2	3.1	6.1	34	58	34	24	58
M80	108	43	66	39	15.2	4.7	10.5	31	81	38	43	47
	Mg				Ca				S			
	Total	RYC	EXP	ryc	Total	RYC	EXP	% recy	Total	RYC	EXP	ryc
	kg/ha			%	kg/ha			%	kg/ha			%
TAVY	10.6	2.8	7.8	26	13.5	2.7	10.7	20	7.9	0.8	7.1	10
M0	9.8	6.9	2.9	70	10.4	8.7	1.6	84	6.1	3.4	2.7	55
M40	14.6	10.4	4.2	71	18.2	15.8	2.5	86	8.8	5.1	3.7	58
M80	21.4	14.9	6.4	70	27.8	22.2	5.6	80	11.0	5.5	5.4	50

* RYC: recycled, EXP: exported

Looking at the percentage of nutrients recycled and exported, the values were similar for the mulch treatments. Approximately 40% of N was recycled, as were ca 30% of P, ca 50% of K and S, ca 70% of Mg, and ca 80% of Ca. This shows again the critical position of P and the risk of its being mined. For the *tavy* treatment this looked very different, with only 3% of K, 10% of N, P, and S, 20% of Ca, and 26% of Mg recycled.

4.2. Nutrient uptake in four fallows

4.2.1. Total nutrient uptake over the entire rotation.

Nutrient uptake for the macro- and micro-elements is presented for all three crops in Figure 39 and Appendix 22. Increasing total nutrient uptake from *Imperata* to *Trema* was observed for most nutrients in the rice crop, a phenomenon that persisted in the bean crop. The situation changed with the ginger crop, with low productivity on *Trema* soil. The reasons were discussed in the yield section. The crops on the *Rubus* fallow had taken up most of the nutrients over the time of the rotation for N, P, K, Mg, and S, followed by crops on *Psiadia* and *Trema*. *Imperata*'s nutrient uptake for rice and beans combined represented only ca one-third of the nutrients taken up in the ginger crop.

Overall, the highest uptake of micro nutrients and other nutrients was observed also in Fe, B, Ni, Cu, Al, and Na for *Rubus*.

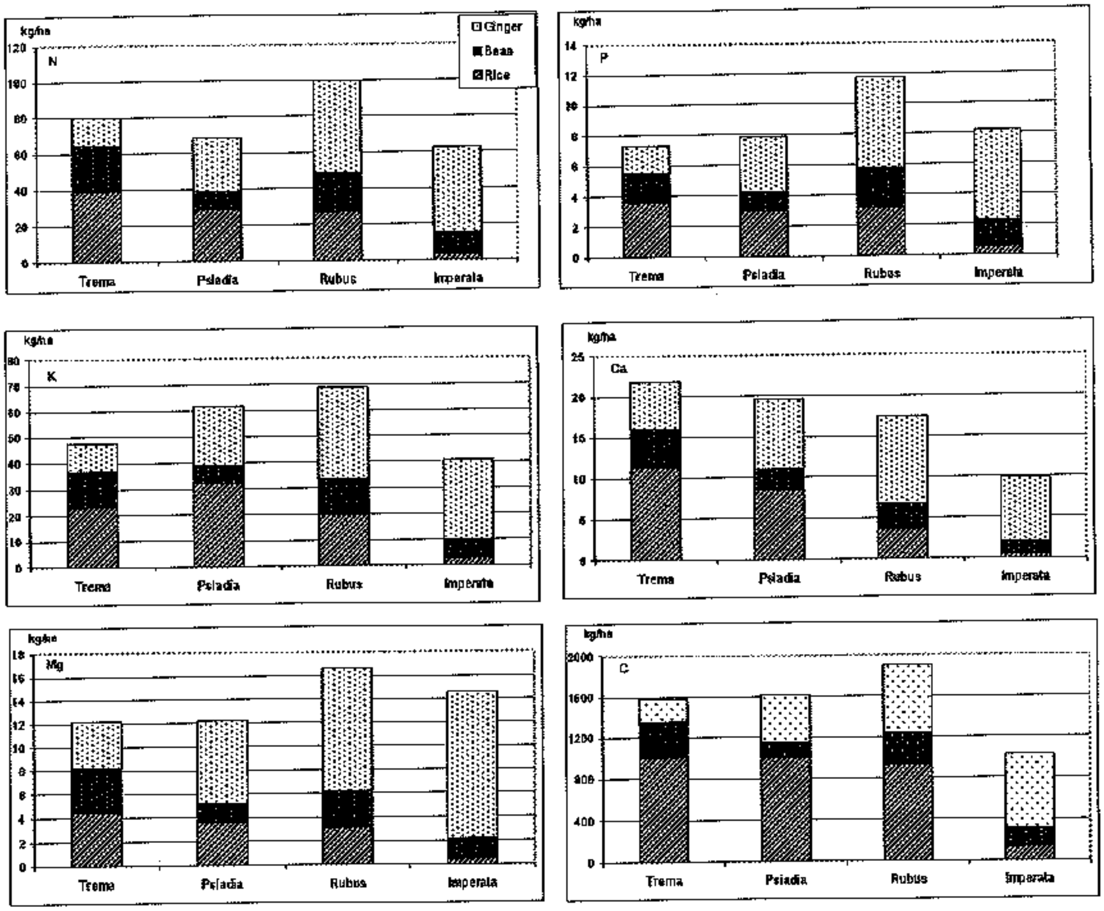


Figure 39: Macronutrient uptake and carbon sequestration (kg/ha) for three crop on four fallows

4.2.2. Nutrient uptake per crop

Looking at the percentage distribution of nutrient uptake between the crops for each of the fallows (Table 43) a dissimilar picture presents itself for the fertile and infertile soils. Whereas on *Trema* two-thirds of the nutrients were taken up in rice and beans, on *Imperata* two thirds were allocated in ginger. For *Rubus,* ca 50% was found in rice and beans and ca 50% of the total nutrients were attributed to ginger. For *Psiadia* that same

Table 43: Distribution of nutrients taken up between the three crops for the four fallows.

	N				**P**				**K**			
	Rice	Bean	Ginger	total	Rice	Bean	Ginger	total	Rice	Bean	Ginger	total
Trema	49	32	19	100	49	26	24	100	48	28	24	100
Psiadia	42	14	44	100	38	16	45	100	52	11	37	100
Rubus	27	21	52	100	27	22	51	100	29	20	51	100
Imperata	6	19	76	100	7	21	72	100	7	17	76	100

	Mg				**Ca**				**S**			
	Rice	Bean	Ginger		Rice	Bean	Ginger		Rice	Bean	Ginger	
Trema	37	30	33	100	52	21	27	100	58	25	17	100
Psiadia	29	13	58	100	44	13	44	100	49	13	38	100
Rubus	19	18	63	100	21	18	61	100	30	17	53	100
Imperata	3	12	85	100	5	16	80	100	7	17	76	100

ratio was ca 60:40, respectively. This again reflects very well the adaptation and requirements of the crops to soil and environmental conditions. Rice and beans were more dependent on fertile soils, whereas ginger was able to thrive on already degraded land. It also suggests that the more fertile soils found today at higher altitudes have lost due to the higher elevation some of their productivity. It showed also that the shrubby fallows such as *Rubus*, which grow on already half-degraded soils and at lower altitudes, demonstrate the best overall crop productivity if compared with the other situations in the region. Another observation refers the the cropping cycle length. Whereas rice and beans are short rotation crops of 3 to 5 months, ginger can accumulate nutrients over a period of 10 to 12 months.

4.2.3. Within-crop nutrient uptake distribution

The within-crop nutrient distribution (Nutrient Harvest Index) did not show any clear trends. It is therefore referred to the analysis done under the treatment section, which was based on the average values across all plots for each of the three crops.

4.2.4. Recycled and exported nutrients

In the fallow comparison, the recycled nutrients equal the nutrients in the straw because the treatment differences are not taken into account on the fallow comparison level. Summed up over the three crops, we detect a trend that wasn't visible by looking at each crop separately (Section c). The budgets of exported and recycled nutrients on the four fallows are presented in Tables 44-46. A higher percentage of crop nutrients were exported on the *Trema* fallow, followed by the two shrub fallows, with the *Imperata* fallow exporting the lowest percentage. This was the case for the macro-elements N, P, Mg, Ca, and S, except for K, of which the lowest export percentage was obtained on *Trema*. The latter is due to low ginger productivity on *Trema*, as ginger was accumulating and exporting abundant K in its roots. These results also indicate that crops on *Imperata* accumulated more nutrients in the vegetative parts and less in the harvested products, which translated finally to lower overall crop productivity on *Imperata*, confirming the degradation sequence.

Table 44: Total nutrient uptake, total nutrients recycled, and total nutrients exported (kg/ha) over the cultivation period of three crops and percentage of total nutrients recycled, for four fallows

	N				**P**				**K**			
	Total	RYC*	EXP	ryc	Total	RYC	EXP	ryc	Total	RYC	EXP	ryc
	----------- kg/ha -----------			%	----------- kg/ha -----------			%	----------- kg/ha -----------			%
Trema	81	26	55	32	7	2	6	24	49	23	26	47
Psiadia	72	25	48	34	8	2	6	27	65	25	40	39
Rubus	100	34	66	34	12	3	8	28	69	29	40	42
Imperata	62	26	36	42	8	3	5	36	40	16	24	40
	Mg				**Ca**				**S**			
	Total	RYC	EXP	ryc	Total	RYC	EXP	ryc	Total	RYC	EXP	ryc
	----------- kg/ha -----------			%	----------- kg/ha -----------			%	----------- kg/ha -----------			%
Trema	12	7	6	54	22	15	8	66	8	4	5	42
Psiadia	13	7	6	56	20	13	7	65	9	4	5	41
Rubus	17	11	6	64	17	14	4	78	10	4	6	43
Imperata	15	11	4	72	10	8	2	80	7	3	3	50

* RYC: recycled, EXP: exported

Table 45: Recycled nutrients (kg/ha) for rice, beans and ginger and the sum of all three crops for 4 fallows

	C			N			P			K			Mg			Ca			S		
	Mean		SE	Mean		SE	Mean		SE	Mean		SE	Mean		SE	Mean		SE	Mean		SE
Rice																					
Trema	412		98.0471	14.7		3.17	0.66		0.185	12.5		4.52	1.83		0.432	6.57	a	1.261	2.08		0.513
Psiadia	340		79.3176	8.9		2.61	0.57		0.152	13.9		3.68	1.45		0.346	3.96	ab	1.001	1.60		0.415
Rubus	352		77.9059	8.9		2.54	0.64		0.148	9.8		3.60	1.31		0.342	2.43	ab	0.993	1.17		0.408
Imperata	39		123.18	1.0		4.02	0.14		0.234	1.3		5.69	0.18		0.540	0.23	b	1.569	0.15		0.645
p-value	0.190			0.119			0.325			0.350			0.176			0.043			0.177		
Beans																					
Trema	144	a	11.0178	5.1	a	0.54	0.41	ab	0.056	6.7	a	0.67	2.39	a	0.189	3.06	a	0.323	0.80	a	0.089
Psiadia	74	b	8.3417	3.2	bc	0.39	0.37	ab	0.040	3.7	b	0.55	1.11	b	0.146	1.74	bc	0.246	0.58	ab	0.060
Rubus	123	a	8.1246	4.4	ab	0.41	0.47	a	0.042	6.7	a	0.49	1.92	a	0.140	2.06	ab	0.243	0.58	ab	0.067
Imperata	60	b	8.9175	2.0	c	0.41	0.26	b	0.042	2.5	b	0.49	0.95	b	0.140	0.97	c	0.243	0.37	b	0.067
p-value	<.0001			0.001			0.027			<.0001			<.0001			0.001			0.014		
Ginger																					
Trema	85	b	39.71	5.8	b	2.39	0.65	c	0.260	3.0	b	1.64	2.36	b	0.916	4.69	b	1.015	0.59	b	0.292
Psiadia	181	b	38.2562	12.1	b	2.30	1.23	bc	0.254	7.2	ab	1.59	4.41	b	0.886	7.27	ab	0.934	1.48	b	0.278
Rubus	334	a	32.0189	20.6	a	1.94	2.12	ab	0.206	12.5	a	1.30	7.41	a	0.740	9.11	a	0.799	2.45	a	0.236
Imperata	352	a	32.0189	21.9	a	1.94	2.44	a	0.206	11.5	a	1.30	9.06	a	0.740	6.67	ab	0.799	2.62	a	0.236
p-value	0.0003			0.0004			0.0004			0.0020			0.0003			0.0278			0.0004		
Total 3 crops recycled																					
Trema	643		108.34	25.8		4.09	1.74	b	0.321	22.9		5.70	6.66	b	0.878	14.56		1.752	3.52		0.652
Psiadia	596		86.2061	24.7		3.38	2.21	b	0.275	25.4		4.81	7.13	b	0.744	13.26		1.417	3.73		0.535
Rubus	809		85.3769	33.8		3.24	3.23	ab	0.250	29.0		4.57	10.63	a	0.671	13.59		1.392	4.20		0.520
Imperata	474		134.99	25.8		5.12	2.90	ab	0.396	15.9		7.23	10.56	a	1.060	8.02		2.201	3.28		0.822
p-value	0.200			0.262			0.019			0.501			0.008			0.169			0.759		

* Means that are followed by the same letter are not signficantly different at p<0.05

Table 46: Nutrients exported (kg/ha) by rice, bean and ginger and sum of all three crops for 4 fallows

	C		SE	N		SE	P		SE	K		SE	MG		SE	CA		SE	S		SE
Rice																					
Trema	597		14821	24.4		4.72	2.90		0.632	10.61		3.842	2.65		0.494	4.85		1.219	2.71		0.549
Psiadia	640		14821	19.5		4.50	2.40		0.503	17.30		3.469	2.06		0.468	4.38		1.172	2.58		0.517
Rubus	566		10739	18.0		3.76	2.53		0.432	9.99		2.784	1.84		0.375	1.25		0.884	1.78		0.410
Imperata	88		16980	2.5		5.94	0.42		0.684	1.52		4.402	0.30		0.593	0.24		1.397	0.30		0.648
p-value	0.9990			0.0843			0.0754			0.0970			0.0675			0.0572			0.0648		
Beans																					
Trema	199	a*	15.7	20.2	a	1.55	1.51	b	0.163	6.74	a	0.563	1.30	a	0.126	1.54	a	0.169	1.28	a	0.102
Psiadia	88	b	13.6	7.3	b	1.37	0.99	b	0.142	3.46	b	0.469	0.57	b	0.108	0.93	b	0.140	0.63	b	0.085
Rubus	194	a	12.0	16.9	a	1.26	2.10	a	0.120	7.04	a	0.416	1.13	a	0.093	1.03	ab	0.125	1.11	a	0.078
Imperata	120	b	12.0	9.6	b	1.26	1.43	b	0.120	4.56	b	0.416	0.76	b	0.093	0.58	b	0.125	0.73	b	0.078
p-value	<.0001			<.0001			0.0003			0.0001			0.0009			0.0037			0.0003		
Ginger																					
Trema	174	b	28.9	9.8	c	2.57	1.13	b	0.346	8.25	b	2.322	1.64	b	0.275	1.15	b	0.135	0.79	b	0.217
Psiadia	323	a	24.1	19.5	b	2.43	2.52	ab	0.333	17.99	a	2.208	3.00	a	0.237	1.77	a	0.107	1.98	a	0.196
Rubus	370	a	23.7	31.3	a	2.11	3.85	a	0.281	22.71	a	1.897	3.08	a	0.223	1.51	a	0.108	2.69	a	0.180
Imperata	356	a	23.0	25.3	ab	2.11	3.49	a	0.281	19.33	a	1.897	3.28	a	0.223	1.25	b	0.108	2.43	a	0.180
p-value	<.0001			0.0001			0.0002			0.0022			0.0020			0.0061			<.0001		
Total nutrients exported by three crops																					
Trema	1044		17844	55.0	ab	5.33	5.58	b	0.647	26.10		5.121	5.59		0.554	7.55	a	1.296	4.82	ab	0.617
Psiadia	1062		16453	47.6	ab	5.07	6.02	b	0.614	39.68		4.809	5.67		0.524	7.13	ab	1.256	5.29	ab	0.586
Rubus	1132		12494	66.2	a	4.11	8.48	a	0.496	39.75		3.973	6.05		0.405	3.79	bc	0.939	5.58	a	0.460
Imperata	541		18688	36.2	b	6.49	5.15	b	0.784	23.76		6.282	4.06		0.640	2.00	c	1.485	3.29	b	0.727
p-value	0.9999			0.0114			0.0070			0.0789			0.1303			0.0400			0.1156		

* Means that are followed by the same letter are not signficantly different at p<0.05

4.3. Nutrient uptake in four cycles

4.3.1. Total nutrient uptake over rotation

Nutrient uptake for all three crops for the four cycles is presented for the macro- and micronutrients in Appendix 23 and Figure 40. Highest nutrient uptake was observed in C2 for all elements, followed by C1, and finally by C3 and C4, which had values comparable to one another's. C1 reached ca 70-80% of the C2 uptake for all macronutrients except K, of which the uptake was only two-thirds that of C2. C3 and C4 accumulated only ca 50% of macronutrients compared with C2, and was also lower in K, with only 30%. The proportionally lower K uptake in the more advanced cycles may indicate that, on the more highly degraded soils, K is more readily lost from the system and not taken up at the same rate as in C2.

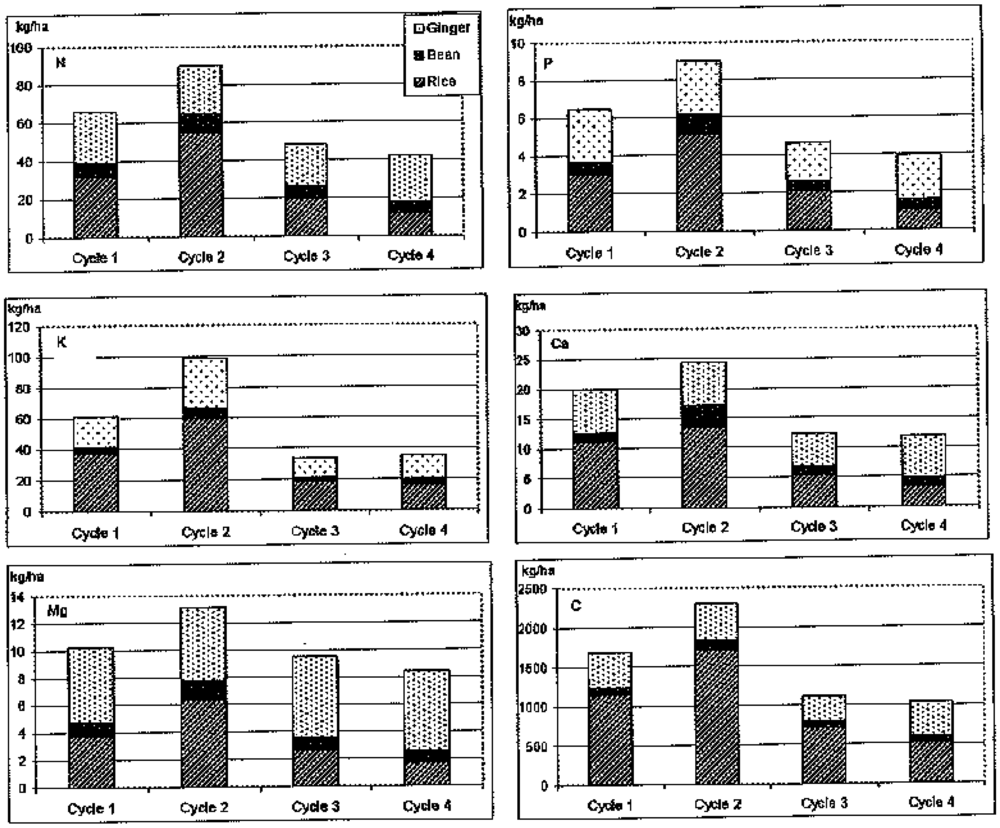


Figure 40: Macronutrient uptake and carbon sequestration (kg/ha) of three crops for four cycles

4.3.2. Nutrient uptake by crop

The biggest differences in nutrient uptake between the cycles were observed in the rice crop, where C2 had significantly higher nutrient uptake than C1, and uptake was more important to C1 than to C3 and C4. For the bean crop there were no significant differences except for Ca, which was highest in C2 compared with the other cycles. Ginger crop differences were not noteworthy. The proportional distribution among the crops shows similar responses to what we observed in the fallow comparison. For the most productive cycle, C2, most of the nutrients were allocated to rice (50-60%), while only ca 30% were used for ginger. It was the opposite case for C4, with 30% used for rice and ca 60% for ginger. C1 and C3 occupied intermediate positions. Beans had similar proportions for all cycles, 10-15%. (See Table 47)

Table 47: Distribution of nutrients taken up among the three crops for the four cycles

	N				P				K			
	Rice	Bean	Ginger	total	Rice	Bean	Ginger	total	Rice	Bean	Ginger	total
Cycle 1	49	10	42	100	46	10	43	100	61	6	32	100
Cycle 2	61	11	28	100	57	12	32	100	61	6	33	100
Cycle 3	41	13	46	100	44	12	44	100	53	10	37	100
Cycle 4	29	14	58	100	27	13	60	100	47	9	44	100

	Mg				Ca				S			
	Rice	Bean	Ginger	total	Rice	Bean	Ginger	total	Rice	Bean	Ginger	total
Cycle 1	37	10	54	100	57	7	37	100	58	8	34	100
Cycle 2	48	12	40	100	55	15	30	100	61	11	28	100
Cycle 3	28	10	62	100	43	11	45	100	49	11	40	100
Cycle 4	20	10	70	100	30	12	58	100	34	13	53	100

4.3.3. Recycled and exported nutrients

Recycled and exported nutrients (Tables 48-50) showed similar trends in the cycle comparison to those observed for total nutrient uptake with highest values for C2. An exception was exported Ca, which was highest in C1. The differences between the

Table 48: Recycled nutrients (kg/ha) for rice, beans and ginger and the sum of all three crops for 4 cycles

	C		SE	N		SE	P		SE	K		SE	MG		SE	CA		SE	S		SE
Rice																					
Cycle 1	290	ab	99.7	6.2	b	3.11	0.421	b	0.180	12.3	b	4.86	1.04	b	0.4564	2.87	b	1.289	1.42	ab	0.547
Cycle 2	624	a	113.6	20.1	a	3.53	1.164	a	0.205	32.2	a	5.55	2.90	a	0.5174	8.15	a	1.464	3.54	ab	0.624
Cycle 3	189	b	99.7	4.0	b	3.11	0.229	b	0.180	6.3	b	4.86	0.89	b	0.4564	2.65	b	1.289	0.77	b	0.547
Cycle 4	145	b	99.7	4.0	b	3.11	0.273	b	0.180	5.1	b	4.86	0.69	b	0.4564	1.49	b	1.289	0.69	b	0.547
p-value	0.0136			0.0038			0.0058			0.0034			0.0087			0.0075			0.0055		
Beans																					
Cycle 1	36		13.1	1.5	b	0.74	0.127	b	0.075	1.6		0.62	0.52		0.2053	0.58	b	0.408	0.28		0.143
Cycle 2	65		14.3	4.5	a	0.81	0.439	a	0.083	3.0		0.68	0.96		0.2246	2.56	a	0.453	0.74		0.159'
Cycle 3	33		13.1	1.8	b	0.74	0.139	b	0.075	1.4		0.62	0.44		0.2053	0.72	b	0.408	0.28		0.143
Cycle 4	35		13.1	2.1	b	0.74	0.189	b	0.075	1.6		0.62	0.54		0.2053	0.94	b	0.408	0.44		0.143
p-value	0.1411			0.0079			0.0101			0.1147			0.1449			0.0031			0.0629		
Ginger																					
Cycle 1	133	ab	15.2	9.0		0.96	0.739		0.079	4.3	b	0.58	3.04		0.331	5.80		0.559	1.12	ab	0.127
Cycle 2	176	a	17.5	10.4		1.11	0.928		0.091	11.4	a	0.67	2.67		0.3821	5.66		0.645	1.54	a	0.146
Cycle 3	82	b	15.2	7.6		0.96	0.588		0.079	3.0	b	0.58	3.21		0.331	4.23		0.559	0.84	b	0.127
Cycle 4	156	a	15.2	9.9		0.96	0.804		0.079	4.3	b	0.58	3.44		0.331	5.35		0.559	1.32	ab	0.127
p-value	0.0028			0.2450			0.0638			<.0001			0.4967			0.2267			0.0101		
Total 3 crops recycled																					
Cycle 1	458	ab	113.4	16.6	a	3.94	1.288	b	0.254	18.2	b	5.68	4.60		0.6784	9.24	b	1.708	2.83	b	0.683
Cycle 2	865	a	129.2	34.9	b	4.48	2.532	a	0.289	46.6	a	6.46	6.56		0.7757	16.39	a	1.949	5.81	a	0.776
Cycle 3	304	b	113.4	13.4	a	3.94	0.956	b	0.254	10.6	b	5.68	4.54		0.6784	7.60	b	1.708	1.89	b	0.683
Cycle 4	336	b	113.4	15.9	a	3.94	1.266	b	0.254	11.1	b	5.68	4.67		0.6784	7.78	b	1.708	2.45	b	0.683
p-value	0.0093			0.0038			0.0017			0.0006			0.1603			0.0059			0.0029		

* Means that are followed by the same letter are not signficantly different at p<0.05

Table 49: Nutrients exported (kg/ha) by rice, bean and ginger and sum of all three crops for 4 cycles

	C		SE	N		SE	P		SE	K		SE	MG		SE	CA		SE	S		SE
Rice																					
Cycle 1	859	a*	76.1	26.0	b	2.16	2.58	b	0.275	25.22	a	2.586	2.73	a	0.227	8.42	a	0.497	3.77	a	0.278
Cycle 2	1083	a	87.9	34.4	a	2.48	3.96	a	0.312	27.69	a	2.986	3.42	a	0.263	5.35	b	0.574	4.00	a	0.321
Cycle 3	518	b	76.1	16.0	c	2.16	1.84	b	0.275	11.78	b	2.586	1.77	b	0.227	2.68	c	0.497	2.11	b	0.278
Cycle 4	378	b	76.1	8.2	d	2.16	0.80	c	0.275	11.48	b	2.586	1.01	b	0.227	2.03	c	0.497	1.26	b	0.278
p-value	<.0001			<.0001			<.0001			0.0003			<.0001			<.0001			<.0001		
Beans																					
Cycle 1	58		15.5	5.1		1.56	0.55		0.159	2.32		0.631	0.46		0.115	0.72	ab	0.177	0.45		0.119
Cycle 2	66		17.5	5.7		1.65	0.60		0.169	2.91		0.667	0.58		0.123	1.08	a	0.195	0.56		0.126
Cycle 3	51		15.5	4.2		1.56	0.40		0.159	2.01		0.631	0.47		0.115	0.69	ab	0.177	0.36		0.119
Cycle 4	47		16.4	3.6		1.56	0.33		0.159	1.48		0.631	0.29		0.115	0.46	b	0.177	0.29		0.119
p-value	0.6290			0.4129			0.1995			0.0885			0.0867			0.0468			0.0728		
Ginger																					
Cycle 1	309		21.1	18.4		1.16	2.05	a	0.134	15.33	b	1.022	2.48		0.199	1.54		0.119	1.89		0.132
Cycle 2	291		24.3	15.0		1.34	1.91	ab	0.155	21.36	a	1.180	2.65		0.229	1.65		0.138	1.90		0.152
Cycle 3	242		21.1	14.6		1.16	1.46	b	0.134	9.56	c	1.022	2.72		0.199	1.35		0.119	1.53		0.132
Cycle 4	277		21.1	14.4		1.16	1.56	b	0.134	11.20	c	1.022	2.39		0.199	1.56		0.119	1.72		0.132
p-value	0.1896			0.0781			0.0179			<.0001			0.6445			0.4144			0.2141		
Total nutrients exported by three crops																					
Cycle 1	1225	a	82.2	49.5	a	3.49	5.18	b	0.410	42.87	a	2.774	5.66	ab	0.307	10.68	a	0.487	6.11	a	0.342
Cycle 2	1440	a	94.6	55.1	a	3.79	6.48	a	0.447	52.08	a	3.203	6.65	ab	0.352	8.07	b	0.559	6.46	a	0.389
Cycle 3	811	b	82.2	34.9	b	3.49	3.70	c	0.410	23.36	b	2.774	4.95	b	0.307	4.72	c	0.487	4.00	b	0.342
Cycle 4	693	b	82.2	26.3	b	3.49	2.68	c	0.410	24.16	b	2.774	3.69	c	0.307	4.04	c	0.487	3.26	b	0.342
p-value	<.0001			<.0001			<.0001			<.0001			<.0001			<.0001			<.0001		

* Means that are followed by the same letter are not signficantly different at p<0.05

Table 50: Total nutrient uptake, total nutrients recycled, and total nutrients exported (kg/ha) over the cultivation period of three crops and percentage of total nutrients recycled, for four cycles

	N				P				K			
	Total	RYC*	EXP	ryc	Total	RYC*	EXP	ryc	Total	RYC*	EXP	ryc
	kg/ha			%	kg/ha			%	kg/ha			%
Cycle 1	66	17	49	25	6	1	5	20	61	18	43	30
Cycle 2	90	35	55	39	9	3	6	28	99	47	52	47
Cycle 3	48	13	35	28	5	1	4	21	34	11	23	31
Cycle 4	42	16	26	38	4	1	3	32	35	11	24	31

	Mg				Ca				S			
	Total	RYC*	EXP	ryc	Total	RYC*	EXP	ryc	Total	RYC*	EXP	ryc
	kg/ha			%	kg/ha			%	kg/ha			%
Cycle 1	10	5	6	45	20	9	11	46	9	3	6	32
Cycle 2	13	7	7	50	24	16	8	67	12	6	6	47
Cycle 3	9	5	5	48	12	8	5	62	6	2	4	32
Cycle 4	8	5	4	56	12	8	4	66	6	2	3	43

* RYC: recycled, EXP: exported

cycles for recycled nutrients were bigger than for exported nutrients, especially the differences observed between the first two cycles when compared with C3 and C4. These results confirm on the one hand the results from the fallow comparison, where higher nutrient uptakes were observed on more fertile soils for rice. On the other hand—contrary to the fallow results—the uptake for beans and ginger were similar independently of cycles. This may confirm the assumption that ginger productivity declines with increasing altitude, but shows also that ginger exhibits similar productivity on both fertile and less fertile soils.

5. Nutrient budgets for the experimental period

Nutrient budgets have been established for macronutrients for the four treatments on the four fallows and are reported in detail in Table 51. The nutrient inputs are the mulched portion of the biomass (see details in the Table), ash, and guano-phosphate. In the *tavy* treatment, ash nutrient stocks were calculated with aboveground biomass and the

Table 51: Macronutrient balance (kg/ha) after 1 rotation of upland rice, beans and ginger, for 4 treatments and 4 fallows

	Trema			*Psiadia*			*Rubus*				*Imperata*			
	Tavy	M0	M40	Tavy	M0	M40	Tavy	M0	M40	M80	Tavy	M0	M40	M80
Nitrogen														
Nutrient inputs														
Mulch*	8.5	30.3	30.3	4.6	26.0	26.0	25.3	56.1	56.1	56.1	5.3	21.1	21.1	21.1
Ash**	1.5			1.2			1.3				0.5			
Guano														
Total Input	10.0	30.3	30.3	5.8	26.0	26.0	26.5	56.1	56.1	56.1	5.8	21.1	21.1	21.1
Crop nutrient uptake														
Rice	48.8	27.4	43.3	46.4	15.1	24.8	38.9	19.2	24.8	24.5	6.2	2.2	3.8	1.5
Bean	17.4	23.0	26.4	4.2	5.0	9.8	12.1	11.3	26.8	34.9	7.4	7.4	15.3	16.1
Ginger	6.3	11.0	9.1	20.3	23.5	30.7	23.1	43.6	63.5	77.3	26.9	44.4	55.1	62.6
Total crops	72.4	61.4	78.8	70.9	43.7	65.3	74.2	74.0	115.1	136.7	40.6	54.0	74.2	80.2
Recycled	1.4	26.8	34.0	7.0	21.5	30.8	6.1	29.6	46.2	53.4	12.8	22.8	31.4	32.3
Exported	71.1	34.6	44.8	63.9	22.1	34.5	68.0	44.5	68.8	83.3	27.7	31.1	42.7	47.9
Balance*	-61.1	-4.3	-14.6	-58.1	3.9	-8.5	-41.5	11.6	-12.7	-27.2	-22.0	-10.0	-21.6	-26.7
Phosphorus														
Nutrient inputs														
Mulch	0.8	2.3	2.3	0.4	1.9	1.9	4.3	9.4	9.4	9.4	1.5	3.0	3.0	3.0
Ash	2.6			1.4			4.1				0.7			
Guano			40.0			40.0			40.0	80.0			40.0	80.0
Total Input	3.4	2.3	42.3	1.8	1.9	41.9	8.4	9.4	49.4	89.4	2.2	3.0	43.0	83.0
Crop nutrient uptake														
Rice	4.2	2.1	3.8	4.5	1.0	2.7	3.7	1.9	3.1	4.1	0.8	0.3	0.8	0.3
Bean	1.0	1.1	1.7	0.4	0.3	1.2	0.9	0.8	3.4	5.1	0.7	0.7	2.4	3.0
Ginger	0.3	0.7	0.6	2.0	2.0	3.5	2.4	4.0	7.6	10.0	2.7	4.4	7.4	9.3
Total crops	5.5	3.9	6.1	6.8	3.3	7.4	7.0	6.6	14.0	19.2	4.2	5.3	10.6	12.6
Recycled	0.1	1.2	1.7	0.5	1.2	2.6	0.5	2.1	4.5	5.8	1.1	2.0	3.9	4.3
Exported	5.4	2.7	4.4	6.3	2.1	4.7	6.4	4.6	9.6	13.4	3.1	3.3	6.7	8.2
Balance	-2.0	-0.4	37.9	-4.5	-0.2	37.2	1.9	4.9	39.9	76.1	-0.9	-0.3	36.3	74.8

* Mulch: for TAVY treatment: root nutrient stocks; For MULCH treatments: Trema and Psiadia: AGB - (stem, 1/2 branch) + root biomass, for Rubus AGB -1/2 wood, + root biomass, for Imperata: leaf + root bi

** Ash: Nutrient stocks in ash after burning of ABG: for N 3%, P 49%, K 57%, Ca 50% and Mg 56% (Giardina et al, 2000; Mackensen et al, 1996)

*** Balance = Total nutrient input - nutrients exported

Table 51: (Continued)

	Trema			*Psiadia*			*Rubus*				*Imperata*			
	Tavy	M0	M40	Tavy	M0	M40	Tavy	M0	M40	M80	Tavy	M0	M40	M80
Potassium														
Nutrient inputs														
Mulch*	14.8	29.0	29.0	11.7	48.0	48.0	18.9	42.5	42.6	42.5	14.1	29.7	29.7	29.7
Ash **	36.3			42.1			21.5				8.9			
Guano			0.1			0.1			0.1	0.2			0.1	0.2
Total input	**51.1**	**29.0**	**29.2**	**53.8**	**48.0**	**48.1**	**40.4**	**42.5**	**42.7**	**42.8**	**23.0**	**29.7**	**29.8**	**29.9**
Crop nutrient uptake														
Rice	28.8	16.9	26.0	54.6	14.6	26.4	33.3	13.6	14.9	17.2	5.2	1.7	3.2	1.0
Bean	7.7	9.8	13.9	2.5	2.2	6.2	5.2	5.0	17.7	27.3	3.8	3.4	9.8	11.3
Ginger	3.8	8.4	6.3	12.9	20.0	25.4	10.3	26.8	47.7	56.1	16.3	28.4	38.1	40.4
Total crops	**40.3**	**35.2**	**46.2**	**70.1**	**36.9**	**57.9**	**48.8**	**45.4**	**80.3**	**100.5**	**25.2**	**33.6**	**61.1**	**52.7**
Recycled	0.7	22.2	31.0	3.0	21.0	36.3	2.6	23.6	41.4	48.7	5.9	13.5	22.5	19.1
Exported	39.6	13.0	16.2	67.1	15.8	21.6	46.4	21.8	39.0	51.9	19.3	20.1	28.6	33.6
Balance ***	11.4	16.0	13.9	-13.3	32.2	26.5	-6.0	20.7	3.7	-9.1	3.7	9.6	1.2	-3.6
Calcium														
Nutrient Inputs														
Mulch	7.6	19.9	19.9	5.1	18.2	18.2	32.0	60.7	60.7	60.7	0.5	2.8	2.8	2.8
Ash	16.9			19.6			20.2				1.2			
Guano			225.0			225.0			225.0	450.0			225.0	450.0
Total Input	**24.4**	**19.9**	**244.9**	**24.7**	**18.2**	**243.2**	**52.2**	**60.7**	**285.7**	**510.7**	**1.7**	**2.8**	**227.8**	**452.8**
Crop nutrient uptake														
Rice	12.4	7.6	13.7	12.9	4.1	7.5	4.3	2.4	3.5	4.6	0.9	0.3	0.5	0.2
Bean	2.7	3.6	5.3	1.2	0.8	2.8	1.1	1.0	4.0	6.3	0.5	0.5	2.2	2.9
Ginger	2.2	4.7	3.9	5.7	6.4	8.3	3.7	6.0	13.8	19.0	2.9	5.3	10.4	13.0
Total crops	**17.2**	**15.9**	**22.9**	**19.7**	**11.4**	**18.6**	**9.0**	**9.4**	**21.2**	**29.9**	**4.3**	**6.1**	**13.2**	**16.1**
Recycled	1.4	12.9	19.6	4.3	9.6	16.2	2.9	7.9	18.0	25.6	2.4	5.0	10.8	13.3
Exported	15.8	3.1	3.3	15.4	1.7	2.4	6.1	1.5	3.2	4.3	2.0	1.1	2.4	2.8
Balance	8.6	16.8	241.6	9.3	16.5	240.8	46.1	59.2	282.5	506.4	-0.3	1.7	225.5	450.0
Magnesium														
Nutrient Inputs														
Mulch	3.5	7.1	7.1	0.5	2.5	2.5	8.4	24.5	24.6	24.5	1.3	5.4	5.4	5.4
Ash	7.5			2.3			11.8				2.4			
Guano			3.2			3.2			3.2	6.3			3.2	6.3
Total Input	**11.0**	**7.1**	**10.2**	**2.9**	**2.5**	**5.6**	**20.2**	**24.5**	**27.7**	**30.8**	**3.6**	**5.4**	**8.6**	**11.7**
Crop nutrient uptake														
Rice	5.9	2.9	4.7	6.7	1.7	3.4	4.7	2.2	2.5	3.2	0.8	0.3	0.6	0.2
Bean	2.5	2.9	3.9	0.7	0.6	1.6	1.3	1.2	3.9	5.7	1.0	1.0	2.3	2.6
Ginger	1.5	2.8	2.4	4.8	5.6	6.9	4.3	7.8	13.1	16.7	6.7	10.6	15.4	16.6
Total crops	**9.8**	**8.6**	**11.0**	**11.2**	**7.8**	**11.9**	**10.3**	**11.2**	**18.6**	**25.8**	**8.5**	**11.9**	**18.2**	**19.5**
Recycled	0.5	5.7	7.6	2.5	5.0	8.0	2.5	7.8	13.9	18.3	4.9	8.7	13.1	14.0
Exported	9.3	2.9	3.5	8.8	2.8	3.9	7.8	3.4	5.7	7.3	3.6	3.3	5.1	5.5
Balance	1.7	4.2	6.7	-5.9	-0.4	1.7	12.4	21.1	22.0	23.6	0.0	2.2	3.5	6.3

* Mulch: for TAVY treatment: root nutrient stocks; For MULCH treatments: Trema and Psiadia: AGB - (stem, 1/2 branch) + root biomass, for Rubus AGB -1/2 wood, + root biomass, for Imperata: leaf + root bi

** Ash: Nutrient stocks in ash after burning of ABG: for N 3%, P 49%, K 57%, Ca 50% and Mg 56% (Giardina et al, 2000; Mackensen et al, 1996)

*** Balance = Total nutrient input - nutrients exported percentage of nutrients that aren't lost during the burning process (Mackensen et al., 1996; Giardina et al., 2000). In addition, root biomass was added as belowground mulch. Nutrient exports, which were exported over three crops, were deducted from these inputs. The calculated balances from Table 51 are reported in Table 52.

Table 52: Balances of nutrient budgets of nutrient input (fallow mulch, ash, guano) minus nutrient export for 3 crops in kg/ha

	Trema			*Psiadia*		
	Tavy	M0	M40	Tavy	M0	M40
Nitrogen	-61.1	-4.3	-14.5	-58.1	3.9	-8.5
Phosphorus	-2.0	-0.4	37.9	-4.5	-0.2	37.2
Potassium	11.4	16.0	13.9	-13.3	32.2	26.5
Calcium	8.6	16.8	241.6	9.3	16.5	240.8
Magnesium	1.7	4.2	6.7	-5.9	-0.4	1.7

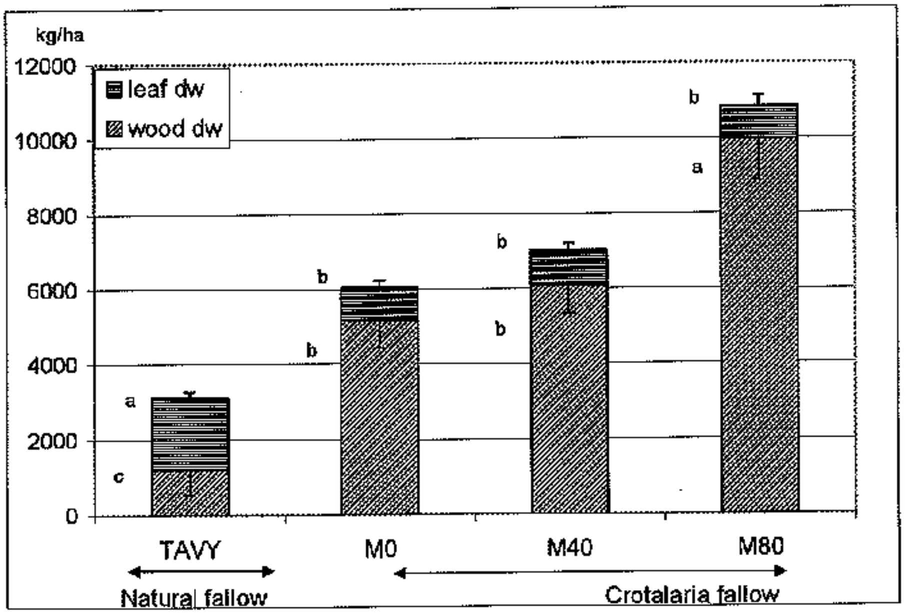
	Rubus				*Imperata*			
	Tavy	M0	M40	M80	Tavy	M0	M40	M80
Nitrogen	-41.5	11.6	-12.7	-27.2	-22.0	-10.0	-21.6	-26.7
Phosphorus	1.9	4.9	39.9	76.1	-0.9	-0.3	36.3	74.8
Potassium	-6.0	20.7	3.7	-9.1	3.7	9.6	1.2	-3.6
Calcium	46.1	59.2	282.5	506.4	-0.3	1.7	225.5	450.0
Magnesium	12.4	21.1	22.0	23.6	0.0	2.2	3.5	6.3

Nitrogen had a negative balance for all treatments and was highest in *tavy*, followed respectively by its levels in M80, M40, and M0. Phosphorus yielded negative balances except where guano was applied. Potassium became negative in *tavy* and M80. Calcium and magnesium balances were low or negative in *tavy* and M0, and were considerably higher in the guano treatments where both nutrients had been added.

6. *Crotalaria* biomass production, nutrient concentration, and nutrient stocks.

Crotalaria was planted in the alternative treatments after the ginger crop, whereas on the *tavy* plots, natural fallow was left to recover. Results for leafy, woody, and seed biomass and for the macronutrient stocks are reported in Table 53 and presented in Figures 41 and 42.

a) Biomass production



b) Nutrient stocks

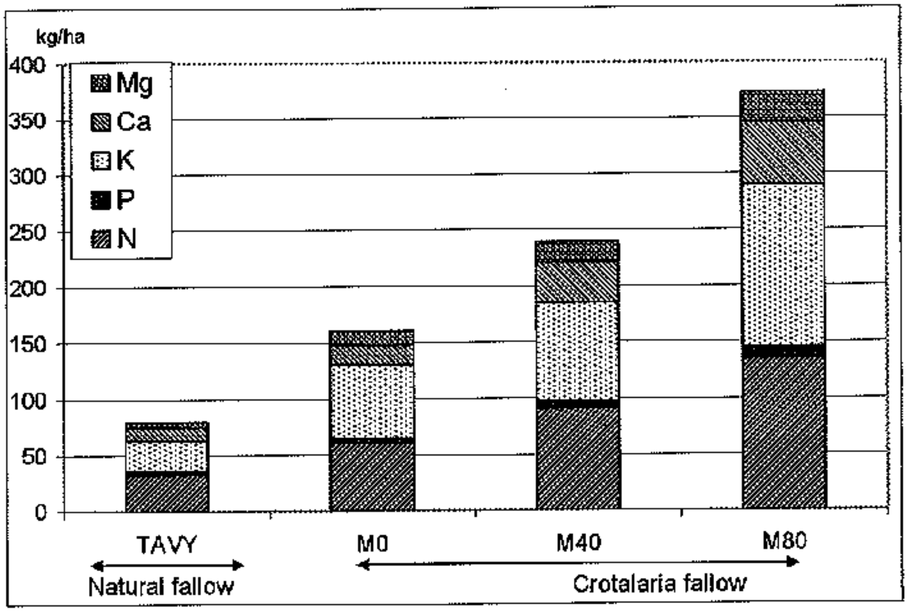
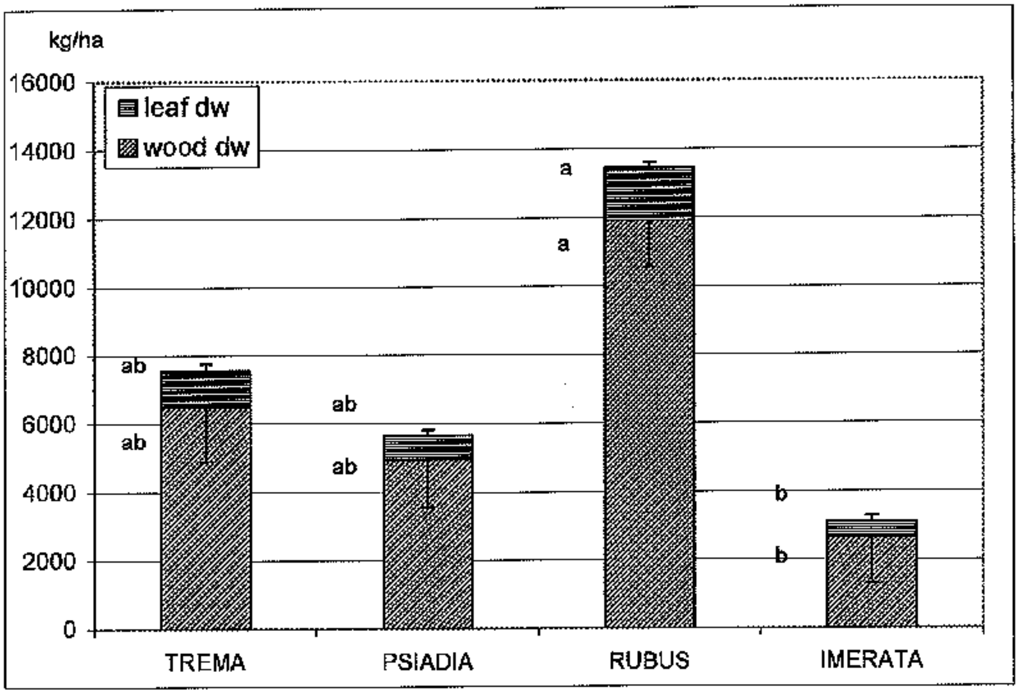


Figure 41: *Crotalaria grahamiana* and natural fallow biomass and nutrient stocks (kg/ha) of four treatments, one year after planting and 33 months after guano-phosphate application

a) Biomass production



b) Nutrient stocks

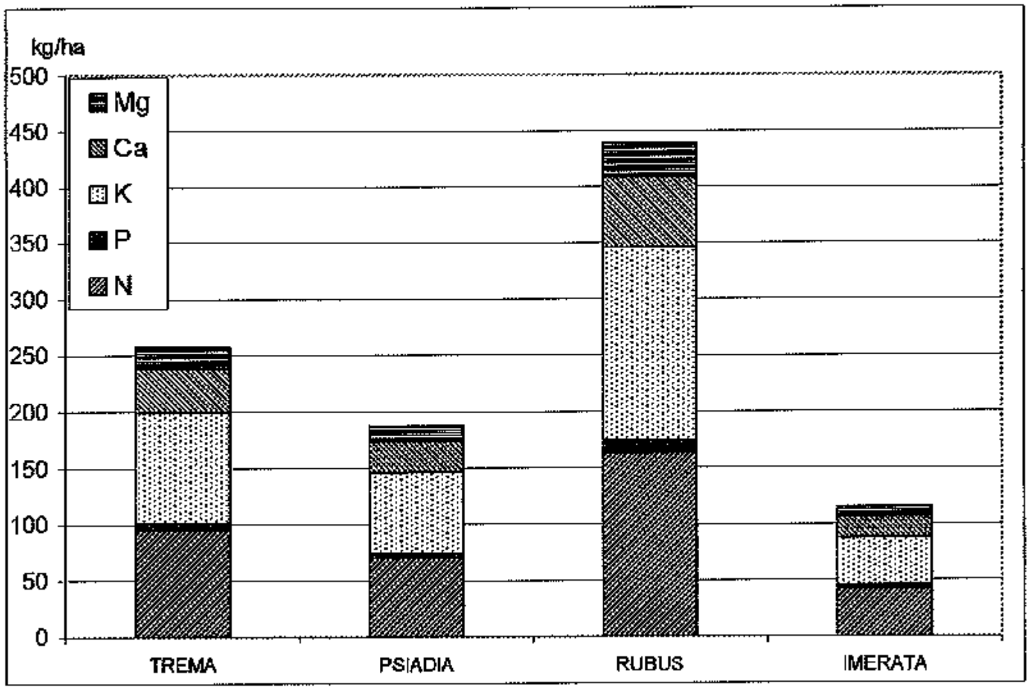


Figure 42: *Crotalaria grahamiana* biomass and nutrient stocks (kg/ha) on four fallows, one year after planting, 33 months after guano-phosphate application.

Table 53: Crotalaria biomass and nutrient stocks at 1 year for 4 treatments and 4 fallows

a) Plant density, height and diameter and biomass production of *Crotalaria grahamiana* at 1 year

	Plants/ha		Height			Diam 10cm			Leaf			Wood			Seed		Leaf+Wood			Total biomass		
		SE	cm		SE	mm		SE	kg/ha		SE	kg/ha		SE	kg/ha	SE	kg/ha		SE	kg/ha		SE
TAVY	-		-			-			1926	a	194	1192	c	559	-		3118	c	660	3219	c	767
M0	155875	16406	133	b*	12.7	7.6	b	1.13	878	b	190	5158	b	724	1948	250	6037	b	725	7934	b	841
M40	151541	16406	148	ab	12.7	8.8	b	1.13	948	b	190	6067	b	724	2227	250	7015	b	725	9192	b	841
M80	169041	20254	156	a	13.3	10.9	a	1.26	870	b	273	9968	a	1101	2679	344	10838	a	1103	13338	a	1270
p-value	0.6319		0,0004			0,0023			0,0001			<0,0001			0.1411		<0.0001			<0,0001		

b) Nutrient stocks for leaves, wood, seeds, leaf and wood, and total biomass (kg/ha) for *Crotalaria grahamiana* for 4 treatments at 1 year

	N			P			K			CA			MG			S			AL		
	kg/ha		SE	kg/ha		SE	kg/ha		SE	kg/ha		SE	kg/ha		SE	kg/ha		SE	kg/ha		SE
Leaves																					
TAVY	27.2		2.38	2.15		0.196	18.01	a	1.52	9.06	c	1.357	4.06	c	0.477	2.93	a	0.251	1.293	a	0.1186
M0	22.7		2,63	1,35		0,203	9.37	b	1.67	9.30	c	1.492	5.98	b	0.623	1.85	b	0.276	0.179	b	0.1303
M40	23,7		2,63	1.66		0.203	8.47	b	1.67	18.85	b	1.492	6.76	a	0,523	2,07	ab	0,276	0.118	b	0.1303
M80	28.2		4.00	1.87		0.309	7.87	b	2.56	29.93	a	2.269	8,31	a	0.796	2,46	ab	0.419	0,036	b	0.1980
p-value	0.4611			0.2800			0.0001			<0,0001			<0.0001			<0.0001			0.0032		
Wood																					
TAVY	5.9	d	6.83	0,65	c	0,460	9.17	c	8.61	2.00	c	1.731	1.12	c	1.119	0.76	c	0.823	0.253	a	0.0338
M0	38.2	c	7.61	2.55	b	0.516	56.62	b	8.36	8,07	c	1.904	6.25	b	1.230	5.71	b	0.906	0.167	ab	0.0354
M40	67,8	b	7,51	4,30	b	0.515	78.96	b	9.36	17.63	b	1.904	10.36	b	1.230	8.97	a	0.905	0.115	b	0.0354
M80	107.0	a	11.42	7.76	a	0.783	136.63	a	14.23	26.82	a	2.894	18.47	a	1.870	11.00	a	1.275	0.258	a	0.0476
p-value	<0.0001			<0.0001			<0.0001			<0,0001			<0.0001			<0.0001			0.0032		
Seeds																					
TAVY	-			-			-			-			-			-			-		
M0	37.6	b	5.24	2.02	b	0,368	17.67	b	2.46	3.86	b	0.551	3.87		0.498	1.59	b	0.246	0.030	a	0.0034
M40	56.2	a	5.24	4.67	a	0.368	26.01	a	2.46	5.81	a	0.551	4.80		0.498	2.54	a	0.245	0.013	b	0.0034
M80	59.0	a	7.28	4.85	a	0.533	28.01	a	3.40	6.27	a	0.762	5.12		0.687	3.26	a	0.341	0.022	ab	0.0050
p-value	0.0046			<0.0001			0.0050			0.0051			0.1348			0.0001			0.0011		
Leaves+Wood																					
TAVY	33.2	d	7.53	2.80	c	0.513	27.18	c	8.47	11.05	c	2.743	5.18	c	1.369	3.69	c	0.868	1.556	a	0.1169
M0	60.9	c	8.28	3.90	c	0.564	65.98	b	9.32	17.37	c	3.016	12.23	b	1.527	7.56	b	0.954	0.326	b	0.1295
M40	91.5	b	8.28	5.85	b	0.564	87.42	b	9.32	36.48	b	3.016	17.11	b	1.527	11.04	a	0.954	0.211	b	0.1295
M80	135.2	a	12.69	9.63	a	0.856	144.51	a	14.16	56.75	a	4.584	26.78	a	2.322	13.46	a	1.450	0.111	b	0.1953
p-value	<0.0001			<0,0001			<0,0001			<0,0001			<0,0001			<0,0001			<0.0001		
Total biomass																					
TAVY	35.7	c	10.11	2.97	d	0.717	26.34	c	9.44	11.31	c	2.995	5.42	c	1.506	3.80	c	0.976	1.557	a	0.1170
M0	97.7	b	11.11	5.86	c	0.769	53.28	b	10.38	21.25	c	3.282	16.02	b	1.765	9.12	b	1.072	0.356	b	0.1286
M40	146.8	a	11.11	10.46	b	0.769	113.06	b	10.38	42.20	b	3.282	21.84	b	1.765	13.55	a	1.072	0.224	b	0.1286
M80	190.5	a	16.89	14.20	a	1.199	170.76	a	15.77	62.63	a	4.399	31.55	a	2.693	16.55	a	1.630	0.132	b	0.1955
p-value	<0,0001			<0.0001			<0.0001			<0,0001			<0.0001			<0.0001			<0,0001		

* Means that are followed by the same letter are not signficantly different at p<0.05

Table 53 (continued)

a) Biomass production, height, diameter and density of *Crotalaria grahamiana* on four fallows at 1 year

	plants/ha	SE	Height cm	SE	Diam mm	SE	Leaves kg/ha		SE	Wood kg/ha		SE	Seeds kg/ha	SE	Leaves+Wood kg/ha		SE	Total Biomass kg/ha		SE
Treme	107351	26138	128	20.7	6.7	1.73	1044	ab*	193	6504	ab	1620	3841	439	7426	ab	1796	10972	ab	2089
Psiedia	220389	28028	115	27.0	7.4	2.02	708	ab	148	4945	ab	1379	1801	499	5653	ab	1486	7454	ab	1687
Rubus	132768	22001	203	18.6	11.9	1.53	1531	a	171	11912	a	1336	2546	346	13320	a	1513	15570	a	1786
Imperata	174768	22001	138	18.6	6.3	1.53	486	b	171	2630	b	1336	951	346	2994	b	1513	3649	b	1786
P-value	0.6319		0.1863		0.3631		0.0490			0.0567			0.0950		0.0501			0.0464		

b) Nutrient stocks of *Crotalaria grahamiana* on four fallows at 1 year

	N kg/ha		SE	P kg/ha		SE	K kg/ha		SE	CA kg/ha		SE	MG kg/ha		SE	S kg/ha		SE	AL kg/ha		SE
Leaves																					
Treme	26.8	ab	4.95	1.79	ab	0.306	9.61	ab	1.93	22.40	ab	2.78	7.36	ab	1.342	2.38	ab	0.415	0.139		0.0329
Psiedia	18.4	ab	3.78	1.22	ab	0.234	6.69	ab	1.48	14.62	ab	2.34	4.95	ab	1.025	1.63	ab	0.317	0.100		0.0258
Rubus	39.4	a	4.37	2.60	a	0.265	14.34	a	1.73	31.17	a	1.91	10.75	a	1.179	3.47	a	0.361	0.215		0.0301
Imperata	12.5	b	4.37	0.85	b	0.265	4.39	b	1.73	11.37	b	1.91	3.43	b	1.179	1.13	b	0.361	0.061		0.0301
P-value	0.0486			0.0478			0.0494			0.0470			0.0491			0.0479			0.0515		
Wood																					
Treme	70.6		13.64	4.83		0.930	89.36		17.78	17.28		3.48	11.64		2.231	7.83		2.086	0.134		0.0380
Psiedia	51.2		11.46	3.58		0.782	65.38		14.89	12.67		2.92	8.58		1.875	5.82		1.794	0.105		0.0326
Rubus	128.0		9.36	8.59		0.638	159.19		12.92	31.05		2.36	20.66		1.531	14.60		1.705	0.246		0.0327
Imperata	32.0		9.36	2.15		0.638	39.34		12.92	7.87		2.36	5.19		1.531	3.30		1.705	0.048		0.0327
P-value	0.0522			0.0524			0.0511			0.0557			0.0520			0.0635			0.0605		
Seeds																					
Treme	85.7		8.18	6.31		0.636	40.1		4.31	8.97		0.985	7.82		0.673	4.00		0.429	0.0383		0.00583
Psiedia	40.7		10.33	3.18		0.687	19.1		4.87	4.27		1.089	3.81		0.967	2.02		0.481	0.0159		0.00596
Rubus	55.7		7.19	4.18		0.480	26.2		3.38	5.87		0.757	5.05		0.685	2.76		0.335	0.0253		0.00435
Imperata	21.6		7.19	1.71		0.480	10.2		3.38	2.27		0.757	1.91		0.685	1.08		0.335	0.0081		0.00435
P-value	0.0858			0.0778			0.0666			0.0867			0.0908			0.0661			0.1350		
Leaves+Wood																					
Treme	95.1	ab	18.68	6.61	ab	1.178	97.41	ab	20.05	39.67	ab	5.71	16.50	ab	3.524	9.97		2.437	0.259	ab	0.0673
Psiedia	69.6	ab	14.60	4.79	ab	0.946	72.07	ab	16.08	27.29	ab	4.79	13.54	ab	2.727	7.45		2.018	0.205	ab	0.0568
Rubus	163.2	a	14.83	11.17	a	0.885	171.97	a	15.55	62.22	a	3.91	30.92	a	2.870	17.83		2.065	0.446	a	0.0612
Imperata	42.3	b	14.83	2.99	b	0.885	42.17	b	15.55	19.23	b	3.91	8.13	b	2.870	4.19		2.065	0.095	b	0.0612
P-value	0.0429			0.0434			0.0470			0.0434			0.0395			0.0513			0.0393		
Total biomass																					
Treme	177.1	ab	25.26	12.96	ab	1.545	134.67	ab	23.14	48.30	ab	6.35	25.77	ab	4.166	13.84	ab	2.683	0.293	ab	0.0713
Psiedia	110.3	ab	19.56	7.97	ab	1.262	91.17	ab	18.02	31.56	ab	5.24	17.15	ab	3.206	9.47	ab	2.149	0.221	ab	0.0601
Rubus	215.1	a	20.55	15.40	a	1.124	195.34	a	18.55	87.75	a	4.51	35.41	a	3.463	20.47	a	2.268	0.467	a	0.0648
Imperata	60.1	b	20.55	4.74	b	1.124	49.47	b	18.55	21.18	b	4.51	9.49	b	3.463	5.14	b	2.268	0.099	b	0.0648
P-value	0.0421			0.0449			0.0440			0.0426			0.0390			0.0468			0.0394		

* Means that are followed by the same letter are not significantly different at $p<0.05$

6.1. *Crotalaria* shrub height, stem diameter, and plant density at 1 year

Treatment results: Shrub height 1 year after planting was significantly higher in M80, at 156 cm compared with M0 at 133 cm. M40 had an intermediary position at 148 cm. Also, stem diameter, at 10 cm, was significantly higher in M80 (10.9 mm) compared with M40 and M0 (8.8 mm and 7.6 mm, respectively). Plant density didn't show any difference among the treatments. Fallow results: Among the four fallows plant density, shrub height, and diameter were not significantly different. (See Table 53)

6.2. Crotalaria biomass

Woody and leafy biomass yielded 3.1 t/ha in *tavy*, whereas *Crotalaria* biomass was 6.0 t/ha, 7.0 t/ha, and 10.8 t/ha in M0, M40, and M80, respectively (Table 53). Seed weight was considerable at 1 year at 2.7 t/ha in M80, 2.2 t/ha in M40, and 1.9 t/ha in M0. Looking at differences among the fallows, the highest *Crotalaria* biomass production was observed in *Rubus* at 13.4t/ha, followed by *Trema* at 7.5 t/ha, *Psiadia* at 5.6t/ha, and finally *Imperata* at 3.1 t/ha. The nutrient stocks followed the same pattern.

6.3. Crotalaria nutrient concentrations

Nutrient concentration analysis could not be performed for each of the replicates individually, but was performed on a composite sample of all the replicates. The results are presented in Table 54. The nutrient concentration in all macronutrients in leaf and wood on the natural fallow was lower than in *Crotalaria* biomass, and higher in Al, Na, Fe, Mn, and Cu. Comparing *Crotalaria* leaf and wood in M80 to the natural fallow, we observe that for most macronutrients the concentrations were twice to three times as high in the leguminous shrub, except for phosphorus, where the increase was ca 50%. Potassium leaf concentrations were similar, whereas the leaf concentration in M80 of Ca was 5.5 times higher than in the natural fallow.

Table 54: Nutrient concentrations of natural fallow and *Crotalaria grahamiana* in 4 treatments (in % and mg/kg)

	N	P	K	Ca	Mg	S	Al
	%			mg/kg			
Leaves							
Tavy*	1.38	1102	9341	4372	1969	1502	686
M0**	2.59	1538	10687	10503	6814	2106	204
M40	2.50	1637	8931	19951	7138	2189	123
M80	2.62	1793	9183	23958	7012	2378	127
Wood							
Tavy	0.35	528	6224	1475	764	414	288
M0	0.74	494	10956	1558	1209	1105	29
M40	1.12	709	13011	2910	1708	1478	16
M80	1.08	774	13743	2697	1852	1126	21
Seeds							
Tavy	-	-	-	-	-	-	-
M0	1.92	1007	9005	2016	1980	810	15.9
M40	2.54	2122	11745	2624	2159	1149	5.5
M80	2.18	1845	10413	2332	1868	1267	8.0

	B	Na	Fe	Mn	Cu	Zn
			mg/kg			
Leaves						
Tavy	26.5	226	238	423	3.83	17.54
M0	31.2	39	72	245	1.19	19.16
M40	31.9	32	63	191	1.15	20.85
M80	36.1	45	76	192	1.50	15.92
Wood						
Tavy	4.7	161	76	95	0.74	3.66
M0	26.2	58	11	31	< det	10.34
M40	31.9	70	13	24	< det	7.56
M80	27.8	84	12	17	< det	3.19
Seeds						
Tavy	-	-	-	-	-	-
M0	24.4	103	26	31	1.40	8.00
M40	27.8	144	24	14	2.85	14.01
M80	25.4	150	26	13	2.57	11.40

* Natural fallow inTavy treatment, ** *Crotalaria* fallow in Mulch treatments

6.4. *Crotalaria* nutrient stocks

The nutrient stocks for treatment and fallows for *Crotalaria* and natural fallow at 1 year are reported in Table 53 and Figures 41 and 42. Nutrient stocks of the natural fallow reached only 20-30% of *Crotalaria*'s stocks in M80, whereas K, Ca, and Mg reached ca 20%, N reached 25% and P reached 30%. Nutrient stocks in M0 compared with those in M80 were 40-45%, except for Ca, for which it yielded only 30%, indicating a higher Ca accumulation in the guano treatments. Nutrient stocks in M40 were 60-65% of M80's stocks.

DISCUSSION

1. Treatment effects on yield

The yield comparison among the three alternative treatments relative to the *tavy* yield and for all three crops is shown in Table 55, where *tavy* yields were set at 100.

Table 55: Relative yield comparison for the three crops with *tavy* set at 100

	Tavy	M0	M40	M80
Rice	100	31	56	62
Beans	100	96	221	324
Ginger	100	126	156	195
Nat fallow**/*Crotalaria* *	100**	200*	233*	366*

The highest yield in the first season was achieved with the <u>*tavy*</u> treatment. But productivity collapsed from the second season onward, with very low yields for beans and ginger. The mulching treatment with no amendments (<u>M0</u>) produced unacceptably low yields for the first two crops, but obtained significantly higher yields for ginger compared with that of *tavy*. Mulching plus 40kg/ha of P applied with guano-phosphate (M40) showed significant yield increases compared with those of *tavy* and M0 for beans, ginger, and *Crotalaria*. M40's performance was inferior to that of M80 in every instance. Treatment M80 (mulching plus 80kg/ha of P applied with guano-phosphate) obtained the best yields from the second season onward. Comparing M80 with *tavy*, we recognize a doubling in yields of ginger, a tripling in yields of beans, but rice in M80 achieved only two-thirds of the *tavy* yield. Aboveground *Crotalaria* biomass production at 1 year was also 3.5 times higher in M80 than the natural fallow biomass produced in the *tavy* treatment. M80 is therefore the treatment showing the best performance and can be recommended to farmers. The lower rice yield at the beginning of the rotation calls for optimization of management practices that make nutrients more readily available. The most essential factors that contributed to the treatment effects were *tavy* ash, mulch, and guano-phosphate, which I now discuss in further detail.

Tavy ash

The rice crop benefited from the immediate availability of nutrients provided through ash. The plants in the *tavy* treatment germinated more quickly and seedlings established themselves faster. This turned into an advantage, as the plants were able to resist the unusual dry spells better during December and January 1999/2000, and the *Heteronychus* sp attack as well, which occurred in December. Benefiting from strong and rapid plant establishment, the rice in the *tavy* treatment achieved the best survival rate as well as highest number in terms of fertile tillers, grain/panicles, and 1000-grain weight. In order to avoid the *Heteronychus* attack, the planting date for rice should ideally come before mid-October or no later than the end of October, according to farmers.

Mulching

The plants in the mulching plots exhibited slower establishment, leaving them more vulnerable to the combination of adverse effects of climate and pests that prevailed in the first season. Although the mulch layer could preserve soil moisture better during dry spells, the small rice plants obviously had trouble establishing well within the mulch. Contrary to other crops such as beans and corn, rice plants are very susceptible to a mulch layer, as their seedlings are very delicate and small throughout the first weeks of plant growth. A careful mulch management is therefore needed not to impede early plant development too much.

Mulching alone didn't produce satisfactory yields and was rejected by the farmers as an acceptable alternative cultivation practice for rice and beans. This is an important finding, as the idea to mulch instead of burn is therefore not a practical short-term option. On the other hand, a significant yield increase of ginger in M0 compared with that in *tavy* was observed, which may indicate that added organic matter had a positive effect on soil production potential beginning to show a year after fallow mulching occurred.

Guano-phosphate

Guano-phosphate improved yields considerably compared with mulching without amendment. A relative comparison is shown in Table 56. It shows that the yields for all crops and for *Crotalaria* were M80 > M40 > M0. The differences in the *Crotalaria* biomass at 33 months after guano application indicate that there is a considerable residual guano effect that is more pronounced in M80 than in M40. Furthermore, beans showed the highest response in yield increase with guano.

Table 56: Yield comparison among alternative treatments showing the residual effect of guano-phosphate

	M0	M40	M80
Rice	100	181	199
Beans	100	230	336
Ginger	100	124	155
Crotalaria	100	116	180

2. Monetary return from the four treatments

A simple calculation was done by looking at the returns from the crops produced under each of the treatments minus the cost of guano. The results are reported in Table 57. They show clearly that the highest return was achieved with the guano treatments. The difference between *tavy* and M80, 1000 $US/ha, is a very significant increase, especially given that the daily salary is 1.23 $US. It is worth mentioning that farmers today are hardly able to plant 1ha due to the seed cost that runs as high as ca 450 $US/ha. A credit system would be help to farmers by enabling them to invest in their crops and benefit from their production. At the same time, sustainable ginger production should be promoted, in order to diminish the soil mining techniques (burning and tilling on steep slopes) that are practiced today (see Chapter 2 for more details on the ginger cropping system).

Thus as seen in Table 56, proportional yield-improving effects of GP were highest with beans, but looking at it in terms of returns (Table 57), the ginger crop benefited most, economically, from the GP.

Table 57: Monetary return/ha for 3 crops and 4 treatments (in $ US/ha)

		Guano cost	Return from harvest	Return - input costs	% of tavy
Tavy	Rice	0	351	351	100
	Beans	0	107	107	100
	Ginger	0	1312	1312	100
	Total	**0**	**1770**	**1770**	**100**
M0	Rice	0	110	110	31
	Beans	0	103	103	96
	Ginger	0	1647	1647	126
	Total	**0**	**1859**	**1859**	**105**
M40	Rice	62	198	136	39
	Beans	62	236	175	163
	Ginger	62	2042	1980	151
	Total	**185**	**2475**	**2291**	**129**
M80	Rice	123	218	94	27
	Beans	123	346	223	209
	Ginger	123	2562	2439	186
	Total	**369**	**3126**	**2757**	**156**

References used were the average prices during the time of experimentation (1999 – 2001): 1 kg rice = 2000 FMG, 1kg bean = 4000 FMG, 1kg ginger (fw) = 2000 FMG; Daily salary: 8000 FMG; 1 $US = 6500 FMG

3. Crop yields in four fallows and four cycles

The degradation sequence that we established originally by investigating the indigenous knowledge base as presented in Chapter 3, and which was confirmed for fallow biomass productivity in Chapter 4, has also been validated with the results on agricultural crop productivity for the selected fallow types as well as for the four cycles following deforestation. The productivity gradient from tree to shrub to herbaceous fallows was confirmed for rice and beans but not for ginger. Although the differences for rice and beans were not significant between tree and shrub fallows. The gradient was also obvious with the cycle comparison, showing highest productivity in C2 and C1, followed by C3 and C4. Differences between C1 and C2 on the one hand and C3 and

C4 on the other hand were significant for rice and beans but not for ginger. This shows that ginger is a crop that produces acceptable yields on less fertile soils, such as C3, C4, or *Imperata*, which confirms farmers' practices of often using these soils for ginger. Nevertheless, considerable ginger yield increases were observed with guano application, especially on more highly degraded soils.

The results also indicate that the altitudinal influence of the associated change in climate was more pronounced than I initially expected. Over the course of time, the shifting cultivators moved from the east coast of Madagascar westwards, pushing back the forest boundary and moving up in elevation. Considerable elevation changes have occurred over the last few decades. The forest boundary today is located in the mountainous range of Vohidrazana. In moving cultivation to higher altitudes, people have maintained the same practices and brought along varieties adapted to lower locations. The production potential of these varieties depends therefore on their plasticity in adapting to these changes.

In our experimentation it was shown that rice and bean varieties took 24 and 26 days longer, respectively, to fulfill their life cycles in Berano (932 m a.s.l.) than in Marolafa, Beforona (550 m a.s.l). Moreover, rice and beans didn't produce significantly higher yields on the tree fallows than on the shrubby fallows growing at lower altitude and characterized by more highly degraded soils. Thus the motivation and driving force leading farmers to engage in deforestation to find more productive soils at these higher altitudes no longer applies.

Ginger is a newly emerging cash crop in the Beforona area. It had not been tested at the higher elevation of Berano; our tests were the first to do so. Unfortunately they showed that ginger does not have the same plasticity as rice and beans. On the other hand, it would be worthwhile to test a two-year cropping cycle for ginger at that altitude, because of the generally experienced longer cropping cycle at that location. Also, if a ginger crop develops meagerly in Beforona, farmers often wait for another year to harvest it. This represents therefore management flexibilities which are common for root and tuber crops. Root crops are often stored in the soil and only harvested when needed.

Thus it can be concluded that crop productivity on shrubby fallows, with intermediate soil fertility and located at lower altitudes, can be as high as on better soils under tree fallows at higher altitudes.

In Chapter 3, I analyzed how land occupation evolved within the landscape on the village territory level. Farmers begin by cropping the lower parts of the hilly landscape. After that land is exhausted, farmers move uphill with their crops. This strategy has similar consequences for the agro-ecosystem as moving up in elevation. With both strategies crop productivity declines, in the first instance mostly because of shallow, quickly deteriorating and eroding soils, and in the latter instance because of the abovementioned altitudinal effects. Simultaneously, higher locations hold a very strategic position within the landscape and play a crucial role in maintaining vital ecological functions such as watershed protection, water conservation, soil erosion prevention, and stabilization of hillsides. In theory these locations need to be unconditionally protected from degradation, an objective that is best assured by forest or tree cover. By cultivating these locations, crop productivity is already lower initially and the benefit margins for the farmers become smaller and smaller, while at the same time ecological changes are induced with very severe long-term consequences.

4. Soil nutrients

The application of guano-phosphate resulted in significant soil nutrient improvement over the course of the rotation. Ca levels had increased significantly by the end of the experiment in M40 and M80. The M80 treatment was also able to maintain the raised pH level that occurred after the first crop until the end of the experiment, contrary to the case with all other treatments, in which pH had by the end dropped to initial values. At the same time, exchangeable Al concentrations were significantly lowered in M80 compared with those of *tavy* after the ginger crop. Values of K and Mg were significantly higher in the mulch treatments compared with those of *tavy* in Time 3. It is also noteworthy that for all treatments the K values had dropped to half of their initial values at the end of the experiment, whereas Mg levels returned to the initial values. The dramatic K decline, to half of the initial values, may be explained by noting that K is a very mobile element and is very prone to leaching and being lost from the soil profile. Although the differences between the mulch treatments and *tavy* were significant, the magnitude of the differences was not very large. Nevertheless these findings would be expected in view of and can be explained by either increased soil organic matter that has been building up under the addition of plant organic matter with the mulching techniques or decreasing soil organic matter in the *tavy* treatment under the influence of burning and mineralization processes. It is anticipated that a higher soil organic matter status increases the cation exchange capacity of the soil, which translates into a better holding and storing capacity for potassium and the other nutrients. In order to confirm these processes, longer-term monitoring would be necessary.

The soil tests show also that there was almost no available P in the soil, with maximum values of only 2mg/kg. At the end of the experimentation, P levels were almost zero in all treatments. It is noteworthy that the Morgan extraction procedure was not the most appropriate analytical method. Although Morton extraction is used for acid soils with low cation exchange capacity, it is mostly used for temperate soils. Other extraction methods that are better adapted to tropical soils, such as Bray P1, Bray P2, and Mehlich No. 3, may have been able to extract the P better and create higher and more distinct values (Soil and Plant Analysis Council Inc., 2000). But finally it is very doubtful that the overall result of very low available P levels would have changed.

Despite the problem of detecting no available soil phosphorus, the effect of the applied guano-phosphorus was higher P concentration in all the plant tissues of the three crops. This translated as well into significantly higher nutrient uptake in bean and ginger in M80 compared with M40, M0 and *tavy*, in that order. With respect to rice, M80, M40, and *tavy* were significantly superior to M0. The added calcium in the guano also stimulates the uptake of nutrients such as P. Calcium is a non-mobile element in the plant and plays an important role in the growth of meristematic tissues. Thus applied calcium induces root growth, which enlarges the soil volume explored by the root system and favors the uptake of phosphorus, which is relatively immobile in the soil (Mills and Jones, 1996).

Given that available phosphorus is scarcely detected in the soil but that a plant response can be identified, the concept of P *capital* seems more appropriate to use than that of P *availability*, especially for management purposes (Sanchez et al., 1997). The goal of managing the P capital is not to maximize nutrient stocks but to maximize the service flows over 5-10 years. Phosphorus that is applied with fertilizers and is subsequently sorbed can represent an asset, because it has the potential to become available to the service flow at later stages through desorption processes (Sanchez et al., 1997).

The processes to make P readily available to plants is complicated and controlled by clay mineralogy, clay content, exchangeable Al, and SOM. In acid soils, P is usually precipitated as aluminum or iron phosphate or adsorbed at clay surfaces. Liming can modify P solution concentration, inactivate Al and Mn, and thus increase P availability (Ruaysoongnern and Keerati-kasikorn, 1998). Liming also causes aluminum to precipitate as Al hydroxides, which fix less P. Furthermore, organic matter complexes with Al which makes it less available (Sanchez, 1976). A positive residual reaction to the guano application lasted throughout the observation period of 33 months. The long-term goal should therefore lie in a gradual build-up of the soil nutrient capital. The moderate P and Ca additions should ideally be repeated with each new rotation cycle and translate, one would hope, into further crop yield increases.

5. Nutrient uptake and nutrient budgets for the three crops

Parallel to the yields, most of the nutrients in the *tavy* treatment were taken up at the beginning of the rotation and declined rapidly with the second crop, whereas nutrients in the mulch treatments were not optimally available in the beginning but increased towards the later stages of rotation. The residual effects of guano application became significant for the second and third crop and for the subsequent leguminous fallow. The low productivity of mulching alone without the addition of any nutrients proved not to be a viable alternative to the slash-and-burn techniques.

Looking at the nutrient budgets, it can be concluded that *tavy* produced the most nutrient mining, which confirms the hypothesis of rapid nutrient loss with this technique. This was achieved by nutrient losses from burning, wind and water erosion of ash and from the almost complete removal of crop residuals. The guano treatments achieved a higher productivity level, with the added consequence of considerable nutrient exports. They were most pronounced in M80, especially affecting N and K, turning the nutrient balance negative. The management and replenishment of these nutrients becomes therefore more critical with increasing cropping intensification. M0 showed the smallest negative balances, but also had very low crop productivity. Exports were relatively low and nutrient replenishment through the natural fallows was sufficient to maintain a slightly positive balance. Although these balances did not consider the nutrients in the soil and surface litter, and didn't account for the rate of biomass decomposition and timely nutrient release, they can be used as a simple tool to keep track of ongoing dynamics that may get reinforced if the system is kept under similar management conditions for a longer period of time.

6. Comparison of *Crotalaria* nutrient stocks with natural fallow nutrient stocks

Crotalaria's biomass productivity at 1 year was much superior to the natural fallow. *Crotalaria*'s nutrient stocks in M80 at 1 year were 135, 9.6, and 144 kg/ha for N, P, and K, respectively, for the leafy and woody biomass. In order to achieve these stocks under natural fallow, it would take a *Trema* fallow 4 to 5 years. For a *Psiadia* fallow in C1 and C2, it would take 9 years to build up the same levels of N and P, 6 years for K. In C3, the time needed would be 13 years for N and P and 8 years for K, while for C4 it stretches to 31 years for N and P, and 17 years for K. The last comparison is theoretical because the established regressions apply only to fallows up to 10 years of age, with a small extrapolation range of a few years, because the *Psiadia* regressions were linear. In *Rubus* and *Imperata*, nutrient stocks stop accumulating at 5 years. For *Rubus* the N, P, and K stocks achieve 50%, 150%, and 40%, respectively, of *Crotalaria*'s stocks at 1 year. The *Imperata* stocks at 5 years are equal to the natural fallow stocks at 1 year, which were 26, 2.7, and 25 kg/ha of N, P, and K. Comparing them to *Crotalaria*, the *Imperata* stocks reached 19%, 28%, and 17% of its N, P, and K stocks, respectively.

This shows the clear superiority of the *Crotalaria* fallow in accumulating nutrients, exceeding all natural fallows at the age of 1 year by multiple times. Thus according to the results from 1 year, it can be recommended that *Crotalaria* be used for all fallow stages, especially if in combination with guano phosphate applications. *Crotalaria* fallows of 2 to 3 years in age may offer a satisfactory technique for accumulating nutrients and making them available for the next crop rotation cycle.

Although *Crotalaria* productivity followed the degradation gradient from *Trema* to *Psiadia* to *Imperata* at 7.5, 5.7, and 3.1 t/ha of leafy and woody biomass, respectively, exceptionally high biomass was obtained by *Crotalaria* on the *Rubus* fallow at 13.4 t/ha. Explanations could lie in the better adaptability of the *Crotalaria* provenance to the lower and warmer conditions in the Beforona area compared with its performance in the forest corridor environment. Another reason could be that soil nutrient availabilities were more favorable under *Rubus*. As seen in Chapter 4, *Rubus* has a relatively higher root biomass with higher nutrient concentrations compared with the other natural fallow species. Thus with slow root decomposition, root nutrients released into the soil may still have been available to *Crotalaria*. Furthermore, it is possible that some efficient mycorrhizal fungi were present in the soil and assisted the roots in nutrient uptake. A comparison of *Crotalaria* nutrient stocks obtained in the experiment with values from the literature are reported in Table 58.

Table 58: *Crotalaria grahamiana* and *Crotalaria anagyroide*: Above-ground biomass (t/ha) and nutrient stocks (kg/ha) in the literature and in the experiments

		Literature						**Experiment**			
Species		---------- *C. grahamiana* ----------					*C.anagyroides*	---------- *C. grahamiana* ----------			
Fallow								*Imperata*	*Rubus*	*Psiadia*	*Trema*
Month after planting		6	6	8	12	12	22	12	12	12	12
Biomass	t/ha	11.8	23.2	15.4	24.5	29.9	16.2	3.1	13.4	5.7	7.6
Nutrient stocks											
N	kg/ha		330	248	251	312		42	163	70	95
P	kg/ha		18	16	14	17		3	11	4.8	6.6
K	kg/ha		110		125	104		42	172	72	97
References		1	2	3	1	2	4				
Location		W Kenya	W Kenya	W Kenya	W Kenya	W Kenya	N Laos				

References : 1 (George et al., 2002), 2 (Niang et al., 2002), 3 (Smestad et al., 2002), 4 (Roder and Maniphone, 1998)

Studies on biomass production and nutrient stocks of *Crotalaria grahamiana* planted as an improved fallow are mostly reported from western Kenya. Niang et al. (2002) comment that 24 t/ha of biomass at 12 months constitute very good yields due to good rainfall conditions and good P contents in the soil. Nutrient stocks obtained in *Rubus*, when compared with the Kenyan *Crotalaria*, yielded half of the N, two-thirds of the P, and 170% of the K. It can be assumed that by optimizing nutrient availability in eastern Madagascar, the yields similar to Kenya's should be achievable.

7. Nutrient requirements for improved production

The nutrient needs for improved crop production can be estimated by taking into account the average nutrient uptake in straw and grain/root for the production of 1 ton of grain/root (Table 59). With a view to increasing crop yields, nutrient requirements were calculated for two different intensification levels (Table 60). Given the aforementioned nutrient stocks obtained from *Crotalaria* and the yields it produced under more favorable conditions, it can be assumed that if nutrient management is further optimized through regular application of guano-phosphate and the recycling of organic matter, Level 1 yields and even Level 2 yields should be achievable.

Table 59: Nutrient uptake in straw and grain/root to produce 1 ton of grain/root* (dry weight)

	N	P	K	Mg	Ca	S
	kg/ha					
Rice	34.5	3.8	28	4.2	7.6	4.4
Beans	55.5	5	28.9	7.5	7.6	4.4
Ginger	46.5	5.2	31.9	10.6	9.2	5.1

* Average values from all the sites for rice, without the *Psiadia* site in beans and without the *Trema* site in ginger, because of extremely low productivity

Table 60: Nutrient requirements (kg/ha) for improved yields at two intensification levels for the three crops of upland rice, beans, and ginger

	N	P	K	Mg	Ca	S
	kg/ha					
Level 1						
Rice 2.5 t/ha	86	10	70	11	19	11
Beans 1t/ha	56	5	29	8	8	4
Ginger 1.5/ha*	70	8	48	16	14	8
Total uptake	**212**	**22**	**147**	**34**	**40**	**23**
Level 2						
Rice 3t/ha	104	11	84	13	23	13
Beans 1.5t/ha	83	8	43	11	11	7
Ginger 2t/ha*	93	10	64	21	18	10
Total uptake	**280**	**29**	**191**	**45**	**53**	**30**

* 1.5 t/ha dw = 12t/ha fw; 2t/ha dw =16 t/ha fw

CONCLUSION AND IMPLICATIONS OF RESEARCH RESULTS

The tested rotation with three crops per cropping cycle, with the application of organic matter and guano-phosphate and the planting of a leguminous shrubby fallow, has shown its potential to significantly increase agricultural productivity. Moreover, the obtained residual effect from the guano—up to 33 months, with significantly higher yields in the leguminous fallow—indicates that this set of techniques may have the potential to gradually build up soil fertility, leading to sustained and increased agricultural productivity over a longer time period. The tested rotation and techniques can represent a start in agricultural intensification. The techniques need further adjustment and optimization, however, in order to create and reinforce synergetic effects towards the ultimate goal of building a productive and sustainable upland farming system.

Optimizations that I would like to propose based on the results include:

1) Improve the effectiveness of guano for the first crop in the rotation.
2) Improve mulch management.
3) Adjust nutrient inputs according to crop requirements.
4) Optimize crop rotation and cropping techniques.
5) Optimally integrate leguminous species.

1. Improve the effectiveness of guano for the first crop in the rotation

Rice under M80 produced only two-thirds of the *tavy* rice yield. The soil-improving characteristics of guano-phosphate weren't fully expressed. The management of the guano needs therefore to be optimized. The two major options lie within the application techniques and the timing of application. Although the banding is recommended when low amounts of nutrients are applied, the techniques pursued in the experiments, some studies indicate that best P recovery on the part of plants from reactive rock phosphate was obtained trough broadcasting and incorporation (Ruaysoongnern and Keerati-kasikorn, 1998; Willett et al., 1998). Broadcasting and soil incorporation will increase contact time and soil volume in contact with the guano in order to increase dissolution (Hedley et al., 1995). A second major consideration is the time of reaction. Highly soluble materials require from 60 to 90 days to react in Ultisols. Thus incorporating the guano in advance may enhance its availability to the first crop (Sanchez and Uehara, 1980; Ruaysoongnern and Keerati-kasikorn, 1998).

In the experiment, guano was applied to the planting pockets and between the lines, so rice roots might not have been able to benefit optimally from it. Additionally, there was a dry spell at the beginning of the rainy season, slowing down chemical reactions in the soil that are needed to release the nutrients from the guano (Hedley et al., 1995). After the rice harvest, the soil was superficially tilled, which did ensure a more even distribution of the guano within the surface soil. The beneficial effect was confirmed by the healthy development and increased yields of the bean crop.

Given current farming practices, tillage immediately before a rice crop is not an option, as the field surface is 1-2 ha. Options would therefore be either to broadcast the guano at the end of the cropping cycle when the soil is freshly tilled from the ginger harvest at the time of the planting of the leguminous crop, or to broadcast the guano into an already established leguminous fallow at least six months before the rice planting. At the same time, fallows can benefit from the guano and be more efficient in nutrient build-up in surface soil, litter, and standing biomass. This practice is reported from Malaysia, where rock phosphate applications were made to leguminous cover crops prior to planting of tree crops (Mutert and Sri Adiningsih, 1998). The application of guano to a cover crop fallow, for instance *Mucuna*, would also be an effective strategy in suppressing *Imperata*, shading it out and bringing the soils back to cultivation again. Futhermore, phosphorus that is taken up by the plant is transformed into organic P, which when applied as mulch is less susceptible to P fixation and is more readily available for the subsequent crop (Buresh et al., 1997).

2. Improve mulch management

The mulch management techniques we applied at the beginning of the cropping cycle should be improved upon. We slashed the fallow biomass ca 1 week before the rice planting, which created a thick mulch layer, causing germination and establishment problems for the rice plants. Also, with this fresh mulch, the separation of woody and leafy biomass demanded manual labor. The mulch management approach I propose is therefore to cut the fallow at least 1 to 3 months before planting, letting the mulch layer begin to decay. The woody biomass will be separated from the leafy biomass through natural processes. At the time of planting, the woody biomass can easily be removed, and the mulch layer is thinner and already decomposing, making it easier to maneuver and control. Ideally, nutrients from the mulch layer would also be partially available to the crop. If guano is applied before the slashing of the fallow biomass, it gets between the soil and the mulch layer and chemical processes that need water will be initiated more favorably. It can be expected that the nutrients will become available at the start of the rice crop. Through mulching leguminous fallow species, the C/N ratio should not present a problem for the subsequent crop (if < 30), as it appears to be when *Imperata* is mulched. Mulching *Imperata* induces N immobilization due to its high C/N ratio (ca 100). Woody stems can be used either for firewood or in the field to form an erosion barrier if arranged along contour lines. In case the mulching material is still too thick for the rice plant, it can be stacked along the contour lines until the rice plants have established themselves and replaced between the plants later on. Here the disadvantage is that this demands labor, which should be avoided whenever possible. In addition, it has to be stressed, that organic matter additions to low CEC tropical soils are of critical importance as it contributes of building up the cation exchange capacity of the soil. (Sanchez, 1976).

3. Adjust nutrient inputs according to crop requirements

The application of guano-phosphate supplies P, Ca, and Mg. That leaves K and N as the next limiting elements. Indeed, nutrient concentration decline was most pronounced with respect to K in ginger leaves, where deficiency-exhibiting leaves reached only 30% of the concentration level of healthy green leaves. For N, the level of concentration was 75%. Thus it should be possible to provide enough N for crops through biological means by integrating leguminous crops more advantageously into the rotation and using leguminous species as cover crops and improved fallows. The production and preservation of organic matter is also of great importance, as it eventually transforms into soil organic matter. With that, the cation exchange capacity in surface soils is increased, which provides a better nutrient holding capacity, especially for potassium

(Hedley et al., 1995). Furthermore, N-fixation increases if P and Ca are supplied in acid soil conditions (Willett et al., 1998). Therefore the integration of leguminous species as fallow species or associated crops should be optimized. Deep rooting fallow species may also be able to recover N and K from the subsoil. Providing external inputs of K might be a problem in eastern Madagascar. One source would be animal manure application, a practice that is rarely pursued in the region due to small livestock numbers and extensive cattle herding. Potassium fertilizers are not available in the region. Madagascar possesses Glauconite reserves that theoretically could be extracted and used for K fertilization (van Straaten, 2002). As seen in Chapter 4, *Psiadia altissima* is a good potassium accumulator in its leaves. Mulching with *Psiadia* leaves would therefore be an efficient means that farmers could use to increase stocks of this element.

4. Optimize crop rotation and cropping techniques

Cropping techniques should assure good and vigorous plant establishment and development. The timing of planting is critically important, as seen in Chapter 2. Within the intensification process, closer spacing is also recommended (Sanchez, 1976; De Datta, 1981) The use of improved varieties could be another recommendation, but there are no improved varieties available in the region. The advantage of traditional varieties is that they are well adapted to acid soil and variable climate conditions.

5. Integrate soil improving species, shrubby legumes, or herbaceous cover crops optimally

Integration of shrubby and herbaceous leguminous species should be optimized. Grain legumes such as *Vigna umbellata* or rice bean (Tsiasisa), *Vigna unguiculata* or cow pea (Voanemba), *Phaseolus sp.*(Tsimidy), and *Phaseolus vulgaris* or common beans, are often associated with other crops (rice, ginger, manioc) where they fulfill the functions of cover crops. The concept of a more intensive use of cover crops is not known in the region. Cover crop species screening is therefore a much-needed research focus. This is also the case for shrubby species. Other than *Crotalaria grahamiana,* only *Tephrosia vogelii* and *Cajanus cajan* are known in the region.

6. Additional research

To confirm and build on these initial improvements with a view to developing a long-term sustainable and diverse upland farming system, additional activities are needed that should be developed in parallel. They include agroforestry technology development, which should start with extensive species screening of agroforestry species, reforestation species, and indigenous trees, and with the training of farmers on tree propagation. Further activities concern erosion control through contour establishment with woody species, reforestation of hilltops, assisted natural regeneration in natural fallows that are set aside and can be complemented by enrichment plantings of valuable forest species. This is just a broad outline of components that could contribute to the development of a sustainable and productive upland system.

Chapter 6

Summary, conclusions, and implications

Slash-and-burn agriculture or *tavy* is the predominant farming system in the eastern region of Madagascar. With increasing population and rapidly decreasing fallow periods, *tavy* is currently the main cause of the destruction of one of the most species-rich primary forests in the world. It is also responsible for landscape degradation and soil fertility depletion, resulting in declining yields and perpetuating rural poverty. Although the negative environmental effects of *tavy* have been recognized for over 150 years, government research and development organizations have not prevented them from occurring, as deforestation and upland degradation continue unabated. The goal of this research was to identify current upland use strategies and upland degradation dynamics and, based on these findings, develop fire-less upland management practices that intensify, improve, and sustain agricultural production and are likely to be adopted by small farmers.

1. Upland use strategies and constraints

Although descriptions of the local farming system existed (Terre-Tany / BEMA, 1997; Terre-Tany / BEMA, 1998), little in-depth information was available, on what farmers upland use strategies are, how they influence long-term agricultural productivity, as well as how farmers perceive production constraints and how they try to overcome them. By studying the farmers' strategies in the forest zone (where primary forests are still present in village proximity, Vohidrazana area) and fallow zone (where all rainforest was cut, Beforona area), this study showed that in the forest zone, current land use trends point to a continuation of deforestation and overharvesting of forest products. In contrast to published studies on Madagascar which suggested that grasslands evolved over hundreds of years, my data suggest that the current landscape in the forest zone is likely to evolve into a treeless landscape within the next two decades, as seen further east in the fallow zone. There, soil fertility depletion has been identified by farmers as the most important constraint on sustainable upland farming. Degradation is so rapid that farmers fear losing the uplands for agricultural purposes within the next ten years. The traditional land tenure regime characterized by sharing land overrules the abilities of a farmer to protect his fallows of being overused. It had thus to be recognized that soil fertility management is independent of soil fertility and land availability and is determined by how many people within the village territory want to crop land.

Despite these trends, *tavy* remains the first farming objective, as it is the traditional and only system people are familiar with. It is also a mixed cropping system that minimizes risk of crop failure via a variety of associated food and cash crops thereby contributing considerably to food security. Farmers consider the extension of irrigated lowland rice and cash crop production as complementary activities that are not suitable substitutes for upland farming activities. My data show that uplands continue degrading despite the diversification efforts and attempts to increase agricultural productivity in the lowlands. Contrary to the initial hypothesis, there are no currently significant upland use strategies at work locally that sustain agricultural productivity. Thus all upland soils are degrading under the current management practices. At the same time there are no feasible technical alternatives locally available to farmers that could prevent the degradation dynamics. Furthermore, farmers lack knowledge about how these trends could be reversed in order to rebuild and, in the long run, maintain a productive upland farming system.

2. Indigenous fallow characterization

Although upland degradation in eastern Madagascar had been identified as a process in which vegetation transitions from rainforest to a *Savoka* or fallow stage, to finally secondary grasslands, it was mostly limited to botanical descriptions and had failed to make the link to agriculture, the main activity on the uplands (Humbert, 1927; Kiener, 1963; Koechlin, 1972; Lowry II et al., 1997; Brand and Pfund, 1998). Very little was therefore known on fallow vegetation dynamics with respect to agricultural practices and how fast the land and vegetation degradation process occurs. My research provides significant new information on both soil and vegetation dynamics as a function of land use intensity in eastern Madagascar. Under the current fallow periods of 3 to 5 years in the study region, significant shifts in fallow species composition can be observed with each additional cycle. Tree fallows, dominated by *Trema orientalis,* only establish in the first post-rainforest fallow cycle. From the second to fifth cycle, shrubby indigenous or exotic species dominate the fallows (*Psiadia altissima, Rubus moluccanus* and *Lantana camara*), but beyond the sixth cycle, ferns and *Imperata cylindrica* replace the shrubs. This is when upland rice agriculture is abandoned. The last stage in species succession is achieved when *Imperata* and fern fallows are replaced by secondary grasslands after a few more cycles. The speed of degradation is therefore much quicker then previously believed. This research shows that a rainforest can be turned into sterile grasslands unsuitable for agriculture within 20 to 30 or possibly 40 years. This is in stark contrast to the 150 to 200 year period predicted in the in the literature (Chauvet, 1972; Brand and Pfund, 1998).

By exploring the indigenous knowledge base, indigenous fallow categories were identified that unveiled significant local qualitative and quantitative knowledge on existing fallow types. These vegetation categories integrate characteristics on species composition, vegetation aspect, agricultural productivity, and management guidelines.

Furthermore these categories can be used as an identification tool for analyzing fallows and landscapes and allowing identifying the stage of degradation and agricultural productivity of a piece land or landscape. The local fallow knowledge also provides indications of the critical production line, below which soils are lost to farming. The critical point therefore occurs when woody species are lost from the fallow vegetation. This can happen when shrubby fallows that have not yet developed into a tall, dense, and dark green stand are cultivated or burned beyond the third cycle following deforestation.

It was also found that with each additional post-deforestation cycle, the fallow periods that are needed to restore soil fertility increase substantially in length. Because of the current population pressure on the rapidly diminishing area of fertile land, most fallows in the fallow zone are cultivated before they can adequately restore soil productivity thereby greatly increasing the rate of land degradation and arrival at the critical "point of no return". Once a grass fallow is established, it is perpetuated with each fire event. This makes it almost impossible for woody species to grow back. It is therefore of great importance to abandon fire use in the farming system, and to develop fire-less practices that help preserve and restore the nutrient stocks for a healthy agricultural system and provide woody plants a safe environment in which to regenerate.

3. Fallow biomass accumulation, nutrient stocks, and soil properties

By building on the just described key-findings on the upland degradation dynamics, a further step was taken to quantify biomass, nutrient stocks, and soil nutrient availability. Although Brand and Pfund (1998) had studied plant and soil nutrients stocks in the region, this study is the first to specifically investigate the nutrient stock dynamic along a gradient of degradation by taking into account fallow age, the cycle number following deforestation, and species composition. Four fallow types were selected from 1 to 10 years in age that were representative of the degradation sequence. They were a *Trema orientalis* tree fallow, the two shrubby fallows *Psiadia altissima* (an endemic species) and *Rubus moluccanus* (an exotic and invasive species), and the herbaceous fallow *Imperata cylindrica.* In addition, four cycles (C1-C4) of *Psiadia altissima* following deforestation were studied.

Accumulated above- and belowground biomass and nutrient stocks were, at the ages of 3 to 5 years, highest for *Rubus* and C1 and C2 *Psiadia.* After the age of 5 years, however, *Trema*'s biomass and nutrient stock accumulation was superior and the established degradation gradient between the fallow types became more distinct with increasing fallow age. *Trema*'s slow early growth refutes the hypothesis of highest productivity in a tree fallow during the first five years. The *Trema* fallow also disappears after the first cycle as a dominant fallow species. As a consequence, the resilience of the agricultural system depends on the shrubby fallows. Natural fallow productivity is low in eastern Madagascar. Biomass production of the shrubby fallows was only a third to half of what is reported in the literature on other rainforest region fallows. Within the species succession, *Rubus* is positioned among the last woody species before the herbaceous fallows. It showed a proportionally larger root system and higher nutrient concentrations in wood and roots compared with those of *Psiadia.* Even though it is an exotic invasive species, which therefore may not be viewed favorably by ecologists and conservationists, *Rubus* maintains a critical position within the agro-ecosystem by holding important nutrient stocks, and its disappearance amounts to large nutrient losses from the system.

If mulching instead of burning of fallow biomass is considered, though, *Rubus*'s drawback is the spiny habit that makes handling it difficult. A mature and thick *Rubus* stand also suppresses the natural regeneration of indigenous species. These disadvantages are not present with *Psiadia*. Furthermore, *Psiadia* is a better potassium accumulator then *Rubus*, a critical element during the early succession phase. *Imperata* has a limited biomass accumulation potential, stalling at circa 5.5 t/ha. Its nutrient concentrations were extremely low, and its high C/N levels in leaves favor N immobilization when mulched. As for the soil nutrient stocks, a downward trend was initiated with the cutting of the rainforest, and with each additional cycle, soil nutrients were continuously depleted. Nutrient stocks in soils under *Imperata* compared with rainforest soils were reduced to one-fourth to one-third of their initial levels for carbon and nitrogen, to 40% to 50% for K, Ca and Mg and to non-detectable levels for P.

4. Fire-less alternative techniques to *tavy*

No published research results on alternative techniques to *tavy* are available and the results of my study represent a significant addition to the relatively sparse data from development and research projects. Fire-less farming techniques were compared with *tavy* for the crop rotation of upland rice, beans, and ginger, followed by a leguminous fallow of *Crotalaria grahamiana* on the four selected fallow types *Trema orientalis*, *Psiadia altissima*, *Rubus moluccanus*, and *Imperata cylindrica* and for four post-deforestation cycles for the *Psiadia* fallow. The alternative techniques consisted, first, of mulching the slashed natural fallow and recycling crop residues without additional nutrients (the <u>M0</u> treatment); second, the same technique supplemented with the application of two modest rates of guano-phosphate, which provided 40 kg/ha of P and 225 kg/ha of Ca (the <u>M40</u> treatment); and third, the same technique again, with the addition of 80kg/ha of P and 450kg/ha of Ca (the <u>M80</u> treatment).

The M80 treatment performed best over the entire rotation. Although its upland rice yielded only two-thirds that of the *tavy* treatment, it outperformed *tavy* with respect to beans, ginger, and *Crotalaria* by 324%, 195%, and 366%, respectively. M40 had significantly higher yields compared with *tavy* from the second season onward, but was always inferior to M80. As for M0, yields for upland rice and beans were not acceptable, but it showed a significant increase in ginger compared with *tavy*. *Tavy* led to the most severe nutrient mining, with only a limited short-term ash effect. The nutrient stocks of *Crotalaria*'s aboveground biomass were, at one year, multiple times higher than on natural fallows. To accumulate the same nutrient stocks it would take a C1 and C2 *Psiadia* fallow 6-9 years, a C3 fallow 8-13 years, and a C4 fallow 17-31 years. The four fallows along the degradation sequence showed a similar trend.

The productivity decline along the degradation sequence, which was established in Chapter 3 and confirmed for fallow productivity in Chapter 4, was also validated for the agricultural crops. A decrease in productivity was also observed with increasing elevation, in the area of current deforestation activities and the least-degraded soils. Productivity at higher altitudes on better soils was slightly higher—although the difference was not statistically significant—than crop productivity at lower altitudes on partially degraded soils. This shows the limitations of the traditional system and indicates the urgency of preventing further deforestation at higher altitudes, especially considering the increasing importance to the overall agro-ecosystem that forests have in these locations.

In conclusion, intensified crop rotation with mulching techniques and guano-phosphate application can be recommended to farmers in the region as feasible cropping system alternatives. This rotation should also include a leguminous fallow phase of 2 to 3 years and the application of guano-phosphate once within the rotation. Still, such techniques need further adjustment and optimization in order to create and reinforce synergetic effects that bring the ultimate goal of building a productive and sustainable upland farming system within reach.

Further research should address ways to enhance the effectiveness of guano-phosphate for the first crop in the rotation through optimized application procedures. There is also the potential for improved mulching management to make nutrients optimally available instead of impeding initial plant development. An adjustment in nutrient inputs should be developed within the system according to crop requirements. Crop rotation and cropping techniques should be optimized so that high productivity can be guaranteed. Leguminous species need to be better integrated, either as crops within the crop rotation or as cover crops or shrubby fallow species.

5. Further implications of these findings

Shifting from fire-dominated land use to fire-free land use is of critical importance if the degradation dynamic is to be stopped and reversed. The encouraging results obtained through agricultural experimentation should be seen as the starting point in upland system improvement efforts that can be carried out on many fronts.

Along with switching to fire-less practices comes a fundamental shift in the guiding principles of natural resource management. The management system must shift its focus from short-term interests and nutrient mining practices towards a system in which each management intervention is judged by its long-term effects. It builds on the principles of recycling, preserving, restoring, and optimizing biological resources and their use within the system. As these principals differ from the current slash-and-burn practices, however, halfway measures that permit even limited fire use should be avoided.

Another important implication that emerged from this research is that in order to improve the agricultural system of the Betsimisaraka, we must work *with* the traditional system and not *against* it by ignoring or stigmatizing it. It is critically important to embrace the system as it is and start working with farmers where they are to develop improvement options. Only with such an approach can the *tavy* system be transformed into a sustainable upland cropping system. It is also recommended that improvement efforts should recognize the upland rice system as an important component of the overall farming system, as it is a valuable mixed cropping system and has strong potential for integration into the intensification and diversification of the crop rotation. It can be hoped that with such an approach, traditional cultural values can evolve organically with changes in the agricultural system, and that the Betsimisaraka's identity can remain rooted in upland agriculture.

Several recommendations for optimizing the intensification process emerge from this research, representing a starting point on a long and difficult road. For any technical improvement work, it is of ultimate importance to monitor carefully the social changes that accompany technical changes, and adapt improvement strategies accordingly, in collaboration with farmers.

Thus, it can be recommended that farmers begin improving their land on a few plots only, allowing them to become familiar with the new principles and techniques and to adapt them to their own preferences and needs. When farmers become more comfortable in managing the new techniques, more plots can be added year by year. Ginger, as a valuable cash crop, can be used as a springboard where guano-phosphate application translates into the highest cash returns, thereby helping farmers purchase more of these inputs. As recognized in the study of the traditional land tenure regime, plot improvement allows a farmer to preserve land from being borrowed by others, which in turn allows the development of a long-term strategy for that land. Such gradual land improvement should be part of a larger plan for improving the local landscape or village territory. Improvement strategies should be worked out collaboratively and agreed upon within the village community. As some plots are intensified in the landscape, other plots can be set aside. On these plots, soil fertility can be restored through the natural restoration process with the optional support of cover crops or improved woody fallow plantings. Plots can also be put aside for indigenous tree regeneration enhanced by enrichment plantings of preferred useful species. This would allow restoration of biodiversity within the agricultural system and the protection of ecologically critical points within the landscape and watershed.

Finally, a significant start in upland improvement was initiated with this research, but there is still much untapped potential for further improving the upland cropping system. More work is needed to continue optimizing the system through improved rotations, cover-cropping, relay-cropping, planting of improved fallows, and periodic guano-phosphate applications in order to build up the soil nutrient capital and elevate the system to the point where it can sustain increased crop yield levels.

Appendix 1

Interview Index

Table 61: Interview Index

ID #	Date	Study	Name	Sex	Age	Village
i1	Jun-99	FS	Janine	f	35	Ambatoharanana
i2	Jul-99	FS	Telovavy	f	25	Ambatoharanana
i3	Jul-99	FS	Ravelo	m	27	Ambatoharanana
i4	Jul-99	FS	Ravelo	m	27	Ambatoharanana
i5	Jul-99	HI	Injva	m	58	Ambatoharanana
i6	Jul-99	FS	Jacqui	m	40	Ambatoharanana
i7	Jul-99	FS	Kodahy Telolahy	m	40	Ambatoharanana
i8	Jul-99	FS	Boavanona	f	50	Ambatoharanana
i9	Jul-99	HI	Millasoa	m	35	Ambatoharanana
i10	Jul-99	FS	4 women	f	25-45	Ambatoharanana
i11	Jul-99	FS	Boavanona	f	50	Ambatoharanana
i12	Jul-99	HI	Tangalamena	m	>60	Ambatoharanana
i13	Jul-99	FS	Gilbert	m	60	Ambatoharanana
i14	Jul-99	FS	Ravelo	m	27	Ambatoharanana
i20	Jun-99	FS	Silvain	m	35	Ambodilazana
i21	Jun-99	FS	Marceline	f	71	Ambodilazana
i22	Jun-99	FS	Boto; Lesianina	m	45	Ambodilazana
i23	Jun-99	FS	Florine	f	35	Ambodilazana
i24	Jun-99	FS	Silvain	m	35	Ambodilazana
i25	Aug-99	FA	5 villagers	m	25-45	Bekorakaka
i26	Aug-99	HI	farmer	m	40	Ampitambe
i27	Aug-99	FA, FS	3 villagers	m	40-50	Ambohimanarivo
i28	Aug-99	HI	Tangalamena	m	50	Ambohimanarivo
i29	Aug-99	FA, FS	6 villagers	m	40-55	Ambohimanarivo
i30	Aug-99	FS	Vincent	m	55	Ambohimanarivo
i31	Aug-99	FA	Vincent	m	55	Ambohimanarivo
i32	Aug-99	HI	Leporaka	m	58	Berano
i33	Aug-99	FA, FS	Woman	f	30	Berano
i34	Aug-99	FA	Razafindiatsara	f	35	Berano
i35	Oct-99	FA	Monsieur Louis	m	75	Ampahitra
i36	Oct-99	FA	Leporaka, Solo	m	58	Berano
i37	Oct-99	FA	Leporaka	m	58	Berano
i38	Nov-99	FA	Silvain	m	35	Ambodilazana
i39	Nov-99	FA	Lemaraina	m	55	Vatomora
i40	Nov-99	FA, FS	Woman	f	40	Ambodilazana
i41	Nov-99	FA	3 villagers	m	25-35	Marolafa
i42	Nov-99	FS	Old man	m	55	Marolafa
i43	Nov-99	FA	Lesabotsy	m	50	Ambavaniasy
i44	Jan-00	FA	Father Manuel	m	55	Ambatomalama
i45	Jan-00	FA, FS	Silvain	m	35	Ambodilazana
i46	Jan-00	FS	10 villagers	m/f	25-40	Marolafa
i47	Apr-00	FA	Joel	m	27	Marolafa
i48	May-00	FA	Lezoma	m	35	Ambavaniasy
i49	May-00	FS	20 villagers	m/f	20-55	Ambavaniasy
i50	May-00	FS	Man	m	40	Ambitambe Forest
i51	Jul-00	HI	20 villagers	m/f	30-70	Ambavaniasy
i52	Jul-00	FS	20 villagers	m/f	30-71	Ambavaniasy
i53	Jul-00	FA	20 villagers	m/f	30-72	Ambavaniasy
i54	Jul-00	FS	Lezoma	m	35	Ambavaniasy
i55	Jul-00	FA, FS	Lez, 2-3 villagers	m	40-55	Ambavaniasy
i56	Jul-00	FS	Lezoma	m	35	Ambavaniasy
i57	Jul-00	FA	Radison	m	45	Ambavaniasy
i58	Jul-00	HI	Rasamuel	m	60	Ambavaniasy
i59	Jul-00	FA	Lezoma	m	35	Ambavaniasy
i60	Jul-00	FA, IS	President Fokontany	m	55	Ampahitra

FS: Farming system, HI: History, FA: Fallow characterization, IS: In-depth study
KP: Key-person interview

Table 61: (Continued)

ID #	Date	Study	Name	Sex	Age	Village
i61	Jul-00	IS	Bernadette	f	35	Ampahitra
i62	Jul-00	IS	Fred	m	30	Ampahitra
i63	Jul-00	IS	Sahasarotra	m	45	Ampahitra
i64	Jul-00	HI	6 men	m	40-70	Ampahitra
i65	Jul-00	FA, FS	3 men	m	45-50	Ampahitra
i66	Jul-00	FA	Monsieur Louis	m	75	Ampahitra
i67	Jul-00	FS	Monsieur Louis	m	75	Ampahitra
i68	Jul-00	FS	10 women, 10 men	m/f	20-60	Ampahitra
i69	Jul-00	FA	President, Louis	m	55,75	Ampahitra
i71	Aug-00	IS	Silvain	m	35	Ambodilazana
i72	Aug-00	IS-KP	Ndrasana	m	25	Marolafa
i73	Aug-00	IS-KP	Boto Jerome	m	65	Marolafa
i74	Aug-00	IS	Diste	m	40	Marolafa
i75	Aug-00	IS	Lesabotsy	m	45	Ambavaniasy
i76	Aug-00	IS-KP	Rabe, Potralahy	m	57,30	Ambinaninsahavolo
i77	Aug-00	IS-KP	Edmont	m	70	Ambinaninsahavolo
i81	Sep-00	IS-KP	Joel	m	27	Marolafa
i82	Sep-00	FA	Leporaka	m	58	Berano
i83	Sep-00	FS	15 farmers	m,f	35-50	Marolafa
i84	Mar-01	IS-KP	Gato and wife	m	55	Ambinaninsahavolo
i85	Mar-01	IS	Ndriantsara and wif	m	55	Ambinaninsahavolo
i86	Mar-01	FS-KP	Joel	m	27	Ambinaninsahavolo
i87	Mar-01	IS	Joel	m	27	Ambinanisahavolo
i88	Mar-01	HI	3 elders	m	>60	Ambinanisahavolo
i90	Mar-01	IS-KP	Ndriantsara and wif	m	55	Ambinanisahavolo
i91	May-01	IS	Rabe	m	57	Ambinanisahavolo
i92	May-01	FS-KP	Joel	m	27	Ambinanisahavolo
i93	May-01	FS	Joel	m	27	Ambinanisahavolo
i94	May-01	FA	Lesab, Kamisy, Joel	m	25-45	Beforona/Ambav
i95	May-01	IS	Lezoma	m	35	Ambavaniasy
i96	May-01	FS	joel	m	27	Ambinanisahavolo
i97	May-01	IS	Gato and Ndriantsar	m	55	Ambinanisahavolo
i98	May-01	IS	Botovola	m	50	Ambinanisahavolo
i99	May-01	IS	Joel	m	27	Ambinanisahavolo
i100	May-01	IS	Joel	m	27	Ambinanisahavolo
i101	May-01	IS	Lemaraina	m	56	Ambinanisahavolo
i102	May-01	IS	Florent	m	25	Ambinanisahavolo
i103	May-01	IS	Rajon	m	43	Ambavaniasy
i104	May-01	IS	Justin	m	46	Ambavaniasy
i105	May-01	IS	Maro Gabriel	m	38	Ambavaniasy
i106	May-01	FS	Lezoma	m	35	Ambavaniasy
i107	May-01	IS	Lezoma	m	35	Ambavaniasy
i108	May-01	FS	Lezoma	m	35	Ambavaniasy
i109	May-01	FS	Lezoma	m	35	Ambavaniasy
i110	May-01	FS	Lezoma	m	35	Ambavaniasy
i111	May-01	IS	Lezoma	m	35	Ambavaniasy
i112	May-01	FS	Pascal	m	55	Ambavaniasy
i113	May-01	FS	Proty	m	75	Ambavaniasy
i114	May-01	FS-KP	Radede	m	45	Ambavaniasy
i115	May-01	FS	Lucille	f	44	Ambavaniasy
i116	May-01	IS	Andre	m	38	Ambavaniasy
i117	May-01	IS	Lezoma	m	35	Ambavaniasy
i118	May-01	IS	Pascal	m	55	Ambavaniasy
i119	May-01	IS	Clarisse	f	35	Ambavaniasy
i120	May-01	IS	Rasamuel	m	60	Ambavaniasy

FS: Farming system, HI: History, FA: Fallow characterization, IS: In-depth study
KP: Key-person interview

Appendix 2

Questionnaire-guides for four main studies on upland use

1. Farming system description study

Farming system components:

- General questions: Which systems components do you have: lowland rice, upland fields, tanimbolys, reforestation plot? What are the crops, trees, animals you have and cultivate?
- Specific questions for farming system component under study:
  Species, cropping calendar and management, rotation and fallow/cropping cycles, land tenure, soil productivity, labor organization within family, self-consumption or cash crop, problems associated with the crops or systems component, are there any improved techniques (from where)

2. Fallow characterization study

- What is the indigenous terminology for fallows?
- How is each term defined?
- How do the fallow types relate to each other?
- What is the species succession that occurs with each additional cycle after deforestation?
- How do species behave towards each other? What are the characteristics of associations, how competitive, suppressive are species towards each other?
- How are species influenced by management? (frequency of slashing, burning, cropping)

3. Farming systems history study

3.1. Group interview with elders

- Since when does the village exists? Who founded it, since when are the lineages in the village, how are they organized?
- Emigration/immigration?
- How were village territorial boundaries determined?
- What were the major historical events and their impact on community, land use and natural resources?
- What were the driving forces for change?
- How did land use, land tenure, agricultural crops, cropping and fallow cycles change over the past 30 to 50 years (as long as elders remember)?
- How has availability and state/quality of natural resources changed over time for forest, agricultural land, fallows?
- Land tenure: how is it organized, land ownership, user rights? Is there a difference for different land types such as: *tanimboly, horaka, tanety, sembotrano, tany masiaka,* different fallow types?

Ranking exercises:

Ranking of natural resources according to their relative importance for present time, 5, 10, 20, 30, 40 years ago for land resources (uplands, lowlands), agricultural crops, fallow land, soil quality, forest surface, forest resources and number of households

3.2. Individual interviews with elders

- How did the landscape look like when he was young?
- Where was the big forest at that point?
- What crops were important?

- How long were the fallow periods?
- Did the village territory have the same boundary then today?
- How did people obtain land and how has that changed?
- What was the influence of the colonial period, Tsiranana (1st republic), Ratsiraka (2nd republic), after Ratsiraka on the village life?
- Agricultural extension service: When was it present, what did they work on
- When was the best period for agriculture?
- When did the problems start?
- Today, which are the biggest problems, and what solutions could there be?
- How will future look like? What should be changed for a better future?

4. Farmers' upland use strategies study

4.1. Key-person interview

- What are the major categories of land management in the village, including land availability, access to land, land tenure situation? What are the differences for the different families in the village?
- What are the maincontraints/limitations for farmers to manage their land in order to maintain long-term productivity of the land?

4.2. Individual strategy interview and plot inventories

4.2.1. Individual interviews

- Historical review of his exploitation
- When did he start farming, how did he obtain his land, did he deforest?
- Agriculture this year: what crops, how much land for each crop?
- How do you use the uplands?

- Have your strategies changed over time?
- What are your first farming objectives?
- Which farming activity is most interesting to you?
- What are the biggest problems to cultivate the upland sustainably?
- What is the land tenure situation of your uplands?
- What are the strategies for improving the use of the land? What are the options?
- Agricultural intensification, is it an option?
- What are alternative techniques that you know?
- Do you know how soil fertility can be restored faster?
- What are the biggest problems in general that you face?
- Vision and wishes for the future, how should agriculture evolve?

In respect to forest resources (in the forest zone only)

- What is the value of the forest to you? (Products, environmental services, cultural, ritual, if the forest disappears what does it mean to you?)
- What forest products to you extract? How often? How difficult is it to find the products these days? What price to you get?
- What are you doing with revenue from forest product extraction? Invest? Where?
- How fast will the resources disappear? What will happen when the rare products today are gone?
- What is the role of the government, forestry service in the region?
- How does forest product extraction influence your agricultural activities?

4.2.2. Plot inventories

- Make a schematic map of the farmer's land in the field by looking at landscape, identify individual plots and let farmer reiterate the history of each plot: year of deforestation, fallow periods, cropping periods, and change of fallow species

- Description of the current fallow vegetation composition for each plot: species, age, cycle and indigenous fallow name.
- Discuss fallow vegetation succession in respect to fallow cycles on the different plots

Additional questions during inventory

- Which land is cultivated this year, which crop, on what type of fallow, how did they decide on choosing location?
- Fallow land: how do they plan to use it in future? What are the options for use?

Appendix 3

Scatter plots and regression plots for aboveground biomass estimation

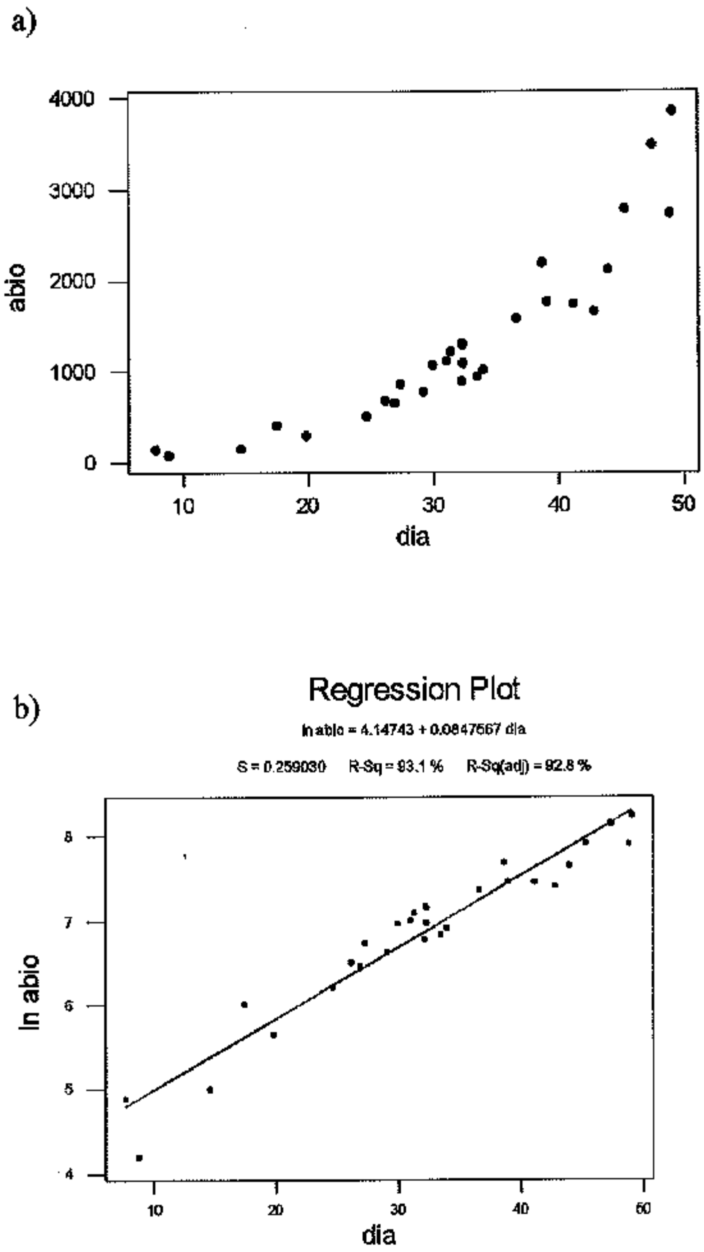
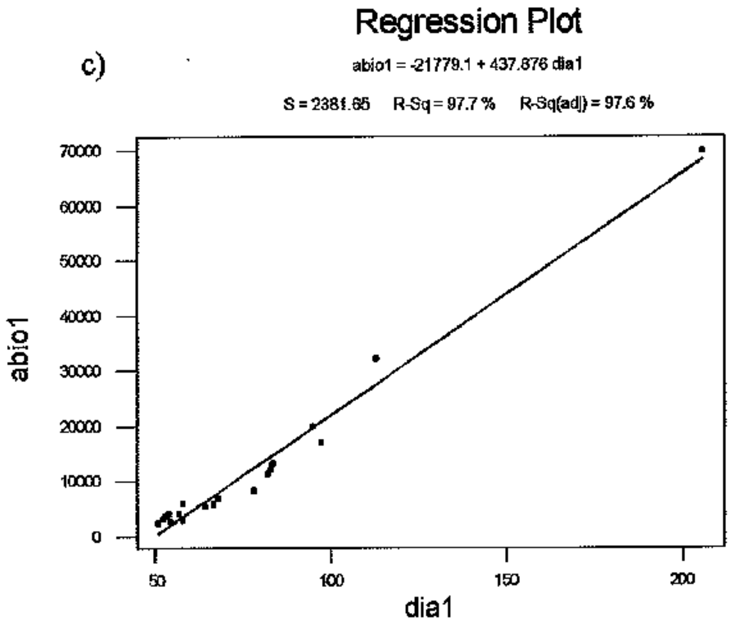


Figure 43: *Trema orientalis* a) scatter plot (dbh in mm (x), above ground biomass in kg/tree (y) and b) ln(y) transformed regression predicting above-ground biomass (y) through dbh diameters 6-50mm(x) and c) linear regression predicting above-ground biomass (y) through dbh diameters 51-200mm(x)

Figure 43: (Continued)



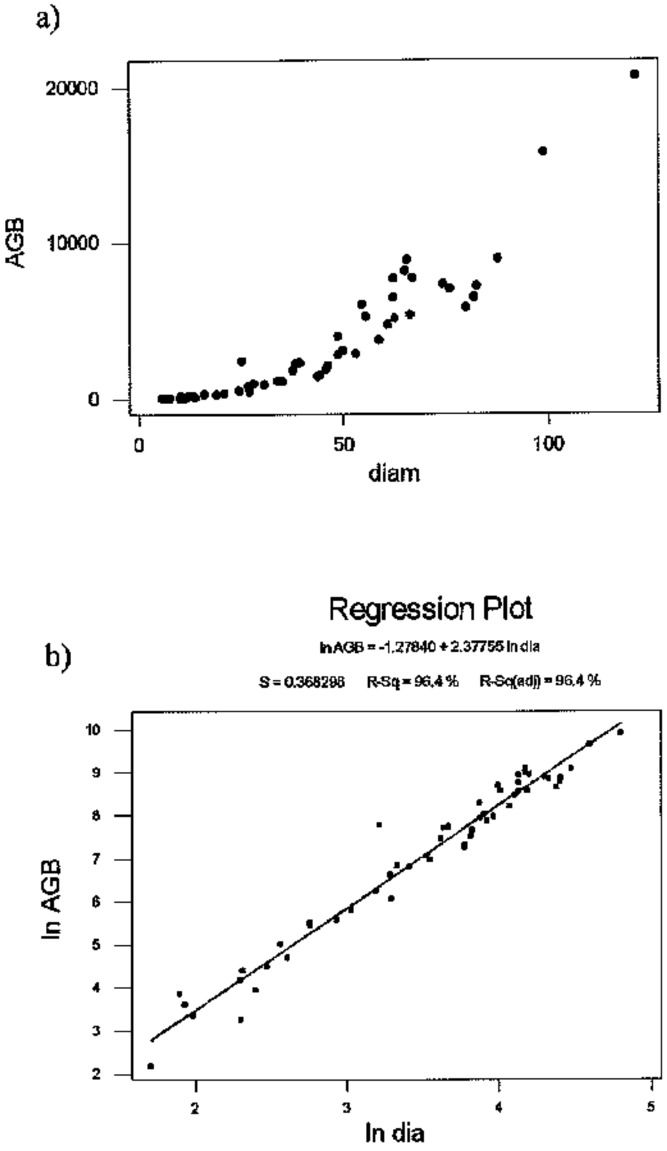


Figure 44: *Psiadia altissima* a) scatter plot (stem diameter at 10cm (x), above-ground biomass in kg/tree (y) and b) ln (x) – ln (y) transformed regression predicting above-ground biomass (ln y) trough stem diameter (ln x)

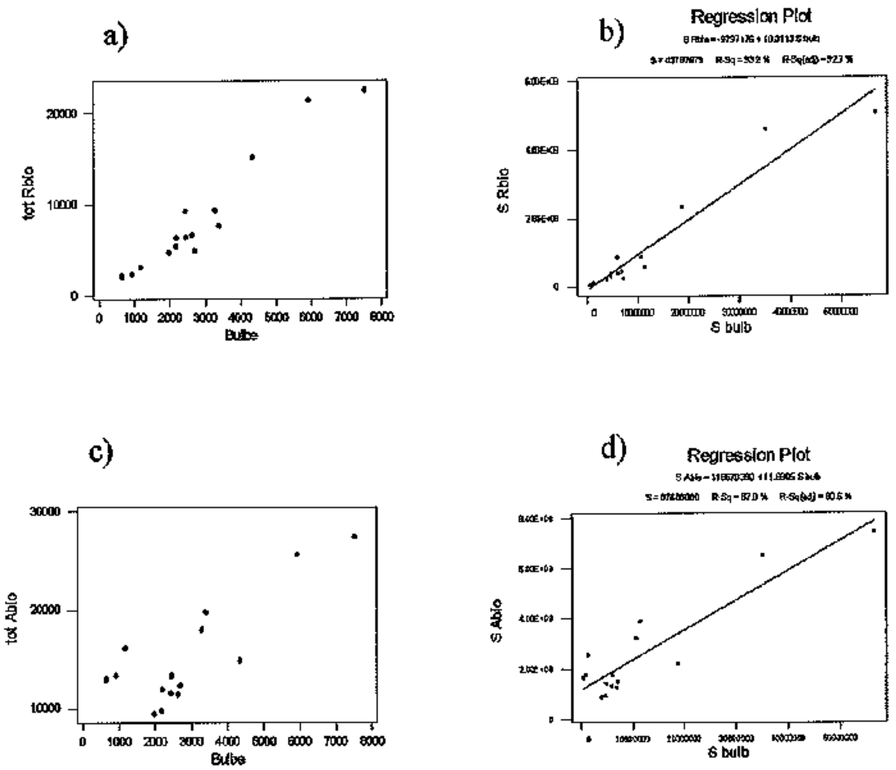


Figure 45: *Rubus moluccanus*: a) scatter plot and b) square (x) and square (y) transformed regression to predict total root biomass (y) (g/tree) through root bulb biomass (x) (g/tree) and c) scatter plot and d) regression predicting a) root biomass and b) above-ground biomass through root bulb biomass square (x) and square (y) transformed regression to predict above-ground biomass (y) (g/tree) through root bulb biomass (x) (g/tree)

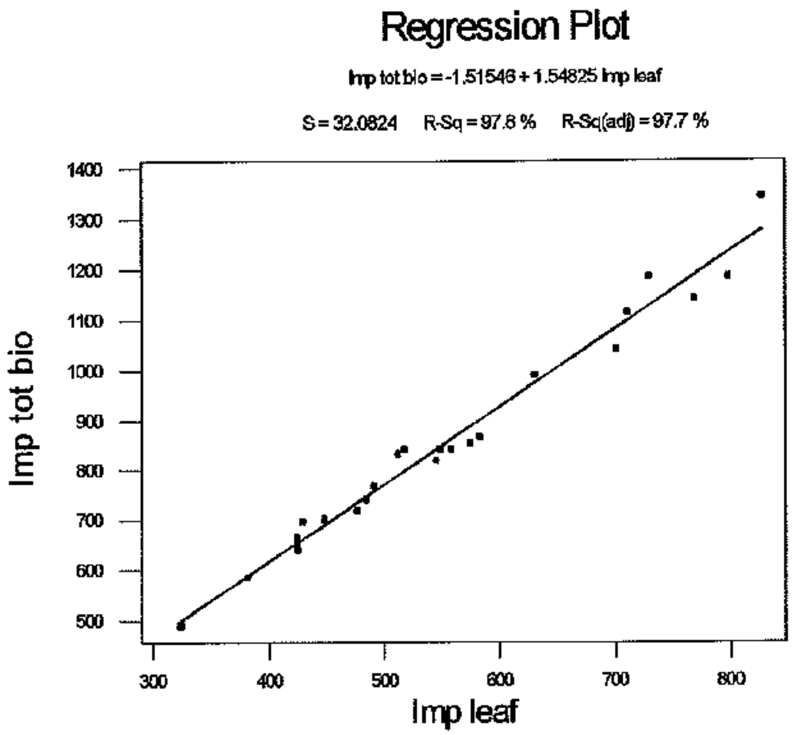


Figure 46: *Imperata cylindrica*: Linear regression predicting total biomass (Y) in g/m^2 through leafy biomass (x) in g/m^2

Appendix 4

Regression models for *Trema orientalis*

Table 62: Regression models for yearly increase in biomass components and major population characteristics of *Trema orientalis*

Parameter (y)	Equation	r2	P	SE slope year	SE slope year^2
Diameter	$y = 20.03 - 6.13\ \text{year} + 1.92\ \text{year}^2$	0.975	0.0001	5.232	0.461
Trees/ha	$\ln y = 9.77 - 0.167\ \text{year}$	0.743	0.0126	0.0441	
Basal area	$y = -2.86 + 3.29\ \text{year}$	0.954	0.0002	0.3246	
Leaves	$y = 105 - 88.7\ \text{year} + 102.9\ \text{year}^2$	0.968	0.0002	248.69	21.92
Stem	$y = -552.7 - 116\ \text{year} + 808\ \text{year}^2$	0.988	0.0001	2011.5	177.23
Branch	$y = 521 - 647\ \text{year} + 246\ \text{year}^2$	0.991	0.0001	418.83	36.9
Wood	$y = 85.72 - 817\ \text{year} + 1059\ \text{year}^2$	0.989	0.0001	2409.3	212.27
Above- bio	$y = 794 - 867\ \text{year} + 1149\ \text{year}^2$	0.99	0.0001	2543.6	224.11
Primary root	$y = -238 + 319\ \text{year} + 66.5\ \text{year}^2$	0.982	0.0003	298.3	26.28
Second. root	$y = -59 + 49.6\ \text{year} + 70.3\ \text{year}^2$	0.985	0.0002	215.62	18.99
Fine root	$y = 3.54 + 1.959\ \text{year}$	0.83	0.0043	0.3966	
Total root	$y = -133 + 266\ \text{year} + 144\ \text{year}^2$	0.983	0.0003	516.53	45.51
Total biomass	$y = -1510 + 1888\ \text{year} + 789\ \text{year}^2$	0.985	0.0002	2747.4	242.07

Appendix 5

Trema orientalis diameter distribution

Table 63: Diameter distribution (number of trees/ha per diameter class) for *Trema orientalis* from 1 to 10 years

dbh (mm)	1 year	2 years	3 years	4 years	5 years	7 years	10 years
0							
< 10	12167	1764		1330	464		
>10-20		4058		5285	2320		
>20-30		3176	2833	2960	2088	361	
>30-40		1941	3833	2400	2784	722	
>40-50		176	1167	336	2088	722	
>50-60		176	83	441	928	722	
>60-70				448	696	1083	
>70-80						722	
>80-90						1444	
>90-100							
>100-110							
>110-120						361	
>120-130							370
>130-140							370
>140-150							185
>150-160							926
>160-170							556
stems/ha	12167	11292	7917	13200	11369	6139	2407

Appendix 6

Regression models for *Psiadia altissima*

Table 64: Regression models for yearly increase in biomass components and population characteristics of *Psiadia altissima* for four cycles after deforestation

Parameter	Regression equation	r^2	p	SE (slope)	Parameter	Regression equation	r^2	p	SE (slope)
	Cycle 1					**Cycle 3**			
Diameter	y = 8.28378 + 4.11757 year	0.921	0.010	0.651	Diameter	y = 5.97 + 3.76 year	0.923	0.002	0.544
Trees/ha	y = 30513 - 2140 year	0.718	0.070	766	Trees/ha	y = 20682 - 1250 year	0.803	0.016	254
Basal area	y = 2.51 +2.251 year	0.828	0.032	0.592	Basal area	y = -0.18 + 1.709 year	0.924	0.002	0.244
Leaves	y = 116 + 277 year	0.934	0.007	42.4	Leaves	y = - 145 + 210 year	0.976	0.000	16.51
Stem	y = 719 + 2145 year	0.935	0.007	327.7	Stem	y = - 1383 + 1677 year	0.975	0.000	133.8
Branch	y = - 9.4 + 1243 year	0.931	0.008	196	Branch	y = - 1487 + 1125 year	0.962	0.001	111.7
Wood	y = 365 + 3568 year	0.933	0.006	552	Wood	y = - 3575 + 3063 year	0.968	0.000	277.5
Above biomass	y = 594 + 3891 year	0.934	0.007	598.7	Above biomass	y = - 3576 + 3267 year	0.970	0.000	285.5
Primary root	y = 25 + 311 year	0.933	0.006	48.3	Primary root	y = - 322 + 269 year	0.967	0.000	24.8
Second. root	y = - 15 + 323 year	0.929	0.008	51.5	Second. root	y = - 412 + 299 year	0.959	0.001	30.8
Fine root	y = 9.76 + 8.51 year	0.923	0.009	1.42	Fine root	y = 2.97 + 5.33 year	0.957	0.001	0.563
Total root	y = 8 + 725 year	0.931	0.008	113.9	Total root	y = - 843 + 650 year	0.963	0.001	63.6
Total biomass	y = 503 + 4598 year	0.933	0.007	710.6	Total biomass	y = - 4554 + 3935 year	0.969	0.000	354.7
	Cycle 2					**Cycle 4**			
Diameter	y = 6.77 + 4.09 Year	0.968	0.000	0.379	Diameter	y = 8.51 + 2.21 year	0.912	0.003	0.341
Trees/ha	y = 24583 - 1321 Year	0.769	0.018	337.7	Trees/ha	y = 17036 - 857 year	0.818	0.013	167.2
Basal area	y = 0.07 + 2.567 Year	0.963	0.001	0.167	Basal area	y = 0.506 + 0.806 year	0.942	0.001	0.099
Leaves	y = - 106 + 276 Year	0.984	0.000	17.8	Leaves	y = 17.2 + 84.3 year	0.953	0.001	9.41
Stem	y = - 1167 + 2218 Year	0.984	0.000	143.3	Stem	y = - 8 + 664 year	0.949	0.001	76.6
Branch	y = - 1626 + 1640 Year	0.975	0.000	124.5	Branch	y = - 344 + 418 year	0.927	0.002	58.63
Wood	y = - 3689 + 4140 Year	0.979	0.000	301.2	Wood	y = - 664 + 1155 year	0.936	0.002	151.9
Above biomass	y = - 3575 + 4394 Year	0.981	0.000		Above biomass	y = - 567 + 1255 year	0.940	0.001	158.8
Primary root	y = - 336 + 365 Year	0.979	0.000	27.0	Primary root	y = - 63.4 + 102 ye	0.935	0.002	13.5
Second. root	y = - 459 + 411 Year	0.972	0.000	34.8	Second. root	y = - 100 + 110 year	0.923	0.002	15.91
Fine root	y = 5.86 + 6.73 Year	0.958	0.001	0.702	Fine root	y = 4.94 + 2.26 year	0.938	0.001	0.292
Total root	y = - 916 + 888 Year	0.975	0.000	70.5	Total root	y = - 190 + 243 year	0.929	0.002	33.6
Total biomass	y = - 4679 + 5316 Year	0.980	0.000	354.5	Total biomass	y = - 629 + 1499 year	0.937	0.002	194.7

Appendix 7

Psiadia altissima diameter distribution

Table 65: Diameter distribution of *Psiadia altissima* for four cycles and from 1 to 8 years in diameter classes of 5 mm

	CYCLE1					CYCLE 2					
stem/ha											
dia	Y1	Y2	Y3	Y4	Y6	Y1	Y2	Y3	Y4	Y6	Y7
0-5	2417	0	500	0	0	2167	0	167	0	0	0
>5-10	14583	2833	1667	417	1349	14417	2583	1000	667	1250	167
>10-15	8250	8167	3000	1500	3372	6750	7417	3833	3583	1750	1458
>15-20	2250	9750	3500	4250	4317	1667	6417	4667	5750	2500	1667
>20-25		6167	4833	5333	2293		2667	3417	4667	2000	1333
>25-30		1667	2583	3667	3372		500	2000	2000	1250	1792
>30-35		1250	1500	1417	1349			2167	2083	1750	708
>35-40		83	2000	1917	1079			1500	1083	2750	1500
>40-45		167	833	1417	674			833	667	1250	1250
>45-50			333	417	809			83	250	1250	1667
>50-55			333	333	135				83	500	1625
>55-60			0	83						250	542
>60-65			83	83						250	625
>65-70										0	42
>70-75										250	250
>75-80										0	125
>80-85										250	0
>85-90											0
>90-95											42
Sum	27500	30083	21167	20833	18750	25000	19583	19667	20833	17250	14792

	CYCLE 3						CYCLE 4					
stem/ha												
dia	Y1	Y2	Y3	Y4	Y7	Y8	Y1	Y2	Y3	Y4	Y6	Y8
0-5	2000	333	250	0	0	0	2167	103	0	0	0	0
>5-10	12833	3250	1083	250	667	0	10417	3196	1583	583	1250	250
>10-15	5750	6333	4250	2083	1833	0	4250	6701	5000	3167	3000	1500
>15-20	1167	5667	6083	3833	2417	1000	417	3918	4667	3500	4000	2500
>20-25		1500	2250	3250	2083	1000		1649	1750	2667	1750	1500
>25-30		250	917	1500	1083	1500		0	750	833	1500	1333
>30-35			667	1500	2083	1000			167	750	0	667
>35-40			833	667	833	500				83	250	833
>40-45			83	83	1250	1500				167	500	750
>45-50					417	1250					250	750
>50-55					333	1000						167
>55-60					83	1250						333
>60-65					167	500						83
>65-70					167	250						
>70-75												
>75-80												
>80-85												
Sum	21750	17333	16417	13167	13417	10750	17250	15567	13917	11750	12500	10667

Appendix 8

Nutrient concentrations of fallow biomass

Table 66: Nutrient concentrations of leaves, wood and roots for four fallow species

	C %	SE	N %		SE	P ppm		SE	K ppm		SE
LEAVES											
Trema	46.80	1.450	2.629	a*	0.146	1666	a	135.5	14840	b	1222
Psiadia	49.58	1.450	2.198	b	0.146	1518	a	135.5	35287	a	1222
Rubus	46.05	1.675	1.260	c	0.168	1248	ab	156.5	6232	c	1411
Imperata	47.54	1.297	0.481	d	0.130	493	c	121.2	4595	c	1093
Fern	46.39	1.450	0.820	cd	0.146	664	bc	135.5	7161	c	1222
p-value	0.492		<0.0001			<0.0001			<0.0001		
WOOD											
Trema	50.25	2.284	0.418	a	0.038	568	ab	154.2	7298	a	844
Psiadia	53.78	2.284	0.233	b	0.038	188	b	154.2	4981	ab	844
Rubus	48.84	2.638	0.290	ab	0.044	795	a	178.0	3519	b	974
p-value	0.371		0.023			0.081			0.049		
ROOT											
Trema	47.61	0.846	0.415	ab	0.036	398	ab	155.4	7212	ab	926
Psiadia	45.60	0.846	0.244	c	0.036	208	b	155.4	6243	ab	926
Rub root	44.67	0.976	0.524	a	0.041	855	a	179.6	3720	b	1070
Rub bulb	46.06	0.976	0.484	a	0.041	910	a	179.5	3983	b	1070
Imperata	44.42	0.756	0.295	bc	0.032	805	a	139.0	7852	a	829
p-value	0.110		0.000			0.027			0.030		

* Means that are followed by the same letter are not signficantly different at $p<0.05$

	Mg ppm		SE	Ca ppm		SE	S ppm		SE	AL ppm		SE	C/N
LEAVES													
Trema	3971	b	401	14619	a	817	1501	b	125.6	139	b	327	18
Psiadia	1876	cd	401	9530	b	817	2532	a	125.6	81	b	327	23
Rubus	7352	a	463	11164	ab	943	1749	b	145.0	257	b	327	37
Imperata	1267	d	359	724	c	731	788	c	112.3	277	b	327	99
Fern	2931	bc	401	3600	c	817	1353	b	125.6	4164	a	366	57
p-value	<0.0001			<0.0001			<0.0001			<.0001			
WOOD													
Trema	1449	a	92	3162		259	281	b	25.6	193	a	23	120
Psiadia	284	b	92	3395		259	370	b	25.6	78	b	23	231
Rubus	1218	a	106	2921		299	523	a	29.6	60	b	23	168
p-value	<0.0001			0.515			0.001			0.003			
ROOT													
Trema	1688	a	147	3638	bc	552	218	c	74.2	1186	ab	180	115
Psiadia	249	b	147	2648	c	552	563	b	74.2	735	b	180	187
Rub root	1906	a	170	5561	ab	637	664	b	85.7	1160	ab	180	85
Rub bulb	1327	a	170	8084	a	637	630	b	85.7	514	b	180	95
Imperata	635	b	132	254	d	494	1217	a	66.4	1846	a	180	151
p-value	<0.0001			<0.0001			<0.0001			0.001			

Appendix 9

Nutrient stocks of *Trema orientalis*

Table 67: Nutrient stocks (kg/ha) of biomass components for *Trema orientalis* from 1 to 10 years

Years	Yield	C	N	P	K	Mg	Ca	S
				kg/ha				
Leaves								
1	119	56	3.1	0.2	1.8	0.5	1.7	0.2
2	339	159	8.9	0.6	5.0	1.3	5.0	0.5
3	765	358	20.1	1.3	11.4	3.0	11.2	1.1
4	1397	654	37	2.3	21	5.5	20	2.1
5	2234	1046	59	3.7	33	8.9	33	3.4
6	3277	1534	86	5.5	49	13.0	48	4.9
7	4526	2118	119	7.5	67	18.0	66	6.8
8	5981	2799	157	10.0	89	23.8	87	9.0
9	7642	3576	201	12.7	113	30.3	112	11.5
10	9508	4450	250	15.8	141	37.8	139	14.3
Branches								
1	120	60	0.5	0.1	0.9	0.2	0.4	0.0
2	211	106	0.9	0.1	1.5	0.3	0.7	0.1
3	794	399	3.3	0.5	5.8	1.2	2.5	0.2
4	1869	939	7.8	1.1	13.6	2.7	5.9	0.5
5	3436	1727	14	2.0	25	5.0	11	1.0
6	5495	2761	23	3.1	40	8.0	17	1.5
7	8046	4043	34	4.6	59	11.7	25	2.3
8	11089	5572	46	6.3	81	16.1	35	3.1
9	14624	7349	61	8.3	107	21.2	46	4.1
10	18651	9373	78	10.6	136	27.0	59	5.2
Stem								
1	139	70	0.6	0.1	1.0	0.2	0.4	0.0
2	2447	1230	10.2	1.4	17.9	3.5	7.7	0.7
3	6371	3202	26.6	3.6	46.5	9.2	20.1	1.8
4	11911	5986	50	6.8	87	17.3	38	3.4
5	19067	9582	80	10.8	139	27.6	60	5.4
6	27839	13990	116	15.8	203	40.3	88	7.8
7	38227	19210	160	21.7	279	55.4	121	10.8
8	50231	25242	210	28.5	367	72.8	159	14.1
9	63851	32087	267	36.3	466	92.5	202	18.0
10	79087	39743	330	44.9	577	114.6	250	22.3
AGB								
1	379	186	4.2	0.3	3.7	0.8	2.6	0.3
2	2998	1495	20.0	2.1	24.4	5.2	13.4	1.3
3	7930	3959	50	5.3	64	13.4	34	3.2
4	15177	7579	94	10.2	121	25.5	64	6.0
5	24737	12354	153	16.5	197	41.5	104	9.7
6	36612	18285	225	24.4	292	61.3	153	14.3
7	50800	25372	312	33.8	405	85.0	212	19.8
8	67301	33614	413	44.8	536	112.6	281	26.2
9	86117	43012	529	57.3	686	144.0	360	33.6
10	107246	53565	658	71.4	854	179.3	448	41.8

Table 67: (Continued)

Years	Yield	C	N	P	K	Mg	Ca	S
				kg/ha				
Root	214	102	0.9	0.1	1.5	0.4	0.8	0.0
2	995	474	4.1	0.4	7.2	1.7	3.6	0.2
3	2049	976	8.5	0.8	14.8	3.5	7.5	0.4
4	3378	1608	14.0	1.3	24.4	5.7	12.3	0.7
5	4979	2371	20.7	2.0	36	8.4	18.1	1.1
6	6855	3264	28	2.7	49	11.6	24.9	1.5
7	9004	4287	37	3.6	65	15.2	33	2.0
8	11426	5440	47	4.6	82	19.3	42	2.5
9	14122	6724	59	5.6	102	23.8	51	3.1
10	17092	8138	71	6.8	123	28.8	62	3.7
Total biomass								
1	592	288	5.1	0.4	5.2	1.2	3.3	0.3
2	3992	1968	24.2	2.5	32	6.9	17.0	1.5
3	9980	4934	59	6.2	78	16.9	41	3.6
4	18554	9187	108	11.5	146	31.2	76	6.7
5	29717	14725	173	18.5	233	50	122	10.8
6	43466	21549	254	27.1	341	73	178	15.8
7	59803	29658	350	37.4	470	100	245	21.8
8	78728	39054	461	49.3	619	132	323	28.7
9	100239	49736	587	62.9	788	168	411	37
10	124338	61703	729	78.2	978	208	510	46
Mulch for agricultural cycle (leaves + 1/2 branches + roots)								
1	393	188	4.3	0.3	3.7	0.9	2.7	0.2
2	1440	685	13.5	1.0	13.0	3.2	8.9	0.8
3	3211	1533	30.3	2.3	29.0	7.1	19.9	1.7
4	5709	2731	55	4.2	52	12.6	36	3.1
5	8931	4280	87	6.7	82	19.8	56	4.9
6	12879	6178	126	9.7	118	28.6	82	7.2
7	17553	8427	173	13.4	161	39	112	9.9
8	22952	11025	228	17.7	212	51	147	13.0
9	29076	13974	290	22.5	269	65	186	16.6
10	35926	17274	360	27.9	332	80	231	20.6

Appendix 10

Nutrient stocks for *Psiadia altissima*

Table 68: Nutrient stocks (kg/ha) for *Psiadia altissima* for four cycles from 1 to 10 years

CYCLE	YEAR	Leaf yield	C	N	P	K	Mg	Ca	S	Stem yield	C	N	P	K	Mg	Ca	S
									kg/ha								
1	1	205	102	4.6	0.31	7.3	0.39	2.0	0.53	1429	753	3.3	0.26	7.1	0.41	4.9	0.52
1	2	670	334	14.9	1.02	24.0	1.28	6.4	1.74	5009	2641	11.5	0.91	24.7	1.43	17.1	1.83
1	3	947	471	21.1	1.44	33.9	1.80	9.1	2.45	7154	3772	16.4	1.30	35.3	2.04	24.4	2.61
1	4	1224	609	27.2	1.86	43.8	2.33	11.8	3.17	9299	4903	21.3	1.69	45.9	2.66	31.7	3.39
1	5	1501	747	33.4	2.29	53.7	2.86	14.4	3.89	11444	6034	26.2	2.08	56.5	3.27	39.0	4.17
1	6	1778	885	39.5	2.71	63.7	3.39	17.1	4.61	13589	7165	31.1	2.47	67.0	3.88	46.3	4.96
1	7	2055	1023	45.7	3.13	73.6	3.91	19.8	5.33	15734	8296	36.0	2.86	77.6	4.49	53.6	5.74
1	8	2332	1161	51.8	3.55	83.5	4.44	22.4	6.04	17879	9427	40.9	3.25	88.2	5.11	60.9	6.52
1	9	2609	1299	58.0	3.97	93.4	4.97	25.1	6.76	20024	10558	45.8	3.64	98.8	5.72	68.2	7.30
1	10	2886	1437	64.2	4.39	103.3	5.50	27.8	7.48	22169	11689	50.7	4.03	109.4	6.33	75.5	8.09
2	1	179	89	4.0	0.27	6.4	0.34	1.7	0.46	1242	655	2.6	0.23	6.1	0.35	4.2	0.45
2	2	448	222	9.9	0.68	16.0	0.85	4.3	1.16	3269	1724	7.5	0.59	16.1	0.93	11.1	1.19
2	3	722	359	16.1	1.10	25.9	1.38	6.9	1.87	5487	2893	12.6	1.00	27.1	1.57	18.7	2.00
2	4	998	497	22.2	1.52	35.7	1.90	9.6	2.59	7705	4063	17.6	1.40	38.0	2.20	26.2	2.81
2	5	1274	634	28.3	1.94	45.6	2.43	12.3	3.30	9923	5232	22.7	1.80	49.0	2.83	33.8	3.62
2	6	1550	772	34.5	2.36	55.5	2.95	14.9	4.02	12141	6401	27.8	2.20	59.9	3.47	41.4	4.43
2	7	1826	909	40.6	2.78	65.4	3.48	17.6	4.73	14359	7571	32.9	2.61	70.8	4.10	48.9	5.24
2	8	2102	1047	46.7	3.20	75.3	4.00	20.2	5.45	16577	8740	37.9	3.01	81.8	4.73	56.5	6.05
2	9	2378	1184	52.9	3.62	85.2	4.53	22.9	6.16	18795	9910	43.0	3.41	92.7	5.37	64.0	6.86
2	10	2654	1321	59.0	4.04	95.0	5.06	25.5	6.88	21013	11079	48.1	3.82	103.7	6.00	71.6	7.67
3	1	145	72	3.2	0.22	5.2	0.28	1.4	0.38	1003	529	2.3	0.18	4.9	0.29	3.4	0.37
3	2	275	137	6.1	0.42	9.8	0.52	2.6	0.71	1971	1039	4.5	0.36	9.7	0.56	6.7	0.72
3	3	485	241	10.8	0.74	17.4	0.92	4.7	1.26	3648	1923	8.3	0.66	18.0	1.04	12.4	1.33
3	4	695	346	15.5	1.06	24.9	1.32	6.7	1.80	5325	2808	12.2	0.97	26.3	1.52	18.1	1.94
3	5	905	451	20.1	1.38	32.4	1.72	8.7	2.35	7002	3692	16.0	1.27	34.5	2.00	23.9	2.55
3	6	1115	555	24.8	1.70	39.9	2.12	10.7	2.89	8679	4576	19.9	1.58	42.8	2.48	29.6	3.17
3	7	1325	660	29.5	2.02	47.4	2.52	12.7	3.43	10356	5460	23.7	1.88	51.1	2.96	35.3	3.78
3	8	1535	764	34.1	2.34	55.0	2.92	14.8	3.98	12033	6344	27.5	2.19	59.4	3.44	41.0	4.39
3	9	1745	869	38.8	2.66	62.5	3.32	16.8	4.52	13710	7229	31.4	2.49	67.6	3.92	46.7	5.00
3	10	1955	973	43.5	2.98	70.0	3.72	18.8	5.07	15387	8113	35.2	2.79	75.9	4.39	52.4	5.61
4	1	104	52	2.3	0.16	3.7	0.20	1.0	0.27	716	378	1.6	0.13	3.5	0.20	2.4	0.26
4	2	186	93	4.1	0.28	6.7	0.36	1.8	0.48	1320	696	3.0	0.24	6.5	0.38	4.5	0.48
4	3	270	134	6.0	0.41	9.7	0.51	2.6	0.70	1984	1046	4.5	0.36	9.8	0.57	6.8	0.72
4	4	354	176	7.9	0.54	12.7	0.68	3.4	0.92	2648	1396	6.1	0.48	13.1	0.76	9.0	0.97
4	5	439	218	9.8	0.67	15.7	0.84	4.2	1.14	3312	1746	7.6	0.60	16.3	0.95	11.3	1.21
4	6	523	260	11.6	0.80	18.7	1.00	5.0	1.36	3976	2096	9.1	0.72	19.6	1.14	13.5	1.45
4	7	607	302	13.5	0.92	21.7	1.16	5.8	1.57	4640	2446	10.6	0.84	22.9	1.33	15.8	1.69
4	8	692	344	15.4	1.05	24.8	1.32	6.7	1.79	5304	2797	12.1	0.96	26.2	1.51	18.1	1.93
4	9	776	386	17.3	1.18	27.8	1.48	7.6	2.01	5968	3147	13.7	1.08	29.4	1.70	20.3	2.18
4	10	860	428	19.1	1.31	30.8	1.64	8.3	2.23	6632	3497	15.2	1.20	32.7	1.89	22.6	2.42

Table 68: (Continued)

CYCLE	YEAR	Branch yield	C	N	P	K	Mg	Ca	S	AGB yield	C	N	P	K	Mg	Ca	S	Root yield	C	N	P	K	Mg	Ca	S
													kg/ha												
1	1	490	258	1.1	0.09	2.4	0.14	1.7	0.18	2124	1114	8.9	0.66	16.8	0.94	8.5	1.23	296	135	0.7	0.06	1.8	0.08	0.8	0.16
1	2	2477	1306	5.7	0.45	12.2	0.71	6.4	0.90	8156	4280	32.0	2.38	60.9	3.41	31.9	4.47	1458	667	3.5	0.29	8.9	0.37	3.8	0.81
1	3	3720	1961	8.5	0.68	18.4	1.06	12.7	1.36	11621	6205	45.9	3.42	87.6	4.91	46.2	6.42	2183	998	5.2	0.44	13.3	0.56	5.7	1.21
1	4	4963	2617	11.4	0.90	24.5	1.42	16.9	1.81	15486	8129	59.8	4.45	114.2	6.40	60.4	8.37	2908	1330	7.0	0.58	17.7	0.74	7.6	1.62
1	5	6206	3272	14.2	1.13	30.6	1.77	21.1	2.26	19151	10053	73.8	5.49	140.8	7.90	74.6	10.33	3633	1661	8.7	0.73	22.1	0.93	9.6	2.02
1	6	7449	3927	17.0	1.35	36.7	2.13	25.4	2.72	22816	11977	87.7	6.53	167.5	9.40	88.8	12.28	4358	1993	10.4	0.88	26.6	1.11	11.5	2.42
1	7	8692	4583	19.9	1.58	42.9	2.48	29.6	3.17	26481	13902	101.8	7.57	194.1	10.89	103.0	14.24	5083	2324	12.2	1.02	31.0	1.30	13.4	2.83
1	8	9935	5238	22.7	1.80	49.0	2.84	33.8	3.62	30146	15826	115.5	8.60	220.7	12.39	117.2	16.19	5808	2656	13.9	1.17	35.4	1.48	15.3	3.23
1	9	11178	5893	25.6	2.03	55.1	3.19	38.1	4.08	33811	17750	129.4	9.64	247.4	13.88	131.4	18.14	6533	2987	15.7	1.31	39.8	1.67	17.2	3.63
1	10	12421	6549	28.4	2.26	61.3	3.55	42.3	4.53	37476	19674	143.3	10.68	274.0	15.38	145.6	20.10	7258	3319	17.4	1.46	44.2	1.85	19.1	4.04
2	1	423	223	1.0	0.08	2.1	0.12	1.4	0.15	1844	967	7.8	0.57	14.6	0.82	7.4	1.07	255	117	0.6	0.05	1.6	0.07	0.7	0.14
2	2	1454	767	3.3	0.26	7.2	0.42	5.0	0.53	5169	2712	20.7	1.54	39.3	2.20	20.4	2.88	861	394	2.1	0.17	5.2	0.22	2.3	0.48
2	3	2994	1579	6.9	0.54	14.8	0.86	10.2	1.09	9203	4831	35.5	2.64	67.7	3.80	35.8	4.97	1749	800	4.2	0.35	10.7	0.45	4.6	0.97
2	4	4534	2391	10.4	0.82	22.4	1.29	15.4	1.65	13237	6950	50.2	3.74	96.1	5.40	51.3	7.05	2637	1206	6.3	0.53	16.1	0.67	6.9	1.47
2	5	6074	3203	13.9	1.10	30.0	1.73	20.7	2.22	17271	9069	64.9	4.85	124.5	7.00	66.8	9.14	3525	1612	8.4	0.71	21.5	0.90	9.3	1.96
2	6	7614	4015	17.4	1.38	37.6	2.17	25.9	2.78	21305	11188	79.7	5.95	153.0	8.59	82.2	11.22	4413	2018	10.6	0.89	26.9	1.13	11.6	2.46
2	7	9154	4826	20.9	1.66	45.2	2.61	31.2	3.34	25339	13306	94.4	7.05	181.4	10.19	97.7	13.31	5301	2424	12.7	1.07	32.3	1.35	13.9	2.95
2	8	10694	5638	24.5	1.94	52.8	3.05	36.4	3.90	29373	15425	109.1	8.15	209.8	11.79	113.1	15.40	6189	2830	14.8	1.24	37.7	1.58	16.3	3.44
2	9	12234	6450	28.0	2.22	60.4	3.49	41.7	4.46	33407	17544	123.9	9.26	238.2	13.39	128.6	17.48	7077	3236	17.0	1.42	43.1	1.81	18.6	3.94
2	10	13774	7262	31.5	2.50	68.0	3.93	46.9	5.02	37441	19663	138.6	10.36	266.7	14.99	144.0	19.57	7965	3642	19.1	1.60	48.6	2.03	20.9	4.43
3	1	335	177	0.8	0.06	1.7	0.10	1.1	0.12	1483	778	6.3	0.46	11.8	0.66	6.0	0.86	203	93	0.5	0.04	1.2	0.05	0.5	0.11
3	2	753	402	1.7	0.14	3.8	0.22	2.6	0.28	3009	1578	12.4	0.92	23.3	1.30	12.0	1.71	457	209	1.1	0.09	2.8	0.12	1.2	0.25
3	3	1888	995	4.3	0.34	9.3	0.54	6.4	0.69	6021	3160	23.5	1.74	44.7	2.51	23.5	3.28	1107	506	2.7	0.22	6.7	0.28	2.9	0.62
3	4	3013	1589	6.9	0.55	14.9	0.86	10.3	1.10	9033	4742	34.5	2.57	66.0	3.71	35.1	4.84	1757	803	4.2	0.35	10.7	0.45	4.6	0.98
3	5	4138	2182	9.5	0.75	20.4	1.18	14.1	1.51	12045	6324	45.6	3.40	87.4	4.91	46.7	6.41	2407	1101	5.8	0.48	14.7	0.61	6.3	1.34
3	6	5263	2775	12.0	0.96	26.0	1.50	17.9	1.92	15057	7906	56.7	4.23	108.7	6.11	58.2	7.98	3057	1398	7.3	0.61	18.6	0.78	8.0	1.70
3	7	6388	3368	14.6	1.16	31.5	1.82	21.8	2.33	18069	9488	67.8	5.06	130.1	7.31	69.8	9.54	3707	1695	8.9	0.74	22.6	0.95	8.7	2.06
3	8	7513	3961	17.2	1.36	37.1	2.15	25.6	2.74	21081	11070	78.9	5.89	151.4	8.51	81.4	11.11	4357	1992	10.4	0.88	26.6	1.11	11.5	2.42
3	9	8638	4554	19.8	1.57	42.6	2.47	29.4	3.15	24093	12652	89.9	6.72	172.7	9.71	92.9	12.67	5007	2289	12.0	1.01	30.5	1.28	13.2	2.79
3	10	9763	5148	22.3	1.77	48.2	2.79	33.3	3.56	27105	14234	101.0	7.54	194.1	10.91	104.5	14.24	5657	2587	13.6	1.14	34.5	1.44	14.9	3.15
4	1	233	123	0.5	0.04	1.1	0.07	0.6	0.08	1053	552	4.5	0.33	8.4	0.47	4.2	0.62	141	64	0.3	0.03	0.9	0.04	0.4	0.08
4	2	492	259	1.1	0.09	2.4	0.14	1.7	0.18	1996	1048	8.3	0.61	15.6	0.87	8.0	1.14	296	135	0.7	0.06	1.8	0.08	0.8	0.16
4	3	910	480	2.1	0.17	4.5	0.26	3.1	0.33	3164	1660	12.6	0.94	24.0	1.34	12.5	1.76	539	248	1.3	0.11	3.3	0.14	1.4	0.30
4	4	1328	700	3.0	0.24	6.6	0.38	4.5	0.48	4330	2273	17.0	1.26	32.3	1.81	17.0	2.37	782	358	1.9	0.16	4.8	0.20	2.1	0.44
4	5	1746	921	4.0	0.32	8.6	0.50	5.9	0.64	5497	2885	21.3	1.59	40.7	2.28	21.5	2.98	1025	469	2.5	0.21	6.2	0.26	2.7	0.57
4	6	2164	1141	5.0	0.39	10.7	0.62	7.4	0.79	6663	3498	25.7	1.91	49.0	2.75	25.9	3.60	1268	580	3.0	0.25	7.7	0.32	3.3	0.71
4	7	2582	1361	5.9	0.47	12.7	0.74	8.8	0.94	7829	4110	30.0	2.24	57.4	3.22	30.4	4.21	1511	691	3.6	0.30	9.2	0.39	4.0	0.84
4	8	3000	1582	6.9	0.54	14.8	0.86	10.2	1.09	8996	4723	34.4	2.56	65.7	3.69	34.9	4.82	1754	802	4.2	0.35	10.7	0.45	4.6	0.98
4	9	3418	1802	7.8	0.62	16.9	0.98	11.6	1.25	10162	5335	38.7	2.89	74.1	4.16	39.4	5.43	1997	913	4.8	0.40	12.2	0.51	5.3	1.11
4	10	3836	2023	8.78	0.697	18.9	1.10	13.1	1.40	11328	5948	43.1	3.21	82.4	4.63	43.9	6.05	2240	1024	5.37	0.45	13.7	0.57	5.9	1.25

Table 68: (Continued)

		Total biomass								Mulching material *							
CYCLE	YEAR	yield	C	N	P	K	Mg	Ca	S	yield	C	N	P stem	K	Mg	Ca	S
										kg/ha							
1	1	2420	1249	9.7	0.720	18.61	1.01	9.29	1.40	746	367	5.8	0.416	10.35	0.54	3.59	0.79
1	2	9614	4947	35.5	2.673	69.81	3.79	35.78	5.28	3366	1653	21.2	1.538	38.99	2.00	14.50	3.00
1	3	14004	7203	51.2	3.856	100.87	5.47	51.89	7.64	4990	2450	30.5	2.219	56.39	2.89	21.19	4.35
1	4	18394	9459	66.8	5.038	131.92	7.15	68.01	9.99	6613	3247	39.9	2.899	73.80	3.78	27.88	5.70
1	5	22784	11714	82.5	6.221	162.98	8.83	84.12	12.36	8237	4044	49.2	3.579	91.20	4.67	34.56	7.04
1	6	27174	13970	98.1	7.404	194.03	10.51	100.23	14.71	9860	4842	58.5	4.260	108.61	5.56	41.25	8.39
1	7	31564	16226	113.8	8.587	225.08	12.19	116.35	17.06	11484	5639	67.8	4.940	126.01	6.45	47.94	9.74
1	8	35954	18482	129.4	9.769	256.14	13.87	132.46	19.42	13107	6436	77.1	5.621	143.42	7.34	54.63	11.09
1	9	40344	20737	145.1	10.952	287.19	15.55	148.57	21.78	14731	7233	86.5	6.301	160.82	8.23	61.32	12.44
1	10	44734	22993	160.7	12.135	318.25	17.23	164.68	24.14	16354	8030	95.8	6.981	178.23	9.12	68.01	13.78
2	1	2099	1084	8.4	0.628	16.18	0.88	8.06	1.21	646	317	5.1	0.362	9.01	0.47	3.11	0.68
2	2	6030	3106	22.8	1.710	44.52	2.42	22.64	3.36	2034	999	13.6	0.984	24.81	1.28	9.08	1.90
2	3	10952	5631	39.7	2.991	78.36	4.24	40.44	5.94	3968	1949	23.7	1.723	43.90	2.25	16.64	3.39
2	4	15874	8156	56.5	4.272	112.20	6.07	58.23	8.52	5902	2898	33.7	2.461	63.00	3.22	24.26	4.88
2	5	20796	10681	73.4	5.554	146.03	7.90	76.02	11.10	7836	3847	43.7	3.200	82.09	4.19	31.87	6.37
2	6	25718	13205	90.2	6.835	179.87	9.72	93.81	13.68	9770	4797	53.7	3.939	101.19	5.17	39.49	7.86
2	7	30640	15730	107.1	8.116	213.71	11.55	111.61	16.26	11704	5746	63.8	4.677	120.28	6.14	47.10	9.35
2	8	35562	18255	124.0	9.397	247.55	13.37	129.40	18.84	13638	6696	73.8	5.416	139.38	7.11	54.71	10.84
2	9	40484	20780	140.8	10.678	281.39	15.20	147.19	21.42	15572	7645	83.8	6.154	158.48	8.08	62.33	12.33
2	10	45406	23305	157.7	11.960	315.22	17.02	164.98	24.00	17506	8595	93.9	6.893	177.57	9.06	69.94	13.82
3	1	1686	870	6.8	0.506	13.03	0.71	6.49	0.98	516	253	4.1	0.292	7.26	0.38	2.50	0.55
3	2	3466	1787	13.5	1.007	26.12	1.42	13.16	1.96	1114	547	8.1	0.580	14.52	0.75	5.15	1.11
3	3	7128	3667	26.1	1.966	51.43	2.79	26.44	3.89	2536	1245	15.6	1.132	28.77	1.48	10.79	2.22
3	4	10790	5546	38.7	2.926	76.74	4.15	39.71	5.62	3959	1944	23.1	1.685	43.03	2.20	16.44	3.33
3	5	14452	7425	51.4	3.885	102.04	5.52	52.99	7.75	5381	2642	30.6	2.238	57.29	2.93	22.08	4.44
3	6	18114	9304	64.0	4.844	127.35	6.89	66.26	9.68	6804	3340	38.1	2.790	71.55	3.66	27.73	5.55
3	7	21776	11183	76.7	5.803	152.66	8.25	79.54	11.60	8226	4039	45.7	3.343	85.80	4.38	33.38	6.66
3	8	25438	13062	89.3	6.763	177.98	9.62	92.81	13.53	9649	4737	53.2	3.895	100.06	5.11	39.02	7.77
3	9	29100	14941	101.9	7.722	203.27	10.99	106.09	15.46	11071	5435	60.7	4.448	114.32	5.84	44.67	8.88
3	10	32762	16820	114.6	8.681	228.58	12.35	119.36	17.39	12494	6134	68.2	5.001	128.58	6.56	50.31	10.00
4	1	1194	617	4.8	0.359	9.27	0.51	4.60	0.69	362	178	2.9	0.208	5.16	0.27	1.77	0.39
4	2	2294	1183	9.0	0.671	17.40	0.95	8.74	1.31	728	358	5.4	0.387	9.67	0.50	3.40	0.74
4	3	3703	1907	13.9	1.045	27.24	1.48	13.87	2.06	1264	621	8.3	0.602	15.20	0.78	5.57	1.17
4	4	5112	2630	18.9	1.419	37.07	2.01	19.01	2.80	1800	884	11.3	0.817	20.73	1.06	7.73	1.60
4	5	6522	3354	23.8	1.793	46.91	2.54	24.15	3.55	2337	1147	14.2	1.033	26.26	1.35	9.89	2.03
4	6	7931	4078	28.7	2.168	56.75	3.07	29.28	4.30	2873	1411	17.1	1.248	31.80	1.63	12.05	2.46
4	7	9340	4801	33.6	2.540	66.59	3.61	34.42	5.05	3409	1674	20.1	1.463	37.33	1.91	14.21	2.89
4	8	10750	5525	38.6	2.914	76.43	4.14	39.55	5.80	3946	1937	23.0	1.678	42.86	2.19	16.38	3.32
4	9	12159	6248	43.5	3.287	86.27	4.67	44.69	6.55	4482	2201	25.9	1.893	48.39	2.48	18.54	3.75
4	10	13568	6972	48.4	3.661	96.10	5.20	49.83	7.29	5018	2464	28.9	2.108	53.92	2.76	20.70	4.18

* Mulching material: leaves, 1/2 branches and roots

Appendix 11

Nutrient stocks of *Rubus moluccanus*

Table 69: Nutrient stocks (kg/ha) for *Rubus moluccanus* for 5 transects

Transect	Yield	C	N	P	K	Mg	Ca	S
					kg/ha			
Leaves								
R 1	1788	823	22.5	2.23	11.1	13.1	20.0	3.13
R 2	2496	1149	31.5	3.11	15.6	18.3	27.9	4.37
R 3	2134	983	26.9	2.66	13.3	15.7	23.8	3.73
R 4	3417	1573	43.1	4.26	21.3	25.1	38.1	5.98
R 5	2864	1319	36.1	3.57	17.8	21.1	32.0	5.01
Average	**2540**	**1169**	**32.0**	**3.17**	**15.8**	**18.7**	**28.4**	**4.44**
SE	283	130	3.6	0.35	1.8	2.1	3.2	0.50
Wood								
R 1	9437	4609	27.4	7.50	33.2	11.5	27.6	4.93
R 2	18023	8802	52.2	14.32	63.4	22.0	52.6	9.42
R 3	13429	6558	38.9	10.67	47.3	16.4	39.2	7.02
R 4	13591	6637	39.4	10.80	47.8	16.6	39.7	7.11
R 5	12442	6076	36.1	9.89	43.8	15.2	36.3	6.51
Average	**13384**	**6537**	**38.8**	**10.64**	**47.1**	**16.3**	**39.1**	**7.00**
SE	1379	673	4.0	1.10	4.9	1.7	4.0	0.72
AGB								
R 1	11225	5432	49.9	9.7	44.4	24.6	47.5	8.1
R 2	20519	9951	83.7	17.4	79.0	40.3	80.5	13.8
R 3	15563	7541	65.8	13.3	60.6	32.0	63.0	10.8
R 4	17008	8211	82.5	15.1	69.1	41.7	77.8	13.1
R 5	15306	7395	72.2	13.5	61.6	36.2	68.3	11.5
Average	**15924**	**7706**	**70.8**	**13.81**	**62.9**	**35.0**	**67.4**	**11.44**
SE	1498	728	6.2	1.26	5.7	3.1	5.9	1.00
Prim and Sec Roots								
R1	4518	2018	23.7	3.86	16.8	8.6	25.1	3.00
R2	9444	4219	49.5	8.07	36.1	18.0	52.5	6.27
R3	2438	1089	12.8	2.08	9.1	4.6	13.6	1.62
R4	6768	3023	35.4	5.78	25.2	12.9	37.6	4.49
R5	3607	1611	18.9	3.08	13.4	6.9	20.1	2.39
Average	**5355**	**2392**	**28.0**	**4.58**	**19.9**	**10.2**	**29.8**	**3.56**
SE	1245	556	6.5	1.06	4.6	2.4	6.9	0.83
Root bulb								
R 1	2405	1107	11.6	2.19	9.6	3.2	19.4	1.51
R 2	4311	1986	20.9	3.92	17.2	5.7	34.9	2.72
R 3	1813	835	8.8	1.65	7.2	2.4	14.7	1.14
R 4	3893	1793	18.8	3.54	15.5	5.2	31.5	2.45
R 5	2121	977	10.3	1.93	8.4	2.8	17.1	1.34
Average	**2909**	**1340**	**14.1**	**2.85**	**11.6**	**3.9**	**23.5**	**1.83**
SE	501	231	2.4	0.46	2.0	0.7	4.0	0.32
Total root								
R 1	6923	3126	35.3	6.05	26.4	11.8	44.6	4.51
R 2	13756	6204	70.3	11.99	52.3	23.7	87.4	8.99
R 3	4251	1924	21.5	3.73	16.3	7.1	28.2	2.76
R 4	10661	4816	54.3	9.33	40.7	18.1	69.1	6.95
R 5	5728	2588	29.1	5.01	21.9	9.7	37.2	3.73
Average	**8264**	**3732**	**42.1**	**7.22**	**31.5**	**14.1**	**53.3**	**5.39**
SE	1735	782	8.9	1.51	6.6	3.0	10.9	1.14
Total biomass								
R 1	18148	8558	85.2	15.8	70.7	36.4	92.1	12.6
R 2	34274	16156	154.0	29.4	131.3	64.0	167.9	22.8
R 3	19814	9465	87.4	17.1	76.8	39.1	91.3	13.5
R 4	27669	13027	136.7	24.4	109.8	59.7	147.0	20.0
R 5	21034	9983	101.3	18.5	83.5	45.9	105.5	15.2
Average	**24188**	**11438**	**112.9**	**21.03**	**94.4**	**49.0**	**120.7**	**16.83**
SE	1379	673	4.0	1.10	4.9	1.7	4.0	0.72

Appendix 12

Nutrient stocks of *Imperata cylindrica*

Table 70: Nutrient stocks (kg/ha) for *Imperata cylindrica* for 5 transects

Transect	**Yield**	C	N	P	K	Mg	Ca	S
					kg/ha			
Leaves								
R 1	4655	2229	27	2.73	17	6.77	3.45	3.35
R 2	5408	2581	26	2.51	20	5.85	3.13	4.60
R 3	6027	2781	27	2.81	30	8.09	2.84	4.85
R 4	4770	2461	22	2.24	23	6.75	5.08	4.13
R 5	6849	3039	30	3.27	38	7.14	5.22	4.80
Average	**5542**	**2618**	**26**	**2.7**	**25.9**	**6.9**	**3.9**	**4.3**
SE	409	138	1.28	0.17	3.77	0.36	0.50	0.28
Roots								
R 1	2368	1100	10.5	2.59	16	1.69	0.43	2.56
R 2	3074	1277	9.0	1.33	12	1.34	0.77	3.30
R 3	3784	1730	8.2	2.74	31	2.41	0.47	4.43
R 4	2553	1130	7.4	1.52	20	1.98	0.89	3.46
R 5	3337	1502	9.0	3.49	39	3.17	1.40	5.09
Average	**3023**	**1348**	**8.8**	**2.3**	**23.6**	**2.1**	**0.8**	**3.8**
SE	258	119	0.51	0.40	4.87	0.32	0.18	0.45
Total biomass								
R 1	7023	3329	37	5.32	34	8.46	3.87	5.91
R 2	8482	3858	35	3.84	33	7.19	3.90	7.90
R 3	9811	4511	35	5.55	61	10.50	3.31	9.28
R 4	7324	3591	29	3.76	43	8.73	5.97	7.59
R 5	10186	4541	39	6.76	77	10.31	6.62	9.89
Average	**8565**	**3966**	**35.2**	**5.0**	**49.6**	**9.0**	**4.7**	**8.1**
SE	637	243	1.60	0.56	8.56	0.62	0.65	0.70

Appendix 13

Rice yield

Table 71: Rice grain and straw yield (kg/ha) and yield parameters

	Rice grain kg/ha dw		SE	Rice straw kg/ha dw		SE	Harvest Index	Survival %		SE	Fertile tillers %		SE	Grain/panicle number		SE	1000 grain weight (g)		SE
Tavy	1140	a *	114	1962	a	228	0.37	48		4.16	69	a	3.74	99	a	5.69	23.2	a	1.71
M0	355	b	114	583	b	229	0.38	40	NS	4.18	45	b	3.76	73	b	5.69	16.3	b	1.72
M40	642	b	114	1053	b	229	0.38	45		4.18	53	b	3.76	84	ab	5.69	18.0	b	1.71
M80	707	ab	165	1123	ab	332	0.39	40		6.17	43	b	6.16	79	ab	9.86	17.2	b	2.73
p trt	<.0001			<.0001				0.2643			0.0002			0.0038			0.0229		
Trema	1073	a	179	1572		369	0.40	42	ab	6.31	29	c	4.68	79	bc	8.51	9.0	b	2.27
Psiadia	795	ab	161	1678		329	0.32	59	a	5.66	59	b	3.89	98	ab	6.88	25.6	a	1.94
Rubus	856	ab	149	1291		309	0.40	43	ab	5.18	76	a	3.39	113	a	6.81	25.8	a	1.72
Imperata	121	b	235	179	NS	468	0.40	29	b	8.19	45	b	5.36	45	c	10.59	14.3	b	2.73
p fallow	0.0498			0.1285				0.0493			<.0001			0.0012			0.0002		
Cycle 1	816	b	123	1886	ab	284	0.30	60	ab	4.24	60	ab	4.07	120		9.52	34.5	a	2.29
Cycle 2	1326	a	138	2998	a	327	0.31	63	ab	4.85	74	a	4.70	111		10.14	22.5	b	2.77
Cycle 3	687	bc	123	1025	b	284	0.40	70	a	4.24	65	ab	4.07	85		8.91	23.7	b	2.15
Cycle 3	353	c	123	902	b	284	0.28	50	b	4.24	52	b	4.07	85		8.91	22.4	b	2.15
p cycle	<.0001			-0.0003				0.0131			0.0132			0.0151			0.0009		

* Means that are followed by the same letter are not signficantly different at p<0.05

Appendix 14

Bean yield

Table 72: Bean grain and straw yield (kg/ha) and yield parameters

	Bean grain			Bean straw			Bean pods			Bean			Harvest	Survival			Pods/plant			Grain/pods			100 grain		
	kg/ha dw		SE	kg/ha dw		SE	kg/ha dw		SE	straw+pods		SE	Index	%		SE	number		SE	number		SE	weight (g)		SE
Tavy	174	c *	23.3	88	b	10.4	85	c	14.1	180	c	19.1	0.50	87		3.0	1.21	c	0.10	2.41	bc	0.097	38.73	b	0.810
M0	167	c	23.4	81	b	10.5	87	c	14.1	171	c	19.3	0.50	89	NS	3.1	1.11	c	0.10	2.36	c	0.097	39.19	b	0.872
M40	384	b	23.4	138	a	10.5	200	b	14.1	327	b	19.8	0.53	86		3.1	2.03	b	0.10	2.84	a	0.097	41.55	a	0.836
M80	563	a	35.6	174	a	15.5	319	a	21.1	493	a	30.3	0.53	91		5.1	2.72	a	0.15	2.80	ab	0.120	42.59	a	1.128
p trt	<.0001			<.0001			<.0001			<.0001				0.6733			<.0001			0.001			0.001		
Trema	408	a	32.0	166	a	17.9	255	a	18.6	421	a	28.2	0.49	96	a	4.5	2.23	a	0.13	2.49	b	0.116	45.40	a	1.466
Psiadia	165	c	26.7	124	ab	15.0	94	b	16.8	217	b	21.9	0.43	74	b	2.9	0.94	c	0.10	-		-	38.80	b	1.352
Rubus	439	a	23.9	117	ab	14.7	233	a	13.8	350	a	22.5	0.56	89	a	3.4	2.27	a	0.10	2.92	a	0.089	39.35	b	1.235
Imperata	276	b	23.9	73	b	14.7	110	b	13.8	182	b	22.5	0.60	92	a	3.4	1.63	b	0.10	2.39	b	0.089	36.52	b	1.235
p fallow	<.0001			0.0099			<.0001			<.0001				0.0008			<.0001			0.004			0.011		
Cycle 1	99	NS	33.3	74	b	23.1	54	NS	15.8	128	b	37.8	0.44	81	NS	8.4	0.74	NS	0.19	no data			38.747	NS	1.3552
Cycle 2	85		35.1	186	a	25.1	45		16.5	237	a	40.3	0.26	69		9.5	0.61		0.20				40.335		1.969
Cycle 3	77		33.3	84	b	23.1	43		15.8	127	b	37.8	0.38	78		8.4	0.56		0.19				-		
Cycle 3	68		33.3	80	b	23.1	34		15.8	114	b	37.8	0.37	64		8.4	0.51		0.186				35.854		1.7522
p cycle	0.7089			0.0009			0.3938			0.0098				0.4011			0.4345			no data			0.3227		

* Means that are followed by the same letter are not signficantly different at p<0.05

Appendix 15

Ginger yield

Table 73: Ginger root and straw yield (kg/ha) and yield parameters

	Ginger root			Ginger straw			Harvest	Survival			Leafs/plant			Root weight ·		
	kg/ha fw		SE	kg/ha dw		SE	Index	%		SE	numbers		SE	g/root dw		SE
Tavy	4264	d *	343.62	234	d	54.706	0.68	0.73	ab	0.015	2.8	c	0.161	27.0	c	2.141
M0	5353	c	345.83	413	c	54.774	0.62	0.77	a	0.015	3.4	b	0.161	33.4	c	2.155
M40	6635	b	345.83	628	b	54.774	0.57	0.72	ab	0.015	3.9	a	0.161	41.4	b	2.155
M80	8326	a	502.49	813	a	76.401	0.59	0.69	b	0.023	4.6	a	0.222	52.1	a	3.133
p trt	<.0001			<.0001				0.0293			<.0001			<.0001		
Trema	2988	b	569.32	192	c	83.150	0.69	0.57	c	0.021	2.4	b	0.253	18.7	b	3.549
Psiadia	6653	a	488.28	432	bc	79.459	0.66	0.75	b	0.017	3.6	a	0.242	41.9	a	3.043
Rubus	7881	a	464.04	704	ab	67.113	0.59	0.76	b	0.016	4.4	a	0.207	49.3	a	2.893
Imperata	7057	a	464.04	762	a	67.113	0.54	0.83	a	0.015	4.3	a	0.207	44.1	a	2.893
p fallow	<.0001			0.0004				<.0001			0.0001			<.0001		
Cycle 1	6190	NS	400.4	308	NS	34.598	0.95	74.86	NS	1.657	3.0	b	0.1049	38.7	NS	2.4785
Cycle 2	6701		462.34	410		39.95	0.94	78.9		1.91	3.7	a	0.1211	41.9		2.8619
Cycle 3	5113		400.4	263		34.598	0.95	73.19		1.657	3.2	b	1049	32.0		2.4785
Cycle 3	5720		400.4	357		34.598	0.94	77.42		1.657	3.2	b	0.1049	36.9		2.4785
p cycle	0.0867			0.0595				0.122			0.0049			0.0887		

* Means that are followed by the same letter are not signficantly different at $p<0.05$

Appendix 16

Exchangeable soil nutrients

Table 74: Exchangeable soil nutrients in mg/kg and pH (water), for Time 1, 2 and 3 (0, 7 and 18 months after experiment establishment) analyzed by a) treatment, b) fallow and c) cycles

a) Treatment analysis

		P		SE	K		SE	MG		SE	CA		SE	AL		SE
T1	Tavy	0.339	NS	0.0759	54.3	NS	6.39	69.1	NS	5.43	535	NS	76.7	156	NS	8.5
	MO	0.276		0.0759	59.5		6.39	60.2		5.43	431		76.7	161		8.5
	M40	0.221		0.1113	53.6		8.07	61.4		7.76	435		108.2	159		10.8
	M80	0.234		0.07891	49.2		6.50	57.9		5.62	317		77.5	160		8.7
	p-value	0.613			0.332			0.257			0.167			0.902		
T2	Tavy	0.434		0.5155	71.5		5.36	90.4		5.62	609		72.6	141		9.5
	MO	1.162	NS	0.5155	71.4	NS	5.39	98.0	NS	5.66	554	NS	73.2	149	NS	9.8
	M40	1.080		0.5155	79.7		5.39	92.2		5.66	659		73.2	146		9.6
	M80	1.957		0.737	77.5		6.77	93.3		7.94	774		102.4	131		13.4
	p-value	0.368			0.168			0.593			0.191			0.626		
T3	Tavy	0.211		0.2485	20.9	b	1.57	55.3	b	4.77	493		81.2	136	a	7.0
	MO	0.094	NS	0.2485	24.6	ab	1.58	62.2	a	4.79	522	NS	81.3	131	ab	7.0
	M40	0.664		0.2485	25.5	a	1.58	62.6	a	4.79	602		81.3	121	ab	7.0
	M80	0.459		0.3627	26.3	a	1.99	68.7	a	5.91	662		107.6	103	b	10.1
	p-value	0.392			0.010			0.045			0.400			0.031		

		FE		SE	MN		SE	ZN		SE	CU		SE	pH		SE
T1	Tavy	7.14		0.6643	9.69		0.906	0.280		0.038	0.166		0.032	5.27		0.066
	MO	6.49	NS	0.6459	8.98	NS	0.900	0.242	NS	0.038	0.280	NS	0.031	5.40	NS	0.067
	M40	6.32		0.6459	10.55		0.900	0.217		0.038	0.209		0.031	5.31		0.067
	M80	6.40		1.2892	9.72		1.294	0.267		0.048	0.238		0.049	5.34		0.096
	p-value	0.867			0.622			0.258			0.058			0.404		
T2	Tavy	4.78		0.807	9.05		0.591	0.345		0.053	0.221		0.036	5.44		0.070
	MO	5.76	NS	0.6107	9.74	NS	0.596	0.358	NS	0.054	0.274	NS	0.037	5.42	NS	0.070
	M40	5.11		0.6107	8.95		0.596	0.335		0.054	0.214		0.037	5.52		0.070
	M80	4.47		1.0948	8.91		0.618	0.319		0.081	0.287		0.057	5.56		0.097
	p-value	0.587			0.502			0.976			0.441			0.297		
T3	Tavy	2.81	ab	0.3103	4.74	a	0.400	0.276	b	0.034	0.246		0.045	5.25		0.076
	MO	3.12	a	0.3124	3.63	ab	0.403	0.423	a	0.034	0.334	NS	0.045	5.30	NS	0.076
	M40	2.22	b	0.3124	2.97	b	0.403	0.325	ab	0.034	0.244		0.045	5.38		0.076
	M80	1.94	b	0.4239	3.54	ab	0.602	0.366	ab	0.048	0.329		0.070	5.52		0.112
	p-value	0.008			0.014			0.003			0.288			0.174		

* Means that are followed by the same letter are not signficantly different at $p<0.05$

Table 74: (Continued)

b) Fallow analysis

		P		SE	K		SE	MG		SE	CA		SE	AL		SE
T1	*Trema*	0.631	a	0.1323	64.2		12.13	133.1	b	9.68	1323	b	120.0	37	c	16.3
	Psiadia	0.226	ab	0.1136	59.8		11.47	57.4	a	8.48	294	a	110.9	163	b	15.4
	Rubus	0,047	b	0.1092	48.8		10.48	27.8	a	8.08	53	a	97.3	244	a	14.1
	Imperata	0.165	ab	0.1092	43.9	NS	10.48	30.2	a	8.08	47	a	97.3	192	ab	14.1
	p-value	0.027			0.571			<,0001			<,0001			<,0001		
T2	*Trema*	2,771		0.7049	85.8		10.34	186.4	a	10.11	1744	a	130.7	31	c	15.2
	Psiadia	0.639		0,7017	78.1		9.73	75.8	b	8.92	526	b	115.5	137	b	13.9
	Rubus	0.605		0.543	74.8		8.96	57.3	b	8.48	173	b	109.7	230	a	12.4
	Imperata	0.417	NS	0.543	61,4	NS	8.96	54.5	b	8.48	154	b	109.7	170	b	12.4
	p-value	0.086			0.363			<.0001			<,0001			<,0001		
T3	*Trema*	1.153		0.3167	29.0	ab	2.85	149.6	a	9.30	1700	a	134.2	15	d	10.6
	Psiadia	0.048		0,318	20.0	ab	2.73	41.3	b	6.62	345	b	130.6	110	c	9.4
	Rubus	0.227		0.2354	30.0	a	2.44	27,2	b	6.09	117	b	112.2	213	a	8.5
	Imperata	0,000	NS	0.2354	18.4	b	2.44	30.7	b	6.09	117	b	112.2	153	b	8.5
	p-value	0.0514			0.0103			<.0001			<,0001			<,0001		

		FE		SE	MN		SE	ZN		SE	CU		SE	pH		SE
T1	*Trema*	0.82	c	1.4223	25.99	a	1.310	0.167	b	0.072	0.668	a	0.048	6.11	a	0.110
	Psiadia	13.62	a	1.1689	7.94	b	1.223	0.520	a	0.066	0.120	b	0.036	5.27	b	0.098
	Rubus	4.85	bc	1.1496	2.88	c	1.031	0.175	b	0.062	0.058	b	0.037	5.01	b	0.090
	Imperata	7.06	b	1.1496	2.12	c	1.031	0.144	b	0.062	0.047	b	0.037	4.93	b	0.090
	p-value	<,0001			<.0001			0,004			<,0001			<.0001		
T2	*Trema*	0.54	c	1.4264	22.30	a	1.080	0,245	b	0.073	0,559	a	0.058	6.24	a	0.127
	Psiadia	9.42	a	1.305	7.46	b	0.968	0,587	a	0.061	0.202	b	0.045	5.43	b	0.113
	Rubus	4.13	bc	1.2027	3.70	bc	0.913	0,268	b	0.054	0.140	b	0.046	5.07	b	0.107
	Imperata	6.02	ab	1.2027	3.18	c	0.913	0.257	b	0.054	0.095	b	0.046	5,20	b	0.107
	p-value	0.003			<,0001			0,003			0,000			<,0001		
T3	*Trema*	0.08	b	0.5713	5.26	a	0.606	0.291	b	0.058	0.771	a	0.073	6.17	a	0.115
	Psiadia	3.68	a	0.5161	4.45	a	0.507	0,568	a	0.052	0.241	b	0.056	5.18	b	0.101
	Rubus	3.11	a	0.4847	3,06	ab	0.475	0.293	b	0.046	0.061	b	0.058	4.96	b	0.090
	Imperata	3,22	a	0.4847	2.11	b	0.475	0.258	b	0.046	0,080	b	0.058	5.14	b	0.090
	p-value	0.001			0.005			0.002			<,0001			<.0001		

* Means that are followed by the same letter are not signficantly different at $p<0.05$

Table 74: (Continued)

c) Cycle analysis

		P			K			MG			CA			AL		
				SE			SE			SE			SE			SE
T1	Cycle 1	0.512	a	0.1104	42.6	b	10.05	50.4	b	9.22	195	b	75.1	245	a	11.1
	Cycle 2	0.283	ab	0.1104	123.9	a	10.05	96.7	a	9.22	532	a	75.1	125	b	11.1
	Cycle 3	0.013	b	0.1104	32.8	b	10.05	45.1	b	9.22	243	b	75.1	132	b	11.1
	Cycle 4	0.101	b	0.1104	29.0	b	10.05	31.7	b	9.22	174	b	75.1	148	b	11.1
	p-value	0.002			<.0001			<.0001			0.003			<.0001		
T2	Cycle 1	0.661	a	0.09554	69.0	b	8.08	68.5	b	10.46	368	NS	77.5	215	a	13.2
	Cycle 2	0.437	ab	0.1103	133.6	a	8.79	112.6	a	11.50	654		87.0	141	b	14.4
	Cycle 3	0.209	b	0.09554	52.1	b	8.08	70.7	b	10.46	510		77.5	102	b	13.2
	Cycle 4	0.183	b	0.09554	56.1	b	8.08	54.8	b	10.46	433		77.5	107	b	13.2
	p-value	0.007			<.0001			0.001			0.055			<.0001		
T3	Cycle 1	0.000	NS	0.02988	15.9	b	1.27	28.1	b	5.08	213	b	45.5	152	a	9.7
	Cycle 2	0.000		0.0345	35.2	a	1.47	65.9	a	5.70	449	a	51.8	119	ab	10.9
	Cycle 3	0.000		0.02988	11.3	b	1.27	34.3	b	5.08	331	ab	45.5	82	c	9.7
	Cycle 4	0.057		0.02988	15.4	b	1.27	29.9	b	5.08	267	b	45.5	114	bc	9.7
	p-value	0.460			<.0001			<.0001			0.009			<.0001		

		FE			MN			ZN			CU			pH		
				SE			SE			SE			SE			SE
T1	Cycle 1	18.36	NS	2.3781	6.95	b	0.743	0.301	c	0.046	0.072	NS	0.054	5.13	b	0.072
	Cycle 2	14.88		2.3781	11.82	a	0.743	0.911	a	0.046	0.221		0.054	5.43	a	0.072
	Cycle 3	11.26		2.3781	5.94	b	0.743	0.518	b	0.046	0.105		0.054	5.29	ab	0.072
	Cycle 4	12.23		2.3781	7.07	b	0.743	0.350	bc	0.046	0.053		0.054	5.24	ab	0.072
	p-value	0.072			0.000			<.0001			0.095			0.049		
T2	Cycle 1	14.65	a	1.1793	7.22	b	1.023	0.427	b	0.060	0.205	NS	0.062	5.24	NS	0.081
	Cycle 2	11.66	a	1.3456	11.24	a	1.157	0.813	a	0.069	0.203		0.071	5.46		0.093
	Cycle 3	5.66	b	1.1793	5.88	b	1.023	0.635	ab	0.060	0.175		0.062	5.51		0.081
	Cycle 4	6.19	b	1.1793	5.84	b	1.023	0.522	b	0.060	0.166		0.062	5.45		0.081
	p-value	<.0001			0.003			0.003			0.948			0.115		
T3	Cycle 1	3.86	NS	0.461	4.03	ab	0.608	0.417	b	0.047	0.130	NS	0.079	4.97	b	0.073
	Cycle 2	4.37		0.5321	6.02	a	0.698	0.851	a	0.054	0.193		0.091	5.08	ab	0.084
	Cycle 3	2.98		0.461	3.14	b	0.608	0.515	b	0.047	0.267		0.079	5.23	a	0.073
	Cycle 4	4.06		0.461	4.66	ab	0.608	0.467	b	0.047	0.302		0.079	5.24	a	0.073
	p-value	0.230			0.027			<.0001			0.427			0.048		

* Means that are followed by the same letter are not signficantly different at $p<0.05$

Appendix 17

Time analysis of exchangeable soil nutrients

Table 75: Time analysis of exchangeable soil nutrients (mg/kg) in three times (Time 1: 0 months, Time 2: 7 months and Time 3: 19 months after experiment establishment): a) Treatment analysis, b) Fallow analysis and c) Cycle analysis

a) Treatment analysis

		INTERACTION TIME*TREATMENT												MAIN FACTOR TIME		
		Tavy mean		SE	M0 mean		SE	M40 mean		SE	M80 mean		SE	TIME mean		SE
P	Time 1	0.238		0.274	0.338		0.261	0.275		0.261	0.222		0.408	0.268	b	0.185
	Time 2	0.547		0.261	1.053		0.263	1.080		0.263	1.959		0.408	1.160	a	0.184
	Time 3	0.240		0.261	0.154		0.263	0.578		0.263	0.460		0.408	0.358	b	0.184
p-value		0.282												<.0001		
K	Time 1	47.9		5.32	54.6		5.20	60.1		5.20	53.4		6.70	54.0	b	4.57
	Time 2	71.3		5.20	71.8		5.22	80.1		5.22	77.7		6.70	75.2	a	4.57
	Time 3	20.1		5.20	28.1		5.22	26.9		5.22	27.0		6.70	25.0	c	4.57
p-value		0.819												<.0001		
Mg	Time 1	57.0		5.46	69.3		5.36	60.3		5.36	61.2		7.08	62.0	b	4.62
	Time 2	90.2		5.36	96.9		5.38	92.2		5.38	93.6		7.08	93.7	a	4.62
	Time 3	55.0		5.38	63.2		5.38	62.8		5.38	69.0		7.08	62.5	b	4.67
p-value		0.374												<.0001		
CA	Time 1	328	c	72.02	518		70.12	431	b	70.12	433	b	100.62	428	c	55.90
	Time 2	608	a	70.08	559		70.53	660	a	70.53	775	a	100.59	651	a	55.86
	Time 3	497	b	70.08	527		70.53	596	a	70.53	663	a	100.59	571	b	55.85
p-value		0.045												<.0001		
AL	Time 1	159	a	8.69	156	a	8.56	161	a	8.58	159	a	12.41	159	a	6.74
	Time 2	135	b	8.56	152	a	8.59	149	b	8.59	130	b	12.41	141	b	6.74
	Time 3	135	b	8.56	131	b	8.59	121	c	8.59	102	c	12.41	122	c	6.74
p-value		0.000												<.0001		
FE	Time 1	7.20		0.726	6.48		0.703	6.31		0.703	6.41		1.020	6.60	a	0.553
	Time 2	4.70		0.702	5.76		0.708	5.07		0.708	4.43		1.019	4.99	b	0.553
	Time 3	2.84		0.702	3.04		0.708	2.18		0.709	1.91		1.019	2.49	c	0.553
p-value		0.577												<.0001		
MN	Time 1	9.64	a	0.657	9.35	a	0.632	10.22	a	0.632	9.72	a	0.915	9.73	a	0.499
	Time 2	9.05	a	0.631	9.75	a	0.637	8.95	b	0.637	8.91	a	0.915	9.16	a	0.498
	Time 3	4.95	b	0.631	3.61	b	0.637	2.92	c	0.637	3.58	b	0.915	3.76	b	0.498
p-value		0.101												<.0001		
ZN	Time 1	0.278	ns	0.043	0.242	b	0.041	0.216	b	0.041	0.265	b	0.061	0.250	b	0.031
	Time 2	0.321		0.041	0.380	a	0.041	0.341	a	0.041	0.321	ab	0.061	0.341	a	0.031
	Time 3	0.267		0.041	0.432	a	0.041	0.327	a	0.041	0.388	a	0.061	0.353	a	0.031
p-value		0.058												0.0001		
CU	Time 1	0.169		0.039	0.280		0.037	0.209		0.037	0.238		0.059	0.224	b	0.025
	Time 2	0.220		0.037	0.278		0.037	0.215		0.037	0.288		0.059	0.250	ab	0.025
	Time 3	0.245		0.037	0.339		0.037	0.245		0.037	0.331		0.059	0.290	a	0.025
p-value		0.973												0.055		
pH	Time 1	5.28	b	0.07	5.40	ab	0.07	5.31	b	0.07	5.34	b	0.10	5.33	b	0.05
	Time 2	5.44	a	0.07	5.42	a	0.07	5.53	a	0.07	5.58	a	0.10	5.49	a	0.05
	Time 3	5.24	b	0.07	5.30	b	0.07	5.39	b	0.07	5.52	a	0.10	5.36	b	0.05
p-value		0.053												<.0001		

* Means that are followed by the same letter are not significantly different at $p<0.05$

Table 75: (Continued)

b) Fallow analysis

		INTERACTION OF TIME*FALLOW												MAIN FACTOR TIME		
		Trema mean		SE	*Psiadia* mean		SE	*Rubus* mean		SE	*Imperata* mean		SE	TIME mean		SE
P	Time 1	0.631	b	0.426	0.230	ab	0.336	0.047	a	0.338	0.165		0.338	0.268	b	0.185
	Time 2	2.771	a	0.426	0.645	a	0.332	0.805	b	0.338	0.417		0.338	1.160	a	0.184
	Time 3	1.153	b	0.426	0.052	b	0.332	0.227	ab	0.338	0.000		0.338	0.358	b	0.184
p-value		0.044												<.0001		
K	Time 1	64.2	b	10.08	59.1	b	8.79	48.8	b	8.70	43.9	b	8.70	54.0	b	4.57
	Time 2	85.8	a	10.08	78.9	a	8.77	74.8	a	8.70	61.4	a	8.70	75.2	a	4.57
	Time 3	29.0	c	10.08	22.8	c	8.77	30.0	c	8.70	18.4	c	8.70	25.0	c	4.57
p-value		0.075												<.0001		
Mg	Time 1	133.1	c	10.36	56.7	b	8.37	27.8	b	8.91	30.2	b	8.91	62.0	b	4.62
	Time 2	186.4	a	10.36	76.7	a	8.35	57.3	a	8.91	54.5	a	8.91	93.7	a	4.62
	Time 3	149.6	b	10.36	42.6	c	8.35	27.2	b	8.91	30.7	b	8.91	62.5	b	4.62
p-value		<.0001												<.0001		
CA	Time 1	1323	b	125.0	286	b	107.1	53	b	104.3	47	b	104.3	428	c	55.9
	Time 2	1744	a	125.0	532	a	106.6	173	a	104.3	154	a	104.3	651	a	55.8
	Time 3	1700	a	125.0	349	b	106.6	117	ab	104.3	117	ab	104.3	571	b	55.8
p-value		0.007												<.0001		
AL	Time 1	37	a	15.2	163	a	12.8	244	a	12.6	192	a	12.6	159	a	6.7
	Time 2	31	a	15.2	135	b	12.7	230	b	12.6	170	b	12.6	141	b	6.7
	Time 3	15	b	15.2	108	c	12.7	213	c	12.6	153	c	12.6	122	c	6.7
p-value		0.004												<.0001		
FE	Time 1	0.820	ns	1.265	13.672	a	0.977	4.853	a	1.053	7.059	a	1.053	6.601	a	0.553
	Time 2	0.539		1.265	9.275	b	0.971	4.132	ab	1.053	6.019	a	1.053	4.991	b	0.553
	Time 3	0.080		1.265	3.561	c	0.971	3.109	b	1.053	3.217	b	1.053	2.492	c	0.553
p-value		<.0001												<.0001		
MN	Time 1	25.99	a	1.119	7.93	a	0.948	2.88	ns	0.930	2.12	ns	0.930	9.73	a	0.499
	Time 2	22.30	b	1.119	7.47	a	0.941	3.70		0.930	3.18		0.930	9.16	a	0.498
	Time 3	5.26	c	1.119	4.62	b	0.941	3.06		0.930	2.11		0.930	3.76	b	0.498
p-value		<.0001												<.0001		
ZN	Time 1	0.167		0.070	0.514		0.059	0.175		0.058	0.144		0.058	0.250	b	0.031
	Time 2	0.245		0.070	0.593		0.059	0.268		0.058	0.257		0.058	0.341	a	0.031
	Time 3	0.291		0.070	0.571		0.059	0.294		0.058	0.258		0.058	0.353	a	0.031
p-value		0.907												0.0001		
CU	Time 1	0.668	ab	0.060	0.123	b	0.038	0.058	b	0.047	0.047	ns	0.047	0.224	b	0.025
	Time 2	0.559	b	0.060	0.207	a	0.037	0.140	a	0.047	0.095		0.047	0.250	ab	0.025
	Time 3	0.771	a	0.060	0.248	a	0.037	0.061	ab	0.047	0.080		0.047	0.290	a	0.025
p-value		0.015												0.055		
pH	Time 1	6.11	ns	0.120	5.27	b	0.098	5.01	ab	0.099	4.93	b	0.099	5.33	b	0.053
	Time 2	6.24		0.120	5.44	a	0.098	5.07	a	0.099	5.20	a	0.099	5.49	a	0.053
	Time 3	6.17		0.120	5.19	b	0.098	4.96	b	0.099	5.14	a	0.099	5.36	b	0.053
p-value		0.005												<.0001		

* Means that are followed by the same letter are not signficantly different at p<0.05

Table 75: (Continued)

c) Cycle analysis

		INTERACTION OF TIME*CYCLE												TIME FACTOR		
		Cylce 1 mean		SE	Cycle 2 mean		SE	Cycle 3 mean		SE	Cycle 4 mean		SE	Time mean		SE
P	Time 1	0.556	a	0.061	0.285	a	0.081	0.016	b	0.081	0.123	ns	0.081	0.245	b	0.040
	Time 2	0.661	a	0.077	0.414	a	0.086	0.209	a	0.077	0.183		0.077	0.367	a	0.040
	Time 3	0.000	b	0.077	0.000	b	0.086	0.000	b	0.077	0.057		0.077	0.009	c	0.040
p-value		0.001												<.0001		
K	Time 1	45.9	b	7.58	129.2	a	7.58	33.1	b	7.56	31.3	b	7.56	59.9	b	4.61
	Time 2	69.0	a	7.30	139.6	a	8.02	52.1	a	7.30	56.1	a	7.30	79.2	a	4.77
	Time 3	15.9	c	7.30	40.9	b	8.02	11.3	c	7.30	15.4	c	7.30	20.9	c	4.77
p-value		<.0001												<.0001		
Mg	Time 1	52.6	b	8.08	97.4	b	8.09	45.8	b	8.06	32.8	b	8.08	57.1	b	5.67
	Time 2	68.5	a	7.98	114.2	a	8.31	70.7	a	7.96	54.8	a	7.96	77.1	a	5.66
	Time 3	28.1	c	7.98	68.0	c	8.31	34.3	c	7.96	29.9	b	7.96	40.1	c	5.66
p-value		0.007												<.0001		
CA	Time 1	207	b	61.6	533	b	61.6	266	b	61.6	170	c	61.6	294	b	41.3
	Time 2	368	a	60.7	655	a	63.2	510	a	60.7	433	a	60.7	491	a	41.2
	Time 3	213	b	60.7	456	b	63.2	331	b	60.7	267	b	60.7	317	b	41.2
p-value		0.032												<.0001		
AL	Time 1	244	a	15.1	129	ns	15.1	128	a	15.1	148	a	15.1	162	a	7.9
	Time 2	215	b	14.7	135		15.7	102	b	14.7	107	b	14.7	140	b	7.6
	Time 3	152	c	14.7	119		15.7	82	b	14.7	114	b	14.7	117	c	7.6
p-value		<.0001												<.0001		
FE	Time 1	18.06	a	1.44	14.41	a	1.44	10.47	a	1.44	11.61	a	1.44	13.64	a	0.82
	Time 2	14.65	b	1.38	11.49	a	1.53	5.66	b	1.38	6.19	b	1.38	9.50	b	0.81
	Time 3	3.86	c	1.38	3.91	b	1.53	2.98	b	1.38	4.06	b	1.38	3.70	c	0.81
p-value		0.000												<.0001		
MN	Time 1	6.79		0.950	12.42		0.950	5.95		0.950	6.76		0.950	7.98	a	0.505
	Time 2	7.22		0.895	11.46		1.022	5.88		0.895	5.84		0.895	7.60	a	0.493
	Time 3	4.03		0.895	6.84		1.022	3.14		0.895	4.66		0.895	4.67	b	0.493
p-value		0.424												<.0001		
ZN	Time 1	0.305		0.070	0.897		0.070	0.469		0.070	0.330		0.070	0.500	b	0.035
	Time 2	0.427		0.067	0.794		0.075	0.635		0.067	0.522		0.067	0.595	a	0.034
	Time 3	0.417		0.067	0.827		0.075	0.515		0.067	0.467		0.067	0.557	ab	0.034
p-value		0.200												0.0722		
CU	Time 1	0.085		0.061	0.234		0.061	0.121		0.061	0.058		0.061	0.125	b	0.030
	Time 2	0.205		0.058	0.232		0.065	0.175		0.058	0.166		0.058	0.195	ab	0.030
	Time 3	0.130		0.058	0.227		0.065	0.267		0.058	0.302		0.058	0.231	a	0.030
p-value		0.151												0.016		
pH	Time 1	5.13	a	0.076	5.42	a	0.078	5.32	b	0.078	5.23	b	0.076	5.28	b	0.039
	Time 2	5.24	a	0.075	5.44	a	0.081	5.51	a	0.075	5.45	a	0.075	5.41	a	0.038
	Time 3	4.97	b	0.075	5.06	b	0.081	5.23	b	0.075	5.24	b	0.075	5.13	c	0.038
p-value		0.026												<.0001		

* Means that are followed by the same letter are not signficantly different at p<0.05

Appendix 18

Crop nutrient concentrations in treatment analysis

Table 76: Nutrient concentrations for rice, bean and ginger in harvestable products and straw for 4 treatments in % for C and N, and mg/kg for all other nutrients

	C		N		P			K			Mg		Ca		S			Al			Mn	
	Mean	SE	Mean	SE	Mean		SE	Mean		SE	Mean	SE	Mean	SE	Mean		SE	Mean		SE	Mean	SE
Rice grain																						
Tavy	43.0	0.86	1.52	0.072	2333	ab	123	3051		194	1103	49	575	41	1263	b	31	26		2.6	107	6.4
MO	40.3	0.86	1.55	0.072	2054	b	123	3167		194	1083	49	691	41	1367	a	31	29		2.6	120	6.4
M40	39.7	0.86	1.52	0.072	2756	a	123	3129		194	1256	49	655	41	1260	b	31	21		2.6	109	6.4
M80	42.0	2.37	1.36	0.109	2922	a	229	3580		275	1284	91	684	77	1219	b	58	20		4.6	103	15.8
p-value	0.0568		0.4594		0.0030			0.3109			0.0565		0.2188		0.0489			0.1539			0.5795	
Rice straw																						
Tavy	41.9	1.02	1.09	0.068	686	b	71	15021	a	1133	1778	96	3700	386	1835		94	291	b	29.9	602	71.6
MO	42.0	1.02	1.26	0.068	751	ab	71	12753	ab	1133	1726	96	3741	386	1903		94	275	b	29.9	480	71.6
M40	40.9	1.02	1.15	0.068	921	a	71	13542	ab	1133	1847	96	4267	386	1768		94	300	b	29.9	464	71.6
M80	42.8	1.90	1.08	0.127	987	a	119	10632	b	1571	1641	179	4340	715	1557		175	556	a	55.8	409	133.7
p-value	0.7519		0.2734		0.0331			0.0371			0.7009		0.6098		0.3793			0.0058			0.4129	

	Zn		Fe		B		Ni		Cu		Na			Co		V		
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean		SE	Mean	SE	Mean		SE
Rice grain																		
Tavy	29.3	2.27	35	3.1	0.90	0.372	9.1	0.90	8.4	2.03	46.5		3.12	0.21	0.028	0.000	b	0.1263
MO	30.2	2.27	40	3.1	1.32	0.372	7.5	0.90	7.9	2.03	50.4		3.12	0.29	0.028	0.177	b	0.1263
M40	33.4	2.27	38	3.1	1.13	0.372	8.2	0.90	10.0	2.03	48.6		3.12	0.28	0.028	0.105	b	0.1263
M80	30.9	3.25	32	4.8	1.65	0.561	5.3	1.68	6.9	3.32	53.9		4.80	0.26	0.077	1.361	a	0.2358
p-value	0.2253		0.2473		0.4861		0.2687		0.7436		0.4324			0.2245		0.0020		
Rice straw																		
Tavy	50.2	13.53	586	45.2	8.36	0.713	32.0	5.64	17.0	1.97	170.7	a	10.68	1.17	0.196	2.351		0.1808
MO	50.0	13.53	593	45.2	10.17	0.713	34.8	5.64	18.4	1.97	118.2	b	10.68	1.46	0.196	2.145		0.1808
M40	55.1	13.53	604	45.2	8.82	0.713	26.5	5.64	14.9	1.97	136.1	ab	10.68	1.09	0.196	1.963		0.1808
M80	45.2	16.14	625	84.4	8.57	1.285	48.6	10.53	14.8	3.68	121.1	ab	18.19	1.52	0.367	2.498		0.3374
p-value	0.8170		0.9748		0.2561		0.3459		0.5772		0.0060			0.4530		0.3588		

* Means that are followed by the same letter are not signficantly different at p<0.05

Table 76: (Continued)

	C			N			P			K			Mg		Ca			S		Al			Mn		
	Mean		SE	Mean		SE	Mean		SE	Mean		SE	Mean	SE	Mean		SE	Mean	SE	Mean		SE	Mean		SE
Bean grain																									
Tavy	40.8	ab	0.75	4.37	ab	0.304	3646	b	231	13692	b	413	1953	37	1785	ab	109	2538	72	30		3.7	22	ab	1.0
MO	42.2	a	0.67	4.98	a	0.303	3287	b	229	13131	b	415	1896	34	1576	b	98	2597	71	27		3.4	21	ab	1.0
M40	39.1	b	0.67	3.99	b	0.303	4488	a	229	14345	ab	415	1919	34	1962	ab	98	2468	71	31		3.4	23	a	1.0
M80	41.1	ab	1.25	3.77	b	0.406	5037	a	319	16008	a	500	1831	62	2390	a	182	2598	101	36		6.2	20	b	1.2
p-value	0.0333			0.0057			<.0001			0.0007			0.4069		0.0100			0.2512		0.6893			0.0280		
Bean straw																									
Tavy	39.9		0.84	2.88	ab	0.283	1808	ab	319	17412		1152	5687	326	10888		2058	3691	464	10908	a	1546.5	213		17.1
MO	39.9		0.78	3.08	a	0.284	1470	b	321	15944		1034	4801	293	8982		2068	3207	447	12014	a	1387.8	211		17.0
M40	40.3		0.78	2.14	b	0.284	2088	a	321	15592		1034	5495	293	12587		2068	4209	447	9947	a	1387.8	220		17.0
M80	40.9		1.41	1.99	b	0.355	2616	a	399	16686		1920	5869	543	13476		2611	4212	688	1087	b	2575.9	173		23.2
p-value	0.9068			0.0010			0.0216			0.6685			0.1669		0.0883			0.2055		0.0254			0.2575		
Bean pods																									
Tavy	41.3		1.57	1.13		0.09109	914		178	16945		2193	7312	452	4592	b	309	1347	221	663		409.8	105		6.1
MO	43.0		1.57	1.48		0.09109	848		178	16744		2193	7366	452	4588	b	309	1249	221	695		409.8	94		6.1
M40	41.1		1.57	1.06		0.09109	1201		178	20169		2193	6959	452	6496	ab	309	1457	221	1005		409.8	98		6.1
M80	42.0		1.57	1.07		0.09109	1603		178	22665		2193	6944	452	7150	a	309	1623	221	408		409.8	81		6.1
p-value	0.8212			0.1169			0.1546			0.3428			0.8592		0.0199			0.6954		0.7902			0.2185		

* Means that are followed by the same letter are not signficantly different at p<0.05

	Zn		Fe			B			Ni		Cu		Na		Co		V		
	Mean	SE	Mean		SE	Mean		SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean		SE
Bean grain																			
MO	40.0	1.41	69		2.7	13.21		0.503	5.4	0.75	9.4	0.28	12.6	3.21	0.15	0.046	0.629		0.0440
M40	44.5	1.41	77		2.7	13.45		0.503	3.6	0.75	10.1	0.28	6.2	3.21	0.22	0.046	0.635		0.0528
M80	43.5	2.61	84		5.0	13.42		0.934	4.6	1.39	10.8	0.51	16.4	6.96	0.19	0.069	0.766		0.0456
Tavy	40.3	1.57	72		3.0	13.52		0.560	4.0	0.83	9.8	0.31	7.3	3.59	0.26	0.047	0.846		0.0878
p-value	0.1166		0.0768			0.9725			0.3494		0.1615		0.3451		0.2037		0.2586		
Bean straw																			
MO	59.0	7.92	4966	a	401.4	44.99	ab	2.365	4.8	0.45	12.8	3.02	355.7	41.38	0.66	0.107	19.395	a	1.3396
M40	60.7	7.92	4259	a	401.4	42.99	ab	2.365	4.2	0.45	12.1	3.02	374.4	41.38	0.66	0.107	18.383	a	1.3396
M80	73.9	10.20	1432	b	744.8	37.23	b	3.267	2.9	0.77	27.5	4.78	428.9	54.02	0.43	0.144	6.738	b	2.4846
Tavy	54.5	7.80	4677	a	447.0	48.16	a	2.380	5.4	0.48	12.4	3.15	393.4	41.31	0.72	0.107	21.970	a	1.4907
p-value	0.2645		0.0121			0.0283			0.0539		0.0615		0.4730		0.2840		0.0025		
Bean pods																			
MO	24.7	2.54	320		167.8	44.61		1.844	0.7	0.12	4.7	0.52	177.5	27.04	0.23	0.054	2.054		1.0000
M40	21.8	2.54	392		167.8	46.26		1.844	0.8	0.12	5.4	0.52	141.8	27.04	0.27	0.054	2.271		1.0000
M80	24.1	2.54	181		167.8	47.48		1.844	0.9	0.12	6.5	0.52	116.2	27.04	0.35	0.054	1.403		1.0000
Tavy	26.0	2.54	274		167.8	42.98		1.844	0.8	0.12	5.6	0.52	121.9	27.04	0.20	0.054	1.485		1.0000
p-value	0.7281		0.8403			0.4609			0.8473		0.2881		0.4783		0.3646		0.9030		

* Means that are followed by the same letter are not signficantly different at p<0.05

Table 76: (Continued)

	C		N		P			K			Mg		Ca		S			Al			Mn	
	Mean	SE	Mean	SE	Mean		SE	Mean		SE	Mean	SE	Mean	SE	Mean		SE	Mean		SE	Mean	SE
Ginger root																						
MO	39.6	1.37	2.4429	0.173	2237	b	181	19788	a	2975	3681	351	1966	109	2692	a	104	1610		151.5	398	80.4
M40	38.0	1.37	2.3907	0.173	2937	a	181	20160	a	2975	3696	351	1942	109	2371	bc	104	1320		151.5	248	80.4
M80	39.5	2.01	2.4042	0.235	3557	a	270	21765	a	3374	3755	484	2208	204	2048	c	194	985		282.8	173	103.3
Tavy	38.4	1.37	2.3447	0.173	2324	b	181	14835	b	2975	3767	351	1994	109	2600	ab	104	1622		151.5	396	80.4
p-value	0.6178		0.9076		<.0001			0.0035			0.9893		0.7294		0.0358			0.1679			0.0784	
Ginger straw																						
MO	44.1	3.54	2.7598	0.110	2196	c	70	18527		3789	10364	1353	14621	1519	3530		154	543	b	222.4	530	180.1
M40	41.1	3.54	2.8382	0.110	2739	b	70	18774		3789	10185	1353	15606	1519	3374		154	515	b	222.4	366	180.1
M80	42.4	4.90	2.8591	0.156	3279	a	131	17248		4752	11447	1818	19798	2718	3176		241	630	b	416.2	390	232.9
Tavy	45.1	3.54	2.8525	0.110	2292	c	70	13902		3789	10844	1353	16615	1519	3460		154	1738	a	222.4	679	180.1
p-value	0.5519		0.8873		<.0001			0.2102			0.8380		0.3967		0.5219			0.0034			0.1267	

	Zn		Fe			B			Ni		Cu			Na		Co			V		
	Mean	SE	Mean		SE	Mean		SE	Mean	SE	Mean		SE	Mean	SE	Mean		SE	Mean		SE
Ginger root																					
MO																					
M40	45.4	3.94	1062		134.0	29.09		2.296	3.1	0.35	10.7	a	0.41	231.9	19.08	0.19		0.097	6.180		1.0265
M80	34.7	3.94	780		134.0	26.05		2.296	2.9	0.35	9.1	b	0.41	272.4	19.08	0.32		0.105	4.581		1.0741
Tavy	31.8	7.26	779		250.1	24.82		2.969	2.0	0.65	8.3	b	0.77	268.1	28.74	0.13		0.125	4.482		1.9119
	38.1	3.94	1127		134.0	26.66		2.296	3.3	0.35	10.2	a	0.41	245.3	19.08	0.34		0.097	6.886		1.0265
p-value																					
	0.1945		0.2287			0.1647			0.4035		0.0238			0.1619		0.0628			0.3989		
Ginger straw																					
MO																					
M40	34.3	4.75	428	b	89.6	38.68	b	1.248	3.5	0.28	9.7	a	0.18	131.4	38.85	0.26	a	0.075	3.387	b	0.5593
M80	41.0	4.75	464	b	89.6	37.78	b	1.248	3.4	0.28	8.5	b	0.18	118.6	38.85	0.28	a	0.076	3.667	b	0.5593
Tavy	39.6	8.87	583	b	167.3	45.03	ab	2.329	3.4	0.52	8.1	b	0.33	149.8	58.76	0.28	ab	0.126	3.726	ab	1.0440
	34.0	4.75	1146	a	89.6	46.31	a	1.248	4.4	0.28	9.8	a	0.18	156.9	38.85	0.51	b	0.075	6.574	a	0.5593
p-value																					
	0.6465		0.0001			0.0006			0.0527		0.0001			0.7253		0.0448			0.0032		

* Means that are followed by the same letter are not signficantly different at p<0.05

Appendix 19

Crop nutrient concentrations in fallow analysis

Table 77: Nutrient concentrations for rice, bean and ginger in harvestable products and straw for 4 fallows in % for C and N, and mg/kg for all other nutrients

	C			N			P			K			Mg			Ca			S			Al			Mn		
	Mean		SE	Mean		SE	Mean		SE	Mean		SE	Mean		SE	Mean		SE	Mean		SE	Mean		SE	Mean		SE
Rice grain																											
Imperata	40.8		1.07	1.3524		0.08705	2801		152	2805	b	229	1222	a	60	319	b	51	1123	b	38	33	a	3.2	93	b	10.4
Rubus	43.8		1.38	1.5137		0.08705	2650		152	2762	b	229	1142	ab	60	318	b	51	1213	b	38	14	b	3.2	73	b	10.4
Psiadia	41.5		0.87	1.5457		0.06882	2292		107	2501	b	160	963	b	43	456	b	36	1241	b	27	14	b	2.2	100	b	7.3
Trema	38.9		1.38	1.5422		0.09804	2321		186	4858	a	253	1401	a	74	1511	a	62	1631	a	47	34	a	3.9	173	a	12.7
p-value	0.0911			0.1755			0.0685			<.0001			0.0004			<.0001			<.0001			0.0002			0.0002		
Rice straw																											
Imperata	43.3		1.26	1.0171	b	0.08393	1315	a	88	12368	b	1326	1817		119	2393	b	478	1666		116	509	a	37.0	444	ab	88.7
Rubus	44.4		1.26	1.1346	b	0.08393	733	b	88	12799	ab	1326	1692		119	2776	b	478	1516		116	467	a	37.0	419	ab	88.7
Psiadia	40.9		0.89	0.9668	b	0.05935	618	b	59	16109	a	945	1647		84	4674	a	336	1890		82	167	b	26.2	707	a	62.7
Trema	38.9		1.54	1.4584	a	0.1028	679	b	109	10671	b	1457	1837		145	6206	a	584	1991		142	280	b	45.4	384	b	108.7
p-value	0.0657			0.0043			<.0001			0.0072			0.5061			0.0006			0.0624			<.0001			0.0197		

	Zn			Fe			B			Ni			Cu			Na			Co			V		
	Mean		SE	Mean		SE	Mean		SE	Mean		SE	Mean		SE	Mean		SE	Mean		SE	Mean		SE
Rice grain																								
Imperata	25.6	b	2.69	34	b	3.7	1.00	b	0.445	5.5	b	1.12	7.6		2.48	54.2	ab	3.77	0.19	b	0.036	0.395		0.1565
Rubus	24.0	b	2.69	29	b	3.7	0.64	b	0.445	6.2	b	1.12	7.1		2.48	48.5	b	3.77	0.21	ab	0.045	0.480		0.1565
Psiadia	31.0	b	1.87	28	b	2.5	0.75	b	0.303	6.0	b	0.79	8.5		1.68	34.3	c	2.53	0.33	a	0.028	0.437		0.1107
Trema	43.2	a	2.96	54	a	4.1	2.60	a	0.499	12.5	a	1.37	10.0		2.88	62.3	a	4.26	0.31	ab	0.045	0.318		0.1917
p-value	<.0001			<.0001			0.0063			0.0041			0.8297			<.0001			0.0238			0.9120		
Rice straw																								
Imperata	45.2		14.78	1209	a	56.0	12.85	a	0.881	82.8	a	6.98	22.5	a	2.45	183.0	a	13.14	2.47	a	0.243	2.738	a	0.2239
Rubus	39.0		14.78	651	c	56.0	10.34	ab	0.881	43.2	b	6.98	19.6	a	2.45	172.9	a	13.14	1.81	a	0.243	1.777	b	0.2239
Psiadia	67.8		12.33	81	b	39.6	5.60	c	0.610	5.5	c	4.94	7.2	b	1.73	126.4	b	8.85	0.42	b	0.172	0.716	c	0.1583
Trema	46.5		15.57	467	c	68.6	7.13	bc	1.069	10.4	c	8.55	15.9	ab	3.00	64.7	c	15.48	0.55	b	0.298	3.726	a	0.2742
p-value	0.0961			<.0001			<.0001			<.0001			0.0006			<.0001			<.0001			<.0001		

* Means that are followed by the same letter are not signficantly different at p<0.05

Table 77: (Continued)

	C Mean	C SE	N Mean	N SE	P Mean	P SE	K Mean	K SE	Mg Mean	Mg SE	Ca Mean	Ca SE	S Mean	S SE	Al Mean	Al SE	Mn Mean	Mn SE
Bean grain																		
Imperata	39.6	0.83	3.6146 b	0.3525	4620 a	270	14241 a	462	2203 a	41	1499 c	121	2373 bc	84	48 a	4.1	27 a	1.1
Rubus	41.0	0.83	4.1266 ab	0.3525	4197 a	270	14495 a	462	2105 a	41	1769 bc	121	2335 c	84	40 a	4.1	23 b	1.1
Psiadia	42.3	0.63	4.2846 ab	0.2533	4432 a	190	14718 a	356	1805 b	32	2251 a	93	2859 a	58	21 b	3.2	18 c	0.8
Trema	40.4	1.01	5.1341 a	0.3844	3158 b	297	12721 b	498	1465 c	51	2193 ab	148	2633 ab	93	15 b	5.1	17 c	1.2
p-value	0.0980		0.0081		0.0015		0.0010		<.0001		0.0024		0.0005		0.0007		<.0001	
Bean straw																		
Imperata	40.0 ab	0.93	2.4856	0.3212	2101 ab	362	14860	1272	4347 b	360	7814 b	2351	3228 b	540	11195 b	1707.3	320 a	19.9
Rubus	37.2 b	0.93	2.4665	0.3212	2118 ab	362	14095	1272	4339 b	360	8738 b	2351	2781 b	540	21510 a	1707.3	252 b	19.9
Psiadia	40.4 ab	0.71	2.7588	0.2449	2402 a	278	16664	974	5446 b	278	12229 ab	1772	5170 a	378	2834 c	1307.4	163 c	14.1
Treme	43.4 a	1.14	2.3872	0.3432	1262 b	387	18016	1558	7719 a	441	17311 a	2620	4144 ab	618	-1582 c	2091.0	81 d	21.8
p-value	0.0108		0.6502		0.0243		0.0531		0.0004		0.0031		0.0132		<.0001		<.0001	
Bean pods																		
Imperata	42.6	1.11	1.1522	0.06441	1282	126	17542	1551	7495	320	5871	219	1525	156	522	288.8	95	4.3
Rubus	40.9	1.11	1.2237	0.06441	1000	126	20715	1551	6795	320	5741	219	1313	156	863	288.8	94	4.3
p-value	0.3137		0.4896		0.2120		0.2436		0.2194		0.8353		0.4077		0.4672		0.8434	

	Zn Mean	Zn SE	Fe Mean	Fe SE	B Mean	B SE	Ni Mean	Ni SE	Cu Mean	Cu SE	Na Mean	Na SE	Co Mean	Co SE	V Mean	V SE
Bean grain																
Imperata	39.0	1.73	90 a	3.3	12.88	0.619	2.7 b	0.92	11.2 a	0.34	22.4 a	3.95	0.16	0.055	0.666	0.0557
Rubus	43.0	1.73	77 ab	3.3	12.98	0.619	3.9 b	0.92	9.8 ab	0.34	6.6 b	3.95	0.26	0.055	0.628	0.0363
Psiadia	45.1	1.33	70 b	2.5	13.97	0.474	2.0 b	0.70	10.6 a	0.26	9.1 b	3.02	0.17	0.038	0.566	0.0430
Trema	41.2	2.12	65 b	4.0	13.77	0.758	9.1 a	1.13	8.6 b	0.42	3.4 b	4.84	0.21	0.062		
p-value	0.0759		0.0021		0.4772		0.0010		0.0018		0.0363		0.3272		0.1658	
Bean straw																
Imperata	50.5	9.08	6010 a	493.8	46.07 ab	2.778	4.0 b	0.55	20.8	3.65	430.7 a	47.68	0.82 a	0.125	29.672 a	1.6468
Rubus	67.6	9.08	6576 a	493.8	47.40 a	2.778	5.4 ab	0.55	12.1	3.65	385.1 ab	47.68	0.81 a	0.125	25.464 a	1.6468
Psiadia	70.8	8.72	1666 b	378.1	40.68 ab	1.963	1.4 c	0.40	17.5	2.57	469.8 a	34.89	0.42 b	0.089	2.881 b	1.2611
Trema	59.1	9.79	1061 b	604.7	39.21 b	3.059	6.4 a	0.65	14.3	4.20	266.8 b	51.61	0.42 b	0.136	8.467 b	2.0169
p-value	0.0998		<.0001		0.0461		<.0001		0.2366		0.0060		0.0093		<.0001	
Bean pods																
Imperata	21.6	1.80	261	118.7	42.55	1.304	0.7	0.08	6.4	0.37	131.5	19.12	0.19	0.038	1.785	0.7071
Rubus	26.7	1.80	322	118.7	48.12	1.304	0.9	0.08	4.7	0.37	146.7	19.12	0.33	0.038	1.822	0.7071
p-value	0.1369		0.7405		0.0567		0.1303		0.0453		0.6126		0.0827		0.9728	

* Means that are followed by the same letter are not signficantly different at p<0.05

Table 77: (Continued)

	C			N			P			K			Mg			Ca			S			Al			Mn		
	Mean		SE	Mean		SE	Mean		SE	Mean		SE	Mean		SE	Mean		SE	Mean		SE	Mean		SE	Mean		SE
Ginger root																											
Imperata	38.2		1.64	2.6341	ab	0.2009	3555	a	217	20610	a	3168	3790		410	1340	c	136	2795	ab	129	1594		187.7	349		74.4
Rubus	37.0		1.64	2.9643	a	0.2009	3569	a	217	20537	a	3168	3293		410	1504	c	136	2812	a	128	1652		187.7	261		74.4
Psiadia	39.5		1.12	2.1973	b	0.1458	2657	b	147	20433	a	2792	3675		293	2224	b	98	2347	b	91	1169		132.7	324		50.2
Trema	40.8		1.83	1.7868	b	0.2195	1274	c	244	14969	b	3289	4141		450	3041	a	166	1757	c	158	1123		229.9	281		87.7
p-value	0.2389			0.0003			0.0004			0.0396			0.2643			<.0001			0.0006			0.1362			0.7684		
Ginger straw																											
Imperata	44.7		4.14	2.7928		0.1296	3057	a	87	16471		4241	11497		1563	7845	c	1877	3511		187	706		275.5	608		204.5
Rubus	46.0		4.14	2.8327		0.1296	2824	a	87	18092		4241	10339		1563	12211	bc	1877	3420		187	1361		275.5	478		204.5
Psiadia	40.1		2.95	2.7973		0.09106	2474	b	61	15697		3345	9940		1147	17204	b	1293	3500		125	778		194.8	579		156.1
Trema	41.9		4.55	2.8869		0.1432	2150	b	106	18190		4531	11064		1702	29379	a	2257	3109		214	581		337.4	300		220.4
p-value	0.4914			0.7401			<.0001			0.8544			0.6865			<.0001			0.2958			0.2728			0.3644		

	Zn			Fe			B			Ni			Cu			Na			Co			V		
	Mean		SE	Mean		SE	Mean		SE	Mean		SE	Mean		SE	Mean		SE	Mean		SE	Mean		SE
Ginger root																								
Imperata	37.2		4.83	730	b	166.0	26.70	ab	2.608	1.5	bc	0.44	10.5		0.51	293.6	a	22.94	0.21		0.111	4.566	b	1.2681
Rubus	37.8		4.88	498	b	166.0	24.51	b	2.608	2.3	b	0.44	9.4		0.51	232.7	ab	22.94	0.20		0.111	2.987	b	1.2681
Psiadia	46.5		3.42	535	b	117.4	25.39	ab	1.990	0.6	c	0.31	9.1		0.36	212.5	b	15.48	0.24		0.087	1.491	b	0.9265
Trema	28.5		5.94	1984	a	203.3	32.01	a	2.810	6.9	a	0.54	9.3		0.63	278.9	ab	25.87	0.33		0.119	13.086	a	1.5531
p-value	0.0599			0.0001			0.0316			<.0001			0.2638			0.0144			0.5708			0.0001		
Ginger straw																								
Imperata	33.3		5.89	337	b	111.0	37.01	bc	1.546	1.9	c	0.35	9.4	ab	0.22	106.4		46.30	0.27		0.092	2.534	b	0.6928
Rubus	42.5		5.89	487	b	111.0	42.35	b	1.546	4.0	b	0.35	8.7	b	0.22	141.0		46.30	0.34		0.092	2.809	b	0.6928
Psiadia	41.3		4.16	429	b	76.5	34.25	c	1.093	1.0	c	0.24	7.7	c	0.16	147.7		31.72	0.31		0.062	2.039	b	0.4899
Trema	31.7		7.21	1368	a	135.9	54.20	a	1.893	7.8	a	0.42	10.3	a	0.27	161.6		51.70	0.41		0.108	9.972	a	0.8485
p-value	0.4360			0.0001			<.0001			<.0001			<.0001			0.7253			0.6928			<.0001		

* Means that are followed by the same letter are not signficantly different at p<0.05

Appendix 20

Crop nutrient concentrations in cycle analysis

Table 78: Nutrient concentrations for rice, bean and ginger in harvestable products and straw for 4 cylces in % for C and N, and mg/kg for all other nutrients

	C		N		P		K		Mg		Ca		S		Al		Mn	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Rice grain																		
CYCLE 1	42.5	1,18	1.497	0,09517	2071	196	2493	144	865	78	371	41	1254	66	15	3,4	95	14,6
CYCLE 2	39.7	1,18	1.7369	0.09517	2245	196	2247	144	911	78	433	41	1272	66	16	3,4	104	14,6
CYCLE 3	41.5	1,18	1,5804	0.09517	2106	196	2063	144	919	78	477	41	1232	66	13	3,4	98	14,6
CYCLE 4	41.4	1,18	1,5341	0.09517	2203	195	2739	144	1019	78	500	41	1283	66	18	3,4	112	14.6
	0,4660		0,3781		0.9097		0.0649		0.5955		0.2235		0,9490		0.7639		0,8381	
Rice straw																		
CYCLE 1	40,7	1.14	0.9683	0,1393	587	93	17587	835	1527	173	4962	751	2075	184	83	41,0	738	144.0
CYCLE 2	38.7	1.14	1.0864	0.1393	685	93	19013	835	1708	173	4462	751	1997	184	125	41.0	818	144.0
CYCLE 3	41,1	1,14	0.8866	0.1393	442	93	15088	835	1832	173	5007	751	1870	184	108	41.0	693	144.0
CYCLE 4	42.1	1.14	1.0167	0.1393	556	93	15888	835	1664	173	3826	751	1895	184	84	41.0	687	144.0
	0.2877		0.7821		0,3990		0.0579		0.6780		0,6732		0.8480		0,8665		0.9092	

	Zn			Fe		B		Ni		Cu			Na		Co		V	
	Mean		SE	Mean	SE	Mean	SE	Mean	SE	Mean		SE	Mean	SE	Mean	SE	Mean	SE
Rice grain	26.6		2.24	27	2,5	0,06	0,319	6.3	1.69	7,0		3.27	34,0	2.44	0.29	0.046	0,000	0.1340
CYCLE 1	34.9		2.24	36	2,5	0.21	0.319	7.4	1.69	13,2		3.27	26.5	2.44	0.38	0.046	0,229	0.1340
CYCLE 2	31,0		2.24	25	2.5	1,08	0.319	6.5	1.69	7,8		3.27	34,2	2.44	0.33	0.046	0.036	0.1340
CYCLE 3	31.7		2.24	28	2.5	1,10	0.319	6,8	1.69	7.9		3.27	37.0	2,44	0,31	0.046	0.213	0.1340
CYCLE 4																		
	0,1717			0.1007		0.1207		0.9656		0.5551			0.0956		0,6292		0.5474	
Rice straw	47,5	b	10.94	67	16,1	5.29	1.002	0.8	0.39	5.0	b	0.70	125.6	12.87	0.37	0.051	0.662	0,2220
CYCLE 1	98.6	a	10.94	87	16.1	7,25	1.002	1,9	0.39	10,2	a	0.70	144.9	12.87	0.47	0.051	0.792	0.2220
CYCLE 2	79,5	ab	10.94	72	16,1	5.22	1.002	0.8	0.39	6,8	ab	0.70	140,1	12.87	0.29	0.051	0.694	0.2220
CYCLE 3	52,3	ab	10.94	65	16.1	5.20	1.002	1,1	0.39	8.7	a	0.70	111.6	12,87	0,26	0.051	0.371	0.2220
CYCLE 4																		
	0.0488			0.7840		0.4501		0,2524		0.0089			0.3431		0.0864		0.6030	

* Means that are followed by the same letter are not signficantly different at p<0,05

Table 78: (Continued)

	C		N		P			K			Mg		Ca		S		Al		Mn		
	Mean	SE	Mean	SE	Mean		SE	Mean		SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean		SE
Bean grain																					
CYCLE 1	41.9	1.35	3.9773	0.4301	4288		212	14545	ab	210	1928	76	2014	89	2919	99	19	4.1	20		1.0
CYCLE 2	42.4	1.35	3.892	0.3251	4502		160	15294	a	159	1792	57	2021	68	2864	75	19	3.1	21		0.8
CYCLE 3	42.8	1.79	4.7745	0.3251	4004		160	14179	b	159	1813	57	2229	68	2704	75	18	3.1	17		0.8
CYCLE 4	41.7	1.79	4.631	0.4301	3736		212	13716	b	210	1834	76	2155	89	2895	99	22	4.1	18		1.0
	0.9568		0.3076		0.1312			0.0129			0.5779		0.2386		0.3693		0.9103		0.1240		
Bean straw																					
CYCLE 1	41.0	2.14	2.2416	0.2414	1874	ab	243	19261		1414	5279	721	8158	2625	5262	936	4163	2517.4	201	a	4.1
CYCLE 2	40.2	1.62	3.47	0.1825	2914	a	184	19938		1069	5436	545	15677	1984	5255	707	4606	1903.0	194	a	3.1
CYCLE 3	40.9	1.62	2.8697	0.1825	1805	b	184	17550		1069	5249	545	11434	1984	4222	707	4898	1903.0	140	b	3.1
CYCLE 4	38.1	2.14	2.9279	0.2414	2290	ab	243	18929		1414	5495	721	11862	2625	5788	936	6349	2517.4	189	a	4.1
	0.7129		0.0637		0.0437			0.5277			0.9884		0.2773		0.6030		0.9139		0.0007		

	Zn			Fe		B		Ni		Cu		Na			Co		V	
	Mean		SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean		SE	Mean	SE	Mean	SE
Bean grain																		
CYCLE 1	44.5		2.40	69	5.9	12.43	1.059	2.1	0.39	10.7	0.48	5.9		2.68	0.14	0.059	0.602	0.0585
CYCLE 2	46.3		1.81	67	4.4	14.52	0.801	2.3	0.30	10.6	0.36	7.4		2.01	0.26	0.044	0.594	0.0585
CYCLE 3	44.3		1.81	68	4.4	14.45	0.801	1.6	0.30	10.1	0.36	8.1		2.01	0.12	0.044	0.552	0.0585
CYCLE 4	42.9		2.40	66	5.9	13.16	1.059	2.6	0.39	10.0	0.48	8.2		2.68	0.15	0.059		
	0.7131			0.9595		0.4526		0.3593		0.6177		0.8905			0.2698		0.9285	
Bean straw																		
CYCLE 1	58.9	b	3.87	2162	1012.0	41.75	2.507	1.5	0.85	8.9	3.18	558.9	a	23.65	0.51	0.145	5.651	3.4846
CYCLE 2	84.3	a	2.92	2480	765.0	47.59	1.895	2.4	0.64	19.2	2.40	376.3	b	17.88	0.69	0.109	7.674	2.8113
CYCLE 3	64.2	b	2.92	2334	765.0	41.81	1.895	1.2	0.64	12.0	2.40	486.1	a	17.88	0.32	0.109	4.838	2.8113
CYCLE 4	63.4	b	3.87	2461	1012.0	41.79	2.507	2.5	0.85	13.1	3.18	475.7	ab	23.65	0.45	0.145	8.611	3.4846
	0.0168			0.9933		0.2454		0.5408		0.0186		0.0140			0.2673		0.8834	

* Means that are followed by the same letter are not signficantly different at $p<0.05$

Table 78: (Continued)

	C		N			P		K			Mg		Ca		S		Al		Mn	
	Mean	SE	Mean		SE	Mean	SE	Mean		SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Ginger root																				
CYCLE 1	41.9	1.35	2.4586	a	0.1197	2712	135	20414	ab	1663	3431	369	2116	199	2565	109	1247	226.7	401	90.1
CYCLE 2	37.5	1.35	1.9455	b	0.1197	2392	136	26985	a	1663	3479	369	2184	199	2493	109	1455	226.7	471	90.1
CYCLE 3	39.6	1.35	2.4009	a	0.1197	2400	135	15686	b	1663	4474	369	2227	199	2508	109	1140	226.7	289	90.1
CYCLE 4	37.9	1.35	1.9726	b	0.1197	2065	135	15142	b	1663	3278	369	2128	199	2328	109	1365	228.7	308	80.1
	0.1843		0.0417			0.0768		0.0077			0.1901		0.9757		0.5021		0.7789		0.5006	
Ginger straw																				
CYCLE 1	43.1	3.90	2.9226		0.0849	2378	78	13714		3650	10063	1584	19277	2826	3651	174	1253	390.9	794	178.6
CYCLE 2	42.7	3.90	2.5646		0.0849	2191	76	25179		3650	7063	1584	14848	2826	3693	174	578	390.9	932	178.8
CYCLE 3	32.2	3.90	2.911		0.0849	2245	78	11222		3650	12299	1584	15853	2826	3242	174	878	390.9	310	178.8
CYCLE 4	43.5	3.90	2.7487		0.0849	2212	78	12494		3650	9354	1584	14656	2826	3695	174	705	390.9	415	178.8
	0.2201		0.0729			0.3760		0.1104			0.2382		0.6517		0.2865		0.6588		0.1336	

	Zn		Fe		B			Ni		Cu		Na		Co		V	
	Mean	SE	Mean	SE	Mean		SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Ginger root																	
CYCLE 1	45.8	3.82	499	186.3	26.51	ab	1.724	0.8	0.36	9.0	0.45	232.0	13.15	0.42	0.086	1.227	1.1925
CYCLE 2	44.9	3.82	808	185.3	30.89	a	1.724	1.4	0.35	9.3	0.45	231.7	13.15	0.41	0.113	5.263	1.5396
CYCLE 3	56.8	3.82	500	185.3	25.65	ab	1.724	0.7	0.35	10.4	0.46	186.8	13.15	0.11	0.086	1.038	1.1925
CYCLE 4	46.0	3.82	544	185.3	21.64	b	1.724	0.6	0.35	9.5	0.45	181.2	13.15	0.16	0.113	1.254	1.1925
	0.1945		0.6158		0.0484			0.4811		0.2782		0.0573		0.1465		0.2374	
Ginger straw																	
CYCLE 1	41.9	8.29	622	143.7	32.26		1.899	1.2	0.31	7.9	0.22	100.6	54.74	0.46	0.120	2.601	0.7413
CYCLE 2	39.6	8.29	375	143.7	32.49		1.699	1.7	0.31	8.0	0.22	180.6	54.74	0.34	0.120	2.806	0.7413
CYCLE 3	43.8	8.29	401	143.7	35.12		1.699	0.8	0.31	8.0	0.22	89.7	54.74	0.24	0.120	1.783	0.7413
CYCLE 4	36.9	8.29	414	143.7	33.03		1.699	1.0	0.31	8.4	0.22	205.5	54.74	0.25	0.120	1.782	0.7413
	0.9392		0.6233		0.6448			0.3286		0.4793		0.4164		0.5534		0.6797	

* Means that are followed by the same letter are not signficantly different at $p<0.05$

Appendix 21

Crop nutrient uptake in treatment analysis

Table 79: Nutrient uptake (kg/ha) by rice, bean and ginger in harvestable products and straw for 4 treatments

	C		SE	N		SE	P		SE	K		SE	MG		SE	CA		SE	S		SE	MN		SE
Rice Grain																								
Tavy	495	a	47.0	17.2	a	1.94	2.46	a	0.287	3.56	a	0.441	1.18	a	0.133	0.70		0.112	1.48	a	0.157	0.120	a	0.0157
M0	144	b	47.2	5.6	b	1.94	0.70	b	0.288	1.36	b	0.442	0.43	c	0.133	0.39		0.112	0.53	b	0.157	0.057	b	0.0157
M40	253	b	47.2	10.3	ab	1.94	1.86	a	0.288	2.25	ab	0.442	0.80	b	0.133	0.55		0.112	0.87	b	0.157	0.078	ab	0.0157
M80	238	b	68.1	8.7	ab	2.75	2.29	a	0.416	2.81	ab	0.636	1.00	ab	0.188	0.57		0.151	0.81	ab	0.224	0.081	ab	0.0222
p-value	<.0001			<.0001			<.0001			0.001			<.0001			0.085			<.0001			0.007		
Rice Straw																								
Tavy	802	a	91.8	21.1	a	2.81	1.12	a	0.173	31.74	a	4.140	3.43	a	0.397	7.59	a	1.265	3.58	a	0.469	1.212	a	0.2089
M0	241	b	92.4	8.6	b	2.82	0.41	b	0.174	7.45	b	4.167	1.04	b	0.400	2.81	b	1.270	1.23	b	0.472	0.313	b	0.2096
M40	424	b	92.4	13.1	ab	2.82	0.82	ab	0.174	14.28	b	4.167	1.89	b	0.400	5.48	ab	1.270	1.94	ab	0.472	0.491	b	0.2096
M80	456	ab	135.7	12.7	ab	4.08	0.85	ab	0.244	14.25	b	6.060	1.91	ab	0.584	6.05	ab	1.823	1.95	ab	0.692	0.630	ab	0.3171
p-value	<.0001			0.001			0.002			<.0001			<.0001			0.029			0.000			0.008		
Rice total																								
Tavy	1294	a	133.8	38.8	a	4.50	3.58	a	0.440	35.31	a	4.392	4.64	a	0.511	8.29	a	1.334	5.05	a	0.605	1.331	a	0.2199
M0	387	b	134.6	14.0	b	4.53	1.11	b	0.441	8.83	b	4.420	1.48	b	0.514	3.20	b	1.339	1.76	b	0.608	0.370	b	0.2207
M40	678	b	134.6	23.1	b	4.53	2.47	a	0.441	16.49	b	4.420	2.68	b	0.514	6.02	ab	1.339	2.80	b	0.608	0.567	b	0.2207
M80	694	b	194.8	22.4	b	6.36	3.14	a	0.623	17.07	b	6.405	2.91	ab	0.739	6.82	ab	2.011	2.86	b	0.879	0.711	ab	0.3326
p-value	<.0001			<.0001			<.0001			<.0001			<.0001			0.024			<.0001			0.005		

	FE		SE	B		SE	NI		SE	CU		SE	ZN		SE	AL		SE	NA		SE
Rice Grain																					
Tavy	0.038	a	0.0048	0.001		0.0002	0.0098	a	0.0013	0.0090	a	0.0010	0.033	a	0.0042	0.027	a	0.0034	0.051	a	0.0056
M0	0.018	b	0.0048	0.000		0.0002	0.0042	b	0.0013	0.0035	b	0.0010	0.011	b	0.0042	0.011	b	0.0034	0.021	b	0.0056
M40	0.026	ab	0.0048	0.001		0.0002	0.0062	ab	0.0013	0.0049	b	0.0010	0.022	b	0.0042	0.014	b	0.0034	0.032	b	0.0056
M80	0.024	ab	0.0065	0.001		0.0003	0.0048	ab	0.0018	0.0046	b	0.0014	0.024	ab	0.0058	0.010	b	0.0050	0.034	ab	0.0080
p-value	0.001			0.058			0.0032			0.0001			0.000			0.001			0.001		
Rice Straw																					
Tavy	0.637	a	0.1065	0.013	a	0.0018	0.0208	ab	0.0068	0.0245	a	0.0032	0.092	a	0.0225	0.424	a	0.0804	0.297	a	0.0356
M0	0.256	b	0.1065	0.007	b	0.0018	0.0105	b	0.0068	0.0106	b	0.0032	0.022	b	0.0226	0.112	b	0.0804	0.069	b	0.0357
M40	0.459	ab	0.1065	0.008	ab	0.0018	0.0163	b	0.0068	0.0139	b	0.0032	0.046	ab	0.0226	0.251	ab	0.0804	0.115	b	0.0357
M80	0.632	ab	0.1577	0.008	ab	0.0029	0.0478	a	0.0103	0.0232	ab	0.0048	0.046	ab	0.0303	0.598	a	0.1280	0.144	b	0.0517
p-value	0.040			0.022			0.0274			0.0004			0.010			0.005			<.0001		
Rice total																					
Tavy	0.674	a	0.1097	0.014	a	0.0019	0.0305	ab	0.0071	0.0342	a	0.0039	0.125	a	0.0256	0.451	ab	0.0816	0.348	a	0.0386
M0	0.274	b	0.1098	0.007	b	0.0019	0.0147	b	0.0071	0.0137	b	0.0040	0.032	b	0.0256	0.122	b	0.0816	0.080	b	0.0388
M40	0.485	ab	0.1098	0.009	ab	0.0019	0.0226	b	0.0071	0.0185	b	0.0040	0.068	ab	0.0256	0.285	ab	0.0816	0.147	b	0.0388
M80	0.656	ab	0.1622	0.009	ab	0.0030	0.0527	a	0.0108	0.0281	ab	0.0057	0.069	ab	0.0342	0.608	a	0.1246	0.177	b	0.0558
p-value	0.036			0.019			0.0257			<.0001			0.002			0.004			<.0001		

* Means that are followed by the same letter are not significantly different at p<0.05

Table 79:(Continued)

	C		SE	N		SE	P		SE	K		SE	MG		SE	CA		SE	S		SE	MN		SE
Bean grain																								
Tavy	71	c	8.8	8.0	c	0.88	0.60	c	0.118	2.33	c	0.341	0.33	c	0.048	0.31	c	0.053	0.45	c	0.055	0.004	c	0.0008
M0	70	c	8.7	8.1	c	0.89	0.53	c	0.119	2.16	c	0.342	0.30	c	0.048	0.27	c	0.053	0.43	c	0.056	0.003	c	0.0006
M40	151	b	9.7	14.5	b	0.89	1.74	b	0.119	5.54	b	0.342	0.75	b	0.048	0.76	b	0.053	0.94	b	0.056	0.009	b	0.0006
M80	230	a	14.8	19.4	a	1.31	2.91	a	0.179	8.46	a	0.523	1.11	a	0.072	1.25	a	0.081	1.39	a	0.085	0.012	a	0.0008
p-value	<.0001			<.0001			<.0001			<.0001			<.0001			<.0001			<.0001			<.0001		
Bean straw and pods																								
Tavy	74	c	7.4	3.4	c	0.41	0.23	c	0.041	3.02	c	0.493	1.19	c	0.125	1.36	c	0.226	0.47	c	0.063	0.026	c	0.0029
M0	72	c	7.5	3.4	c	0.41	0.17	c	0.042	2.90	c	0.496	1.09	c	0.127	1.14	c	0.227	0.39	c	0.064	0.024	c	0.0030
M40	133	b	7.5	4.7	b	0.41	0.46	b	0.042	6.22	b	0.496	2.11	b	0.127	2.82	b	0.227	0.85	b	0.064	0.047	b	0.0030
M80	200	a	11.8	6.7	a	0.61	0.89	a	0.063	10.72	a	0.763	3.21	a	0.200	4.00	a	0.338	1.17	a	0.098	0.061	a	0.0045
p-value	<.0001			<.0001			<.0001			<.0001			<.0001			<.0001			<.0001			<.0001		
Bean total (grain, straw, pods)																								
Tavy	150	c	15.5	11.7	c	1.09	0.89	c	0.134	5.59	c	0.751	1.59	c	0.157	1.75	c	0.250	0.95	c	0.101	0.031	c	0.0033
M0	142	c	15.5	11.5	c	1.09	0.73	c	0.134	5.07	c	0.751	1.40	c	0.157	1.36	c	0.250	0.81	c	0.101	0.027	c	0.0033
M40	272	b	15.5	18.5	b	1.09	2.06	b	0.134	11.27	b	0.751	2.73	b	0.157	3.39	b	0.250	1.71	b	0.101	0.054	b	0.0033
M80	429	a	25.7	26.0	a	1.63	3.78	a	0.220	19.10	a	1.205	4.30	a	0.264	5.20	a	0.413	2.54	a	0.169	0.072	a	0.0054
p-value	<.0001			<.0001			<.0001			<.0001			<.0001			<.0001			<.0001			<.0001		

	FE		SE	B		SE	NI		SE	CU		SE	ZN		SE	AL		SE	NA		SE
Bean grain																					
Tavy	0.012	c	0.0020	0.002	c	0.0003	0.0007	c	0.0001	0.0017	c	0.0002	0.007	c	0.0011	0.005	c	0.0013	0.001	b	0.0006
M0	0.011	c	0.0020	0.002	c	0.0003	0.0007	c	0.0001	0.0015	c	0.0002	0.006	c	0.0011	0.004	c	0.0013	0.002	b	0.0006
M40	0.031	b	0.0020	0.005	b	0.0003	0.0014	b	0.0001	0.0039	b	0.0002	0.018	b	0.0011	0.015	b	0.0013	0.002	b	0.0006
M80	0.048	a	0.0030	0.007	a	0.0004	0.0024	a	0.0002	0.0060	a	0.0004	0.024	a	0.0017	0.022	a	0.0020	0.008	a	0.0009
p-value	<.0001			<.0001			<.0001			<.0001			<.0001			<.0001			<.0001		
Bean straw and pods																					
Tavy	0.362	b	0.0454	0.008	c	0.0010	0.0005	b	0.0000	0.0016	c	0.0002	0.007	c	0.0010	0.786	b	0.1276	0.047	c	0.0056
M0	0.340	b	0.0455	0.007	c	0.0010	0.0005	b	0.0000	0.0013	c	0.0002	0.007	c	0.0010	0.754	b	0.1278	0.045	c	0.0056
M40	0.654	a	0.0456	0.015	b	0.0010	0.0008	a	0.0000	0.0026	b	0.0002	0.012	b	0.0010	1.551	a	0.1278	0.082	b	0.0056
M80	0.456	ab	0.0686	0.022	a	0.0015	0.0009	a	0.0001	0.0041	a	0.0003	0.019	a	0.0015	0.876	b	0.1907	0.119	a	0.0090
p-value	<.0001			<.0001			<.0001			<.0001			<.0001			0.000			<.0001		
Bean total (grain, straw, pods)																					
Tavy	0.364	b	0.0454	0.011	c	0.0012	0.0013	c	0.0002	0.0034	c	0.0004	0.015	c	0.0018	0.801	b	0.1198	0.051	c	0.0056
M0	0.356	b	0.0454	0.010	c	0.0012	0.0012	c	0.0002	0.0028	c	0.0004	0.013	c	0.0018	0.761	b	0.1198	0.045	c	0.0056
M40	0.649	a	0.0454	0.019	b	0.0012	0.0021	b	0.0002	0.0061	b	0.0004	0.028	b	0.0018	1.464	a	0.1198	0.081	b	0.0056
M80	0.497	ab	0.0719	0.029	a	0.0019	0.0032	a	0.0002	0.0100	a	0.0006	0.043	a	0.0030	0.882	b	0.1896	0.126	a	0.0093
p-value	0.000			<.0001			<.0001			<.0001			<.0001			0.000			<.0001		

* Means that are followed by the same letter are not significantly different at $p<0.05$

Table 79:(Continued)

	C		SE	N		SE	P		SE	K		SE	MG		SE	CA		SE	S		SE	MN		SE
Ginger roots																								
Tavy	199	c	17.4	12.1	c	1.61	1.23	c	0.225	7.64	c	1.482	1.77	c	0.169	0.91	c	0.082	1.38	c	0.128	0.188		0.0216
M0	273	b	18.7	18.4	b	1.61	1.76	c	0.226	14.00	b	1.484	2.28	c	0.170	1.15	c	0.082	1.85	b	0.129	0.258	NS	0.0216
M40	318	b	17.2	22.3	b	1.61	2.93	b	0.229	18.58	b	1.484	2.89	b	0.170	1.46	b	0.082	2.05	b	0.129	0.243		0.0216
M80	434	a	25.5	33.1	a	2.21	5.06	a	0.312	28.06	a	2.048	4.06	a	0.247	2.16	a	0.127	2.63	a	0.179	0.183		0.0319
p-value	<.0001			<.0001			<.0001			<.0001			<.0001			<.0001			<.0001			0.053		
Ginger straw																								
Tavy	111	b	26.3	6.7	c	1.57	0.53	c	0.180	2.86	c	1.122	2.52	c	0.604	2.79	c	0.693	0.87	c	0.191	0.185	b	0.0374
M0	182	b	26.3	12.1	b	1.67	0.97	c	0.180	6.85	b	1.122	4.39	c	0.605	4.37	c	0.695	1.52	b	0.192	0.301	ab	0.0374
M40	269	a	26.3	17.7	a	1.67	1.94	b	0.180	11.69	a	1.122	6.58	b	0.605	7.65	b	0.695	2.13	ab	0.192	0.359	a	0.0374
M80	369	a	36.6	23.9	a	2.18	2.99	a	0.254	12.80	a	1.582	9.74	a	0.840	12.94	a	1.000	2.62	a	0.267	0.436	a	0.0513
p-value	<.0001			<.0001			<.0001			<.0001			<.0001			<.0001			<.0001			<.0001		
Ginger total																								
Tavy	306	c	35.0	19.7	c	2.74	1.83	c	0.348	11.88	d	2.164	4.36	c	0.705	3.83	c	0.749	2.39	c	0.263	0.391	b	0.0529
M0	445	b	35.0	29.9	b	2.74	2.69	c	0.348	20.15	c	2.164	6.58	c	0.705	5.42	c	0.749	3.27	b	0.263	0.543	a	0.0529
M40	567	ab	35.0	38.7	b	2.74	4.71	b	0.348	27.95	b	2.164	9.26	b	0.705	8.76	b	0.749	3.94	b	0.263	0.573	a	0.0529
M80	741	a	56.8	56.6	a	3.87	8.01	a	0.507	40.32	a	3.460	13.72	a	1.012	14.99	a	1.129	5.20	a	0.411	0.610	a	0.0802
p-value	<.0001			<.0001			<.0001			<.0001			<.0001			<.0001			<.0001			0.040		

	FE		SE	B		SE	NI		SE	CU		SE	ZN		SE	AL		SE	NA		SE
Ginger roots																					
Tavy	0.409	b	0.0537	0.014	c	0.0013	0.0011	b	0.0002	0.0050	c	0.0005	0.019	b	0.0021	0.709	b	0.1070	0.115	c	0.0162
M0	0.623	a	0.0537	0.018	b	0.0013	0.0017	ab	0.0002	0.0070	b	0.0005	0.028	a	0.0022	1.144	a	0.1071	0.159	c	0.0162
M40	0.578	ab	0.0537	0.021	b	0.0013	0.0021	a	0.0002	0.0076	ab	0.0005	0.033	a	0.0022	1.347	a	0.1071	0.240	b	0.0162
M80	0.580	ab	0.0790	0.026	a	0.0018	0.0013	ab	0.0003	0.0097	a	0.0007	0.037	a	0.0032	1.207	ab	0.1572	0.328	a	0.0226
p-value	0.039			<.0001			0.0026			<.0001			<.0001			0.001			<.0001		
Ginger straw																					
Tavy	0.206	ab	0.0236	0.010	b	0.0022	0.0006	c	0.0002	0.0023	c	0.0005	0.009	c	0.0021	0.418	ab	0.0592	0.032	c	0.0077
M0	0.140	b	0.0237	0.015	b	0.0022	0.0013	bc	0.0002	0.0040	b	0.0005	0.014	c	0.0021	0.272	b	0.0593	0.041	bc	0.0077
M40	0.159	b	0.0237	0.023	a	0.0022	0.0016	ab	0.0002	0.0051	ab	0.0005	0.023	b	0.0021	0.313	b	0.0593	0.060	b	0.0077
M80	0.310	a	0.0343	0.036	a	0.0030	0.0022	a	0.0003	0.0063	a	0.0006	0.034	a	0.0029	0.666	a	0.0839	0.100	a	0.0112
p-value	0.001			<.0001			0.0001			<.0001			<.0001			0.001			<.0001		
Ginger total																					
Tavy	0.621		0.0671	0.025	c	0.0029	0.0018	b	0.0003	0.0077	c	0.0008	0.030	c	0.0035	1.149	b	0.1437	0.162	c	0.0196
M0	0.751	NS	0.0871	0.032	bc	0.0029	0.0029	ab	0.0003	0.0108	b	0.0008	0.042	b	0.0035	1.388	ab	0.1437	0.194	c	0.0196
M40	0.726		0.0671	0.042	b	0.0029	0.0037	a	0.0003	0.0123	ab	0.0008	0.052	b	0.0035	1.624	ab	0.1437	0.279	b	0.0196
M80	0.884		0.1001	0.063	a	0.0045	0.0034	a	0.0006	0.0159	a	0.0012	0.070	a	0.0057	1.659	a	0.2109	0.425	a	0.0307
p-value	0.179			<.0001			0.0008			<.0001			<.0001			0.022			<.0001		

* Means that are followed by the same letter are not signficantly different at p<0.05

Appendix 22

Crop nutrient uptake in fallow analysis

Table 80: Nutrient uptake (kg/ha) by rice, bean and ginger in harvestable products and straw for 4 fallows

	C		SE	N		SE	P		SE	K		SE	MG		SE	CA		SE	S		SE	MN		SE
Rice Grain																								
Trema	408		71.9	16.2		8.01	2.54	a	0.432	5.34	a	0.693	1.51	a	0.205	1.56	a	0.169	1.64	a	0.245	0.180	a	0.0235
Psiadia	319		84.7	12.6		2.78	1.96	ab	0.397	1.89	b	0.606	0.78	ab	0.188	0.34	b	0.165	0.97	ab	0.224	0.081	b	0.0222
Rubus	354		59.3	12.5		2.51	2.27	ab	0.356	2.42	b	0.522	0.98	ab	0.169	0.27	b	0.142	1.04	ab	0.206	0.061	b	0.0194
Imperata	49		93.8	1.6		3.97	0.34	b	0.562	0.34	b	0.823	0.15	b	0.267	0.04	b	0.224	0.14	b	0.324	0.011	b	0.0307
p-value	0.058			0.060			0.049			0.002			0.012			<.0001			0.024			0.004		
Rice Straw																								
Trema	601		146.2	22.9		4.39	1.02		0.276	17.77		6.664	2.97		0.636	9.86	a	1.797	3.15		0.732	0.645		0.2986
Psiadia	680		129.7	16.3		3.86	1.05		0.253	30.19		5.943	2.81		0.565	8.21	ab	1.613	3.31		0.855	1.388		0.2672
Rubus	564		121.8	14.4		3.65	0.90		0.232	17.33		5.567	2.16		0.530	3.41	ab	1.435	1.91		0.606	0.525		0.2590
Imperata	78		192.2	1.8		5.77	0.22		0.287	2.43		9.603	0.33		0.836	0.43	b	2.269	0.32		0.958	0.088		0.3778
p-value	0.126			0.087			0.318			0.121			0.115			0.019			0.095			0.061		
Rice total																								
Trema	1009		211.2	39.1		7.24	3.56		0.883	23.11		7.078	4.48		0.820	11.43	a	1.912	4.79		0.962	0.824		0.3150
Psiadia	999		189.6	28.9		6.62	3.01		0.691	32.07		8.329	3.60		0.739	8.55	ab	1.725	4.28		0.859	1.470		0.2632
Rubus	918		175.8	26.9		6.09	3.17		0.571	19.75		8.920	3.14		0.687	3.68	b	1.536	2.95		0.793	0.586		0.2528
Imperata	127		378.0	3.4		9.64	0.56		0.902	2.77		9.360	0.47		1.086	0.47	b	2.429	0.45		1.253	0.099		0.3897
p-value	0.096			0.080			0.103			0.134			0.078			0.013			0.079			0.070		

	FE		SE	B		SE	NI		SE	CU		SE	ZN		SE	AL		SE	NA		SE
Rice Grain																					
Trema	0.0564	a	0.0077	0.0024	a	0.0003	0.0135	a	0.0018	0.0101	a	0.0014	0.0438	a	0.0066	0.0360	a	0.0047	0.0661	a	0.0082
Psiadia	0.0216	b	0.0072	0.0002	b	0.0003	0.0057	b	0.0018	0.0057	ab	0.0013	0.0251	ab	0.0061	0.0086	b	0.0045	0.0229	b	0.0078
Rubus	0.0240	b	0.0065	0.0003	b	0.0002	0.0051	b	0.0016	0.0055	ab	0.0011	0.0181	b	0.0055	0.0124	b	0.0038	0.0417	ab	0.0067
Imperata	0.0041	b	0.0103	0.0001	b	0.0003	0.0008	b	0.0024	0.0009	b	0.0018	0.0028	b	0.0087	0.0040	b	0.0060	0.0066	b	0.0106
p-value	0.007			<.0001			0.006			0.013			0.016			0.003			0.003		
Rice Straw																					
Trema	0.7995	a	0.1401	0.0116		0.0029	0.0178	b	0.0086	0.0265		0.0051	0.0455		0.0569	0.4260	ab	0.1021	0.1070		0.0541
Psiadia	0.1737	b	0.1390	0.0091		0.0024	0.0102	b	0.0089	0.0151		0.0045	0.1300		0.0345	0.2593	ab	0.0982	0.2481		0.0493
Rubus	0.7878	a	0.1100	0.0127		0.0023	0.0522	a	0.0066	0.0244		0.0043	0.0250		0.0315	0.6107	a	0.0779	0.2249		0.0447
Imperata	0.2214	ab	0.1740	0.0023		0.0067	0.0152	ab	0.0104	0.0043		0.0068	0.0046		0.0497	0.0884	b	0.1231	0.0351		0.0707
p-value	0.009			0.167			0.008			0.053			0.139			0.017			0.074		
Rice total																					
Trema	0.8558	a	0.1461	0.0141		0.0030	0.0313	ab	0.0091	0.0386	a	0.0064	0.0693		0.0421	0.4620	ab	0.1043	0.1732		0.0592
Psiadia	0.1954	b	0.1436	0.0094		0.0025	0.0159	b	0.0091	0.0209	ab	0.0067	0.1553		0.0394	0.2680	ab	0.1004	0.2712		0.0540
Rubus	0.8118	a	0.1149	0.0130		0.0024	0.0573	a	0.0070	0.0299	ab	0.0054	0.0431		0.0360	0.6231	a	0.0799	0.2666		0.0490
Imperata	0.2255	ab	0.1807	0.0024		0.0038	0.0160	b	0.0111	0.0051	b	0.0085	0.0074		0.0568	0.0924	b	0.1263	0.0416		0.0775
p-value	0.008			0.123			0.013			0.043			0.158			0.017			0.106		

* Means that are followed by the same letter are not significantly different at $p<0.05$

Table 80: (Continued)

	C		SE	N		SE	P		SE	K		SE	MG		SE	CA		SE	S		SE	MN		SE
Bean grain																								
Trema	165	a	13.1	19.0	a	1.41	1.44	b	0.158	5.36	ab	0.463	0.66	b	0.064	0.86	a	0.071	1.06	a	0.080	0.008	b	0.0007
Psiadia	68	b	10.8	5.8	b	1.20	0.87	c	0.136	2.53	c	0.362	0.32	c	0.055	0.39	b	0.069	0.43	b	0.064	0.003	c	0.0007
Rubus	180	a	9.7	16.3	a	1.13	2.06	a	0.117	6.50	a	0.342	0.92	a	0.047	0.86	a	0.053	1.04	a	0.061	0.010	a	0.0005
Imperata	109	b	9.7	9.1	b	1.13	1.40	b	0.117	4.10	b	0.342	0.60	b	0.047	0.48	b	0.053	0.68	b	0.061	0.008	b	0.0005
p-value	<.0001			<.0001			<.0001			<.0001			<.0001			<.0001			<.0001			<.0001		
Bean straw and pods																								
Trema	177	a	11.8	6.3	a	0.71	0.48		0.070	8.09	a	0.676	3.03	a	0.187	3.73	a	0.373	1.03	a	0.106	0.042	ab	0.0047
Psiadia	88	b	8.9	4.4	ab	0.59	0.47		0.057	4.52	bc	0.544	1.34	c	0.138	2.28	b	0.309	0.76	ab	0.084	0.031	b	0.0036
Rubus	138	a	8.2	5.0	a	0.58	0.51		0.057	7.27	ab	0.499	2.13	b	0.141	2.23	b	0.301	0.65	ab	0.085	0.051	a	0.0038
Imperata	76	b	9.2	2.5	b	0.58	0.30	NS	0.057	2.98	c	0.499	1.11	c	0.141	1.07	b	0.301	0.43	b	0.085	0.033	b	0.0038
p-value	<.0001			0.006			0.086			<.0001			<.0001			0.001			0.005			0.008		
Bean total (grain, straw, pods)																								
Trema	341	a	22.8	25.3	a	1.63	1.92	ab	0.198	13.44	a	1.072	3.68	a	0.236	4.60	a	0.383	2.09	a	0.151	0.050	ab	0.0049
Psiadia	149	b	14.8	9.6	b	1.02	1.27	c	0.129	6.74	b	0.757	1.58	b	0.148	2.48	b	0.257	1.13	b	0.095	0.032	c	0.0032
Rubus	317	a	16.9	21.3	a	1.20	2.57	a	0.144	13.78	a	0.791	3.05	a	0.174	3.09	a	0.289	1.69	a	0.111	0.061	a	0.0036
Imperata	186	b	16.8	11.6	b	1.20	1.70	bc	0.144	7.06	b	0.791	1.70	b	0.174	1.55	b	0.289	1.10	b	0.111	0.041	bc	0.0036
p-value	<.0001			<.0001			<.0001			<.0001			<.0001			<.0001			<.0001			<.0001		

	FE		SE	B		SE	NI		SE	CU		SE	ZN		SE	AL		SE	NA		SE
Bean grain																					
Trema	0.0276	ab	0.0026	0.0055	a	0.0004	0.0022	a	0.0002	0.0036	b	0.0003	0.0167	ab	0.0015	0.0078	b	0.0017	0.0021	b	0.0008
Psiadia	0.0133	c	0.0023	0.0022	c	0.0003	0.0005	b	0.0002	0.0018	c	0.0003	0.0072	c	0.0013	0.0050	b	0.0017	0.0022	b	0.0008
Rubus	0.0349	a	0.0019	0.0055	a	0.0003	0.0017	a	0.0001	0.0044	a	0.0002	0.0197	a	0.0011	0.0182	a	0.0013	0.0023	b	0.0006
Imperata	0.0264	b	0.0019	0.0037	b	0.0003	0.0007	b	0.0001	0.0032	b	0.0002	0.0111	bc	0.0011	0.0143	a	0.0013	0.0062	a	0.0006
p-value	<.0001			<.0001			<.0001			<.0001			<.0001			<.0001			0.001		
Bean straw and pods																					
Trema	0.3429	b	0.0606	0.0182	a	0.0014	0.0012	a	0.0001	0.0030		0.0003	0.0147	a	0.0018	0.2582	b	0.1683	0.0896	a	0.0060
Psiadia	0.2644	b	0.0526	0.0098	b	0.0011	0.0003	c	0.0001	0.0023		0.0003	0.0116	a	0.0015	0.5010	b	0.1522	0.0676	ab	0.0056
Rubus	0.7582	a	0.0448	0.0169	a	0.0010	0.0008	b	0.0000	0.0024		0.0003	0.0129	a	0.0015	2.3787	a	0.1243	0.0886	a	0.0059
Imperata	0.4448	b	0.0448	0.0079	b	0.0010	0.0003	c	0.0000	0.0017	NS	0.0003	0.0058	b	0.0015	0.8287	b	0.1243	0.0473	b	0.0059
p-value	<.0001			<.0001			<.0001			0.052			0.007			<.0001			0.001		
Bean total (grain, straw, pods)																					
Trema	0.3705	bc	0.0639	0.0237	a	0.0017	0.0034	a	0.0002	0.0066	ab	0.0006	0.0314	a	0.0026	0.2660	b	0.1676	0.0917	a	0.0083
Psiadia	0.2505	c	0.0469	0.0113	b	0.0011	0.0008	c	0.0002	0.0039	c	0.0003	0.0176	b	0.0017	0.4421	b	0.1255	0.0663	b	0.0052
Rubus	0.7932	a	0.0472	0.0224	a	0.0013	0.0025	b	0.0001	0.0069	a	0.0004	0.0326	a	0.0020	2.3969	a	0.1237	0.0909	a	0.0061
Imperata	0.4712	b	0.0472	0.0116	b	0.0013	0.0010	c	0.0001	0.0049	bc	0.0004	0.0169	b	0.0020	0.8430	b	0.1237	0.0535	b	0.0061
p-value	<.0001			<.0001			<.0001			<.0001			<.0001			<.0001			0.002		

* Means that are followed by the same letter are not signficantly different at p<0.05

Table 80: (Continued)

	C		SE	N		SE	P		SE	K		SE	MG		SE	CA		SE	S		SE	MN		SE
Ginger roots																								
Trema	174	b	28.9	9.8	c	2.67	1.13	c	0.346	8.26	b	2.322	1.64	b	0.275	1.15	b	0.135	0.79	c	0.217	0.086	b	0.0307
Psiadia	323	a	24.1	19.5	bc	2.43	2.52	b	0.333	17.89	a	2.208	3.00	ab	0.257	1.77	a	0.107	1.98	b	0.196	0.241	a	0.0273
Rubus	370	a	23.7	31.3	a	2.11	3.85	a	0.281	22.71	a	1.897	3.08	ab	0.223	1.51	ab	0.106	2.69	a	0.180	0.239	a	0.0236
Imperata	356	a	23.0	25.3	ab	2.11	3.49	ab	0.281	19.33	a	1.897	3.28	a	0.223	1.25	b	0.106	2.43	a	0.180	0.306	a	0.0236
p-value	0.001			<.0001			<.0001			0.002			0.002			0.006			<.0001			0.001		
Ginger straw																								
Trema	85	b	38.7	5.8	c	2.39	0.65	c	0.260	3.04	b	1.635	2.36	b	0.916	4.69	b	1.015	0.59	c	0.292	0.081	c	0.0587
Psiadia	181	b	38.3	12.1	bc	2.30	1.23	bc	0.254	7.16	ab	1.586	4.41	ab	0.888	7.27	ab	0.934	1.48	bc	0.278	0.238	bc	0.0583
Rubus	334	a	32.0	20.6	ab	1.94	2.12	ab	0.206	12.53	a	1.299	7.41	a	0.740	9.11	a	0.789	2.45	ab	0.236	0.401	ab	0.0480
Imperata	352	a	32.0	21.9	a	1.94	2.44	a	0.206	11.48	a	1.299	9.06	a	0.740	6.67	ab	0.799	2.62	a	0.236	0.562	a	0.0480
p-value	<.0001			<.0001			<.0001			0.002			<.0001			0.028			<.0001			<.0001		
Ginger total																								
Trema	226	c	50.5	15.6	b	4.33	1.77	c	0.517	11.28	c	3.437	3.99	c	1.074	5.84	b	1.107	1.38	c	0.433	0.168	c	0.0764
Psiadia	463	b	34.7	30.1	b	3.78	3.57	b	0.468	22.86	b	2.802	7.09	bc	0.968	8.62	ab	0.918	3.25	b	0.337	0.442	bc	0.0631
Rubus	662	a	37.3	51.9	a	3.49	5.97	a	0.408	35.25	a	2.669	10.49	ab	0.859	10.61	a	0.858	5.13	a	0.345	0.640	ab	0.0586
Imperata	708	a	37.3	47.2	a	3.49	5.93	a	0.408	30.81	ab	2.669	12.34	a	0.859	7.93	ab	0.859	5.05	a	0.345	0.868	a	0.0586
p-value	<.0001			<.0001			<.0001			0.001			<.0001			0.027			<.0001			<.0001		

	FE		SE	B		SE	NI		SE	CU		SE	ZN		SE	AL		SE	NA		SE
Ginger roots																					
Trema	0.6383		0.0696	0.0125	b	0.0022	0.0021	ab	0.0002	0.0037	b	0.0008	0.0116	b	0.0031	0.4218	c	0.1432	0.1261	b	0.0249
Psiadia	0.4198		0.0689	0.0209	ab	0.0020	0.0005	c	0.0002	0.0075	a	0.0007	0.0361	a	0.0026	0.9462	bc	0.1347	0.1880	ab	0.0236
Rubus	0.5000		0.0514	0.0241	a	0.0018	0.0022	a	0.0002	0.0091	a	0.0006	0.0361	a	0.0034	1.6556	a	0.1076	0.2523	a	0.0200
Imperata	0.6318	NS	0.0514	0.0237	a	0.0018	0.0013	bc	0.0002	0.0092	a	0.0006	0.0333	a	0.0024	1.3836	ab	0.1076	0.2767	a	0.0200
p-value	0.060			0.006			0.0002			0.0003			<.0001			<.0001			0.002		
Ginger straw																					
Trema	0.1600		0.0353	0.0099	b	0.0033	0.0009	b	0.0003	0.0015	bc	0.0007	0.0078	b	0.0032	0.1375	b	0.0890	0.0264	b	0.0116
Psiadia	0.1692		0.0316	0.0159	b	0.0032	0.0006	b	0.0003	0.0033	ab	0.0007	0.0184	ab	0.0031	0.3331	b	0.0838	0.0636	ab	0.0104
Rubus	0.2688		0.0279	0.0290	a	0.0027	0.0027	a	0.0002	0.0059	a	0.0006	0.0278	a	0.0026	0.7332	a	0.0718	0.0827	a	0.0092
Imperata	0.2272	NS	0.0279	0.0283	a	0.0027	0.0014	b	0.0002	0.0069		0.0006	0.0261	a	0.0026	0.4653	ab	0.0718	0.0598	ab	0.0092
p-value	0.065			0.001			0.000			0.000			0.001			0.001			0.016		
Ginger total																					
Trema	0.7883		0.0884	0.0224	b	0.0048	0.0031	b	0.0006	0.0054	c	0.0013	0.0194	b	0.0056	0.5592	b	0.2041	0.1525	b	0.0307
Psiadia	0.5652		0.0800	0.0347	b	0.0037	0.0011	c	0.0004	0.0102	b	0.0010	0.0514	a	0.0040	1.2216	b	0.1837	0.2360	b	0.0234
Rubus	0.7688		0.0653	0.0532	a	0.0037	0.0049	a	0.0008	0.0150	a	0.0010	0.0639	a	0.0048	2.3888	a	0.1676	0.3349	a	0.0240
Imperata	0.8585	NS	0.0653	0.0519	a	0.0037	0.0027	bc	0.0008	0.0161	a	0.0010	0.0595	a	0.0048	1.8489	ab	0.1676	0.3364	a	0.0240
p-value	0.076			0.000			<.0001			<.0001			0.000			<.0001			0.001		

* Means that are followed by the same letter are not significantly different at p<0.05

Appendix 23

Crop nutrient uptake in cycle analysis

Table 81: Nutrient uptake (kg/ha) by rice, bean and ginger in harvestable products and straw for 4 cycles

	C		SE	N		SE	P		SE	K		SE	MG		SE	CA		SE	S		SE	MN		SE
Rice Grain																								
Cycle 1	357	b	50.7	12,1	b	1.97	1,80	b	0.271	2.11	ab	0.301	0.73	b	0.111	0.29	b	0.050	1,02	b	0.157	0.082	b	0.0123
Cycle 2	538	a	57.1	23.2	a	2.21	3,09	a	0.308	2,82	a	0.340	1.23	a	0.126	0.57	a	0.057	1.66	a	0.176	0.147	a	0.0139
Cycle 3	292	bc	50.7	11,4	b	1.97	1,60	b	0.271	1.32	bc	0.301	0.86	b	0.111	0.31	b	0.050	0,85	bc	0.157	0.063	bc	0.0123
Cycle 4	145	c	50.7	4,8	c	1.97	0,66	c	0.271	0,90	c	0.301	0.30	c	0.111	0.15	c	0.050	0.39	c	0.157	0.036	c	0.0123
p-value	0,0001			<,0001			<.0001			0.001			<.0001			<.0001			<.0001			<.0001		
Rice Straw																								
Cycle 1	791	ab	109.7	20,1	a	3.22	1.21	b	0.190	35.38	b	5.257	3,04	b	0.487	10,99	a	1.353	4,16	ab	0.577	1.674	a	0.2300
Cycle 2	1171	a	126.6	31,3	a	3.98	2.04	a	0.217	57.07	a	6.070	5.08	a	0.557	12.89	a	1.649	5.87	a	0.664	2.524	a	0.2655
Cycle 3	415	b	109.7	8.7	b	3.22	0.47	c	0.190	16.73	c	5.257	2,00	bc	0.487	5.02	b	1.353	2.02	bc	0.577	0.664	b	0.2300
Cycle 4	377	b	109.7	7.4	b	3.22	0.42	c	0.190	15.67	c	5.257	1.40	c	0.487	3.37	b	1.353	1.56	c	0.577	0.732	b	0.2300
p-value	0.0003			<.0001			<.0001			<.0001			0.0002			0.0001			0.000			<.0001		
Rice total																								
Cycle 1	1148	ab	148.4	32.1	b	4.88	3.00	b	0.426	37.50	b	5.473	3.76	b	0.572	11.28	a	1.393	5.19	a	0.701	1.755	a	0.2379
Cycle 2	1703	a	170.0	54.4	a	5.52	5.13	a	0.491	59.64	a	6.315	6.30	a	0.652	13.48	a	1.592	7.52	a	0.801	2.668	a	0.2744
Cycle 3	707	bc	148.4	20.0	bc	4.88	2.07	bc	0.426	18.05	c	5.473	2.66	bc	0.572	5.33	b	1.393	2.87	b	0.701	0.726	b	0.2379
Cycle 4	523	c	148.4	12.2	c	4.88	1.07	c	0.426	18.57	c	5.473	1.70	c	0.572	3.52	b	1.393	1.95	b	0.701	0.768	b	0.2379
p-value	0.0001			<.0001			<.0001			0.0001			0.0001			0.0001			<.0001			<.0001		

	FE		SE	B		SE	NI		SE	CU		SE	ZN		SE	AL		SE	NA		SE
Rice Grain																					
Cycle 1	0.0205	b	0.00382	0.0001	b	0.00007	0.0050	b	0.00075	0.0057	b	0.00079	0.0222	b	0.00389	0.0119	ab	0.00209	0.0245	ab	0.00350
Cycle 2	0.0451	a	0.00427	0.0001	b	0.00008	0.0118	a	0.00085	0.0095	a	0.00090	0.0462	a	0.00437	0.0167	a	0.00233	0.0354	a	0.00397
Cycle 3	0.0165	bc	0.00382	0.0004	a	0.00007	0.0044	b	0.00075	0.0053	bc	0.00079	0.0214	bc	0.00389	0.0060	bc	0.00209	0.0218	bc	0.00350
Cycle 4	0.0086	c	0.00382	0.0002	b	0.00007	0.0024	b	0.00075	0.0032	c	0.00079	0.0095	c	0.00389	0.0038	c	0.00209	0.0110	c	0.00350
p-value	<.0001			0.007			<.0001			<.0001			<.0001			0.0001			0.001		
Rice Straw																					
Cycle 1	0.1409	b	0.02581	0.0097	b	0.00247	0.0016	b	0.00067	0.0103	b	0.00300	0.0883	b	0.02483	0.1732	b	0.04117	0.2579	b	0.03599
Cycle 2	0.2465	a	0.02952	0.0197	a	0.00283	0.0053	a	0.00077	0.0295	a	0.00344	0.3048	a	0.02833	0.3535	a	0.04725	0.4617	a	0.04155
Cycle 3	0.0738	b	0.02581	0.0051	b	0.00247	0.0007	b	0.00067	0.0072	b	0.00300	0.0750	b	0.02483	0.1146	b	0.04117	0.1692	bc	0.03599
Cycle 4	0.0522	b	0.02581	0.0043	b	0.00247	0.0013	b	0.00067	0.0078	b	0.00300	0.0488	b	0.02483	0.0651	b	0.04117	0.1114	c	0.03599
p-value	0.000			0.002			0.001			0.000			<.0001			0.001			<.0001		
Rice total																					
Cycle 1	0.1613	b	0.02905	0.0099	b	0.00252	0.0068	b	0.00119	0.0159	b	0.00358	0.1106	b	0.02780	0.1851	b	0.04237	0.2824	b	0.03835
Cycle 2	0.2913	a	0.03310	0.0198	a	0.00288	0.0171	a	0.00135	0.0390	a	0.00406	0.3507	a	0.03161	0.3720	a	0.04451	0.4965	a	0.04421
Cycle 3	0.0901	bc	0.02905	0.0056	b	0.00252	0.0051	b	0.00119	0.0125	b	0.00358	0.0965	b	0.02780	0.1226	b	0.04237	0.1910	bc	0.03835
Cycle 4	0.0608	c	0.02905	0.0044	b	0.00252	0.0047	b	0.00119	0.0110	b	0.00358	0.0583	b	0.02780	0.0689	b	0.04237	0.1225	c	0.03835
p-value	<.0001			0.002			<.0001			<.0001			<.0001			0.001			<.0001		

* Means that are followed by the same letter are not significantly different at $p<0.05$

Table 81: (Continued)

	C		SE	N		SE	P		SE	K		SE	MG		SE	CA		SE	S		SE	MN		SE
Bean grain																								
Cycle 1	41		13.6	4.0		1.40	0.46		0.147	1.46		0.486	0.19		0.060	0.21		0.072	0.28		0.092	0.002		0.0006
Cycle 2	36		14.4	3.3		1.49	0.41		0.158	1.34		0.518	0.16		0.064	0.18		0.077	0.25		0.098	0.002		0.0007
Cycle 3	32		13.6	3.3		1.40	0.33		0.147	1.12		0.486	0.14		0.060	0.18		0.072	0.20		0.092	0.001		0.0006
Cycle 4	29		13.6	3.0		1.40	0.28		0.147	0.96		0.486	0.12		0.060	0.15		0.072	0.19		0.092	0.001		0.0006
p-value	0.724			0.856			0.506			0.620			0.568			0.824			0.599			0.443		
Bean straw and pods																								
Cycle 1	53	b	15.3	2.6	b	0.88	0.21	b	0.084	2.45	b	0.722	0.79	b	0.239	1.09	b	0.480	0.45	b	0.160	0.019	b	0.0058
Cycle 2	95	a	16.3	6.8	a	0.94	0.63	a	0.092	4.59	a	0.773	1.38	a	0.255	3.45	a	0.501	1.06	a	0.175	0.042	a	0.0063
Cycle 3	52	b	15.3	2.8	b	0.88	0.21	b	0.084	2.27	b	0.722	0.77	b	0.239	1.23	b	0.480	0.44	b	0.160	0.016	b	0.0058
Cycle 4	46	b	15.3	2.7	b	0.88	0.24	b	0.084	2.16	b	0.722	0.70	b	0.239	1.25	b	0.480	0.54	b	0.160	0.018	b	0.0058
p-value	0.012			0.0001			0.0004			0.007			0.026			0.000			0.008			0.001		
Bean total (grain, straw, pods)																								
Cycle 1	94		28.5	6.5		2.22	0.67		0.227	3.92		1.183	0.98		0.297	1.30	b	0.527	0.73		0.248	0.021	b	0.0064
Cycle 2	130		30.2	10.2		2.35	1.04		0.244	5.93		1.271	1.54		0.316	3.63	a	0.572	1.30		0.265	0.044	a	0.0069
Cycle 3	84		28.5	6.0		2.22	0.54		0.227	3.39		1.183	0.91		0.297	1.41	b	0.527	0.64		0.248	0.018	b	0.0064
Cycle 4	74		28.5	5.7		2.22	0.52		0.227	3.13		1.183	0.83		0.297	1.40	b	0.527	0.73		0.248	0.019	b	0.0064
p-value	0.181			0.129			0.105			0.081			0.072			0.001			0.060			0.002		

	FE		SE	B		SE	NI		SE	CU		SE	ZN		SE	AL		SE	NA		SE
Bean grain																					
Cycle 1	0.0072		0.00224	0.0013		0.00048	0.0002		0.00006	0.0011		0.00034	0.0046		0.00151	0.0018		0.00064	0.0006		0.00027
Cycle 2	0.0060		0.00236	0.0013		0.00051	0.0002		0.00007	0.0009		0.00036	0.0042		0.00161	0.0016		0.00068	0.0007		0.00029
Cycle 3	0.0054		0.00224	0.0011		0.00048	0.0001		0.00006	0.0008		0.00034	0.0034		0.00151	0.0015		0.00064	0.0006		0.00027
Cycle 4	0.0044		0.00224	0.0009		0.00048	0.0002		0.00006	0.0007		0.00034	0.0029		0.00151	0.0013		0.00064	0.0004		0.00027
p-value	0.506			0.724			0.332			0.533			0.582			0.766			0.818		
Bean straw and pods																					
Cycle 1	0.1805	b	0.05624	0.0057	b	0.00167	0.0002	b	0.00005	0.0011	b	0.00043	0.0061	b	0.00216	0.3522	b	0.12580	0.0462	ab	0.01157
Cycle 2	0.5219	a	0.06119	0.0112	a	0.00178	0.0005	a	0.00006	0.0032	a	0.00046	0.0175	a	0.00234	1.0059	a	0.13730	0.0760	a	0.01251
Cycle 3	0.1966	b	0.05624	0.0054	b	0.00167	0.0001	b	0.00005	0.0012	b	0.00043	0.0065	b	0.00216	0.4153	b	0.12580	0.0469	ab	0.01157
Cycle 4	0.1678	b	0.05624	0.0048	b	0.00167	0.0002	b	0.00005	0.0013	b	0.00043	0.0062	b	0.00216	0.4065	b	0.12580	0.0417	b	0.01157
p-value	<.0001			0.002			<.0001			0.0004			0.0001			0.0004			0.042		
Bean total (grain, straw, pods)																					
Cycle 1	0.1677	b	0.05818	0.0070	b	0.00212	0.0004	b	0.00011	0.0022	b	0.00075	0.0107	b	0.00359	0.3541	b	0.12640	0.0468	b	0.01178
Cycle 2	0.5279	a	0.06321	0.0125	a	0.00226	0.0006	a	0.00012	0.0041	a	0.00081	0.0217	a	0.00365	1.0074	a	0.13790	0.0766	a	0.01272
Cycle 3	0.2020	b	0.05818	0.0065	b	0.00212	0.0002	b	0.00011	0.0020	b	0.00075	0.0099	b	0.00359	0.4169	b	0.12640	0.0475	b	0.01178
Cycle 4	0.1722	b	0.05818	0.0057	b	0.00212	0.0003	b	0.00011	0.0020	b	0.00075	0.0091	b	0.00359	0.4077	b	0.12640	0.0422	b	0.01178
p-value	<.0001			0.010			0.006			0.024			0.006			0.0004			0.043		

* Means that are followed by the same letter are not signficantly different at $p<0.05$

Table 81: (Continued)

	C		SE	N	SE	P		SE	K		SE	MG	SE	CA	SE	S		SE	MN		SE
Ginger roots																					
Cycle 1	309		21.1	18.4	1.16	2.05	a	0.134	15.33	b	1.022	2.48	0.199	1.54	0.119	1.89		0.132	0.272	ab	0.0227
Cycle 2	291		24.3	15.0	1.34	1.91	ab	0.165	21.36	a	1.180	2.65	0.229	1.65	0.138	1.90		0.152	0.347	a	0.0262
Cycle 3	242		21.1	14.6	1.16	1.48	b	0.134	9.56	c	1.022	2.72	0.199	1.35	0.119	1.53		0.132	0.177	c	0.0227
Cycle 4	277		21.1	14.4	1.16	1.56	ab	0.134	11.20	c	1.022	2.39	0.199	1.56	0.119	1.72		0.132	0.217	bc	0.0227
p-value	0.190			0.078		0.018			<.0001			0.645		0.414		0.214			0.001		
Ginger straw																					
Cycle 1	133	ab	15.2	9.0	0.96	0.74		0.079	4.32	b	0.577	3.04	0.331	5.80	0.559	1.12	ab	0.127	0.230	b	0.0240
Cycle 2	176	a	17.5	10.4	1.11	0.93		0.091	11.43	a	0.666	2.67	0.382	5.66	0.645	1.54	a	0.146	0.340	a	0.0278
Cycle 3	82	b	15.2	7.6	0.96	0.59		0.079	2.96	b	0.577	3.21	0.331	4.23	0.559	0.84	b	0.127	0.084	c	0.0240
Cycle 4	156	a	15.2	9.9	0.96	0.80		0.079	4.34	b	0.577	3.44	0.331	5.35	0.559	1.32	ab	0.127	0.145	bc	0.0240
p-value	0.003			0.245		0.064			<.0001			0.497		0.227		0.010			<.0001		
Ginger total																					
Cycle 1	442	ab	34.1	27.4	1.97	2.79	a	0.200	19.65	b	1.482	6.52	0.499	7.33	0.657	3.01		0.242	0.501	b	0.0441
Cycle 2	467	a	39.3	25.4	2.27	2.84	a	0.231	32.80	a	1.723	5.32	0.576	7.31	0.759	3.44		0.280	0.687	a	0.0509
Cycle 3	324	b	34.1	22.2	1.97	2.05	b	0.200	12.53	c	1.482	5.92	0.499	5.58	0.657	2.37		0.242	0.260	c	0.0441
Cycle 4	433	ab	34.1	24.3	1.97	2.36	ab	0.200	15.54	bc	1.482	5.83	0.499	6.91	0.657	3.03		0.242	0.362	bc	0.0441
p-value	0.044			0.330		0.043			<.0001			0.853		0.240		0.055			<.0001		

	FE		SE	B		SE	NI		SE	CU	SE	ZN	SE	AL		SE	NA		SE
Ginger roots																			
Cycle 1	0.3521	b	0.02832	0.0193	ab	0.00138	0.0006	b	0.00004	0.0066	0.00050	0.0329	0.00251	0.8821	ab	0.07053	0.1698	a	0.01097
Cycle 2	0.5883	a	0.03270	0.0234	a	0.00160	0.0010	a	0.00005	0.0070	0.00057	0.0337	0.00290	1.0654	a	0.08144	0.1825	a	0.01267
Cycle 3	0.3041	b	0.02832	0.0156	b	0.00138	0.0004	b	0.00004	0.0063	0.00050	0.0346	0.00251	0.6937	b	0.07053	0.1137	b	0.01097
Cycle 4	0.3889	b	0.02832	0.0157	b	0.00138	0.0005	b	0.00004	0.0069	0.00050	0.0331	0.00251	0.9951	a	0.07053	0.1293	b	0.01097
p-value	<.0001			0.004			<.0001			0.764		0.962		0.011			0.001		
Ginger straw																			
Cycle 1	0.1698		0.02291	0.0098		0.00118	0.0003	b	0.00004	0.0024	0.00028	0.0132	0.00130	0.3400		0.04372	0.0307	b	0.00773
Cycle 2	0.1294		0.02645	0.0127		0.00136	0.0006	a	0.00005	0.0032	0.00033	0.0163	0.00150	0.2122		0.05048	0.0775	a	0.00892
Cycle 3	0.0924		0.02291	0.0090		0.00118	0.0002	b	0.00004	0.0021	0.00028	0.0122	0.00130	0.1985		0.04372	0.0232	b	0.00773
Cycle 4	0.1422		0.02291	0.0118		0.00118	0.0003	b	0.00004	0.0029	0.00028	0.0129	0.00130	0.2501		0.04372	0.0694	a	0.00773
p-value	0.152			0.161			0.001			0.070		0.216		0.138			0.0001		
Ginger total																			
Cycle 1	0.5219	b	0.04696	0.0291	ab	0.00240	0.0009	b	0.00007	0.0090	0.00073	0.0460	0.00354	1.2221		0.10610	0.2005	ab	0.01655
Cycle 2	0.7178	a	0.05422	0.0362	a	0.00277	0.0016	a	0.00009	0.0102	0.00084	0.0500	0.00408	1.2776		0.12250	0.2600	a	0.01911
Cycle 3	0.3965	b	0.04696	0.0246	b	0.00240	0.0006	b	0.00007	0.0084	0.00073	0.0468	0.00354	0.8922		0.10610	0.1368	b	0.01655
Cycle 4	0.5311	b	0.04696	0.0275	ab	0.00240	0.0008	b	0.00007	0.0098	0.00073	0.0459	0.00354	1.2452		0.10610	0.1987	ab	0.01655
p-value	0.003			0.036			<.0001			0.359		0.868		0.070			0.001		

* Means that are followed by the same letter are not signficantly different at p<0.05

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